Nature-based solutions

for waterfronts reconfigurations:

Litoral Besòs, analysis of an urban sustainability transition in the Barcelona metropolitan area

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With immense gratitude to my beloved family.

Abstract

Cities need to respond urgently to societal challenges, such as urbanization, changes in climate, and risk management. These challenges require innovative solutions in urban systems developed with citizens to provide multiple benefits and more inclusive living environments. Nature-based solutions (NBS) are currently attracting the interest of public policy and urban research for addressing these needs, considering the social, ecological, and technological dimensions with a territorial focus. NBS implementation is-an ongoing, broad and local change process that shifts different urban domains and generates impacts and benefits for all citizens. For example, NBS are used in waterfront reconfigurations as alternative practices to address water quality and quantity challenges, among other issues, while promoting ecosystem services and creating new green infrastructure.

This thesis analyzes NBS implementation as a strategy (understood as processes, results, and impacts) to address water in peri-urban areas and produce transformative effects. The case study method and the concept of urban sustainability transitions as -fundamental, structural, and multidimensional change- are used for this purpose. The research develops a systematic literature review of NBS implementation experiences globally, which aided in identifying barriers and lessons learned, emphasizing communication and monitoring to facilitate actors' participation. Subsequently, a case study in the Barcelona metropolitan area is analyzed in-depth, the *Litoral Besòs*, through semi-structured interviews with local actors, user surveys, and participant observation in public participatory processes in urban planning. The case study has verified how the NBS implemented have favored transformative shifts of the *Litoral Besòs*.

The NBS as a riverside park and constructed wetlands addressed water problems, enabling the development of reuse technologies, natural capital regeneration, and keeping resources in use, which ultimately is an advancement for a more sustainable urban water management. However, citizens (as frequent users) can play a more significant role in NBS management and scalability. Citizens' perceptions, through regular monitoring, could contribute to NBS management while increasing knowledge and awareness about the benefits and biotic management. In addition, by participating in the seafront redevelopment formulation, citizens exposed the need for mediation between the urban sustainability accounts (opposing, non-conflictual, and reinforcing), advocating a more socially just aim in this reconfiguration.

The findings show how NBS promote physical changes and environmental improvements, such as multifunctionality and hybridization for place-based transitions. New cultural experiences and practices include citizenship as a direct beneficiary, user, and participant. This shift in multi-actor dynamics is an iterative process, requiring flexibility for long-term urban change. NBS have the potential to support the needed social-ecological-technological transition to urban sustainability. Therefore, NBS, as providers of adaptive capacities, must still overcome some constraints, which makes necessary to favor institutional shifts, more open-ended urban planning practices, and bottom-up management strategies. Finally, the NBS reframe urban issues by highlighting social and climate justice in alternative visions of the future, encouraging more inclusive and thus more resilient urban reconfigurations.

Keywords: urban governance; social vulnerability; circular economy; place-based transition; multi-actor dynamics; urban experimentation; problem reframing; visioning importance; Besòs riverside park; Three Chimneys litoral front

Resum

Solucions basades en la natura per a reconfiguracions de fronts d'aigua: Litoral Besòs, anàlisi d'una transició urbana sostenible a l'àrea metropolitana de Barcelona

Les ciutats necessiten respondre a reptes urgents com els processos d'urbanització, l'emergència climàtica i la gestió del risc. Això requereix de solucions innovadores en els sistemes urbans de la mà de la ciutadania per aconseguir múltiples beneficis i entorns de vida més inclusius. Actualment, les solucions basades en la natura, SBN, atrauen l'interès de la política pública i de la investigació urbana per abordar aquestes necessitats, ja que consideren les dimensions socials, ecològiques i tecnològiques sota un enfocament territorial. La seva implementació és un procés de canvi continu, ampli i basat en el context que afecta diferents àmbits urbans i generen impactes i beneficis sobre el conjunt de la ciutadania. Per exemple, les SBN es fan servir en les reconfiguracions dels fronts d'aigua com a pràctiques alternatives per abordar diferents reptes associats a la qualitat i quantitat de l'aigua, mentre es promouen serveis ecosistèmics i es crea nova infraestructura verda.

Aquesta tesi analitza la implementació de les SBN, com estratègia (entesa com a processos, resultats i impactes) per abordar els desafiaments de l'aigua en àrees periurbanes i produir efectes transformadors. Per a aquest propòsit, s'utilitza el mètode d'estudi de cas i el concepte de transicions urbanes per explicar un canvi fonamental, estructural i multidimensional. La investigació desenvolupa una revisió bibliogràfica sistemàtica d'experiències d'implementació de SBN a tot el món que ha ajudat a identificar barreres i lliçons apreses, i se'n desprèn la importància de la comunicació i el monitoratge per facilitar la participació dels actors. Posteriorment, s'analitza en profunditat un estudi de cas a l'àrea metropolitana de Barcelona: el Litoral Besòs, a través d'entrevistes semiestructurades amb actors locals, enquestes a usuaris i l'observació participant en processos públics de planificació urbana. El cas d'estudi ha constatat com les SBN implementades han afavorit canvis fonamentals del Litoral Besòs.

Les SBN com a parc fluvial i aiguamolls construïts han abordat els problemes de l'aigua, possibilitant el desenvolupament de tecnologies de reutilització; la regeneració del capital natural i el manteniment dels recursos en ús, el que, en definitiva, és un avenç per a una gestió urbana més sostenible de l'aigua. Tanmateix, els ciutadans, com a usuaris freqüents, podrien exercir un paper més important en la gestió i ampliació de les SBN. Les percepcions de la ciutadania, a través d'un seguiment periòdic, podrien contribuir a la gestió de les SBN, alhora que augmentaria el coneixement i la consciència dels beneficis i de la gestió biòtica. La ciutadania participant en la formulació de la reconfiguració del front Mediterrani, ha exposat la necessitat de mediació entre les diferents discursos de sostenibilitat urbana (contrari, no conflictiu, i reforçant), advocant un objectiu socialment més just en aquesta reconfiguració.

Els resultats indiquen como les SBN promouen canvis físics i millores ambientals, com ara la multifuncionalitat i la hibridació per a transicions basades en el lloc. Les noves experiències i pràctiques culturals inclouen la ciutadania com a beneficiària directa, usuària i participant. Aquest canvi en la dinàmica de múltiples actors és un procés iteratiu, que requereix flexibilitat per a un canvi urbà a llarg termini. Les SBN tenen el potencial de donar suport a la transició social-ecològica-tecnològica necessària cap a una sostenibilitat urbana. Per tant, les SBN, en tant que proveeixen de capacitat d'adaptació, encara, han de superar algunes limitacions i per això cal afavorir canvis institucionals, pràctiques de planificació urbana més obertes i estratègies de gestió de baix a dalt. Finalment, les SBN replantegen els problemes urbans, posant al centre la justícia social i climàtica en visions alternatives de futur, encoratjant reconfiguracions urbanes més inclusives i per tant més resilients.

Paraules clau: governança urbana; vulnerabilitat social; economia circular; transició basada en el lloc; dinàmiques multi-actor; experimentació urbana; replantejament del problema; importància de la visió; parc fluvial Besòs; front litoral de les Tres Xemeneies

Resumen

Soluciones basadas en la naturaleza para reconfiguraciones de frentes de agua: *Litoral Besòs*, análisis de una transición urbana sostenible en el área metropolitana de Barcelona

Las ciudades necesitan responder a retos urgentes como los procesos de urbanización, la emergencia climática y la gestión del riesgo. Esto requiere de soluciones innovadoras en los sistemas urbanos desarrolladas junto a la ciudadanía, para lograr múltiples beneficios y entornos de vida más inclusivos. Actualmente, las soluciones basadas en la naturaleza, SBN, atraen el interés de la política pública y de la investigación urbana porque consideran las dimensiones sociales, ecológicas y tecnológicas bajo un enfoque territorial. Su implementación es un proceso de cambio continuo, amplio y local en el contexto que afecta diferentes ámbitos urbanos y generan impactos y beneficios sobre el conjunto de la ciudadanía. Por ejemplo, las SBN se utilizan en las reconfiguraciones de frentes de agua como prácticas alternativas para abordar diferentes retos asociados a la calidad y cantidad de agua, mientras se promueven servicios ecosistémicos y se crea nueva infraestructura verde.

Esta tesis analiza la implementación de las SBN como estrategia (entendida como procesos, resultados e impactos) para abordar los desafíos del agua en áreas periurbanas y producir efectos transformadores. Para este propósito, se usa el método de estudio de caso y el concepto de transiciones urbanas como un cambio fundamental, estructural y multidimensional. La investigación desarrolla una revisión bibliográfica sistemática de experiencias de implementación de SBN en todo el mundo que ha ayudado a identificar barreras y lecciones aprendidas, enfatizando en la importancia de la comunicación y la monitorización para facilitar la participación de los actores. Posteriormente, se analiza en profundidad un estudio de caso en el área metropolitana de Barcelona: el *Litoral Besòs*, a través de entrevistas semiestructuradas a actores locales, encuestas a usuarios y observación participante en procesos de planificación urbana. El caso de estudio ha constatado cómo las SBN implementadas han favorecido cambios fundamentales del *Litoral Besòs*.

Las SBN como un parque fluvial y humedales construidos abordaron los problemas del agua, permitiendo el desarrollo de tecnologías de reutilización, la regeneración del capital natural y el mantenimiento de los recursos en uso, lo que en última instancia es un avance para una gestión urbana del agua más sostenible. Sin embargo, los ciudadanos, como usuarios frecuentes, podrían desempeñar un papel más importante en la gestión y escalabilidad de las SBN porque las percepciones de la ciudadanía, a través de un seguimiento periódico, contribuirían a la gestión de las SBN a la vez que aumentaría el conocimiento y la conciencia acerca de los beneficios y de la gestión biótica. La ciudadanía, participando en la formulación de la reconfiguración del frente Mediterráneo, ha expuesto la necesidad de mediación entre los diferentes discursos de sostenibilidad urbana (contrario, no conflictivo y reforzado), abogando un objetivo socialmente más justo en esa reconfiguración.

Los resultados indican cómo las SBN promueven cambios físicos y mejoras ambientales, como la multifuncionalidad y la hibridación para transiciones basadas en el lugar. Las nuevas experiencias y prácticas culturales incluyen a la ciudadanía como beneficiaria directa, usuaria y participante. Este cambio en la dinámica de múltiples actores es un proceso iterativo que requiere flexibilidad para un cambio urbano a largo plazo. Las SBN tienen el potencial de apoyar la transición social-ecológica-tecnológica necesaria hacia una sostenibilidad urbana. Por lo tanto, las SBN, en tanto que proveen de capacidad de adaptación, aún deben superar algunas limitaciones y por ello es necesario favorecer cambios institucionales, prácticas de planificación urbana más abiertas y estrategias de gestión de abajo arriba. Finalmente, las SBN replantean los problemas urbanos destacando la justicia social y climática en visiones alternativas de futuros alternativos, alentando reconfiguraciones urbanas más inclusivas y, por tanto, más resilientes.

Palabras clave: Gobernanza urbana**;** vulnerabilidad social**;** economía circular**;** transición basada en el lugar; dinámica multiactores**;** experimentación urbana**;** replanteamiento del problema**;** importancia de la visión**;** parque fluvial Besòs**;** frente litoral de las Tres Chimeneas

Preface

Cities need to respond urgently to different pressures such as urbanization, changes in climate, and risk management. These societal challenges require solutions deployed in cities and developed with the citizens, among the multiple actors of interest, in order to be context-specific solutions. These responses usually developed as innovations in urban systems are under scrutiny for its coherent alignment with the social-ecological-technical dimensions of urban systems.

In this sense, innovation as urban experimentation is a topic of concern, which relates to how the solutions to these societal challenges can be considered outputs and outcomes, as well as process(es) that support transformative changes. For instance, the governance approach for urban planning and a more collaborative oriented management. Governance of urban change is a topic that is relevant for science, practice and policy, as successful urban responses to these societal challenges need to be scaled-up, mainstreamed and transferred.

A better understanding of the new capacities required in urban planning is beneficial to facilitate transformative change, in order to accelerate transitions towards urban sustainability. Hence, it is relevant to research on urban change to advance the knowledge on how to promote transdisciplinary dialogues, flexibility of planning and change as an autonomous and bottom-up process. Furthermore, in contexts with high social vulnerability and low-income experimentation as open-ended initiatives have proven to be central for responding in a resource efficient manner to the multidimensional needs of these territories.

The aim of this thesis is to advance the understanding on the local implications of urban sustainability transitions as fundamental, long-term, and multi-dimensional processes of change. This research focuses on innovation in urban water systems through the implementation of alternative practices. In particular, a case study in the Barcelona metropolitan area, in which Nature-based solutions (NBS) have been used for waterfront reconfiguration. The *Litoral Besòs* exposes how the change has taken place for many years, from different perspectives, and for various reasons.

Personally, the consideration of cities as an example of the most complex human creation resonates with its nature as the place of the most paradoxical unevenness. However, cities are the site for the highest social cooperation and technological advances. My motivation to develop this path of becoming an urban researcher started after following the first courses on the history and theory of my studies in architecture in Bogotá (COL). After some years of practice as a design architect, my interest in urban studies were followed with a master in urbanism in Delft (NL). As an urbanist, I have been involved in different roles and in different capacities, in which the aim for city change has involved collaborations with different disciples. I worked in urban management for some years, in which I have confirmed that change can't be deployed in isolation, and the potential of a more even reality is underpinned in alliances, projects, pilots, partnerships and efforts that should be long-term.

This thesis deals with urban change, from a point of view in which solutions to urban problems are researched and conceptualized as urban sustainability transitions. These years of research in Barcelona were aimed to better understand this concept as the endorsement for systemic changes, in which the spatial and material conditions emerge, and the social dynamics could be explored to identify how consensus and/or contestations are part of these processes of urban change.

Moreover, along this process, I've enjoyed the pleasures of being a city walker, the practice to live and get to know a city at a slow-pace, smelling it, looking at it, and in contact with it as a passerby. As a result, I believe that the teamwork that cities require is shaped by those daily realities in which all of us, the actors of the city, are allowed to participate when interested. If these urban conditions embrace our potentials, as active changers we help cities by making it more diverse, to fit us all. Lastly, this experience has prompted this research about urban change, in which a bias towards the utopian vision for a redistributive future is often present.

This thesis has been possible thanks to multiple efforts and capacities. Especial thanks to my advisors from the Sustainability Institute of Science and Technology at UPC, *Elisabet Roca* and *Joan de Pablo*, for their kind support, patience and commitment to guide me, share their disciplinary understandings, and commitment for change along these years. This thesis has been possible thanks to their research projects, mainly through the involvement and active participation in the Barcelona case for the NATWiP Consortium and for the endorsement of the social aspects of the *Pect Besòs Territori Sostenible,* respectively. My appreciation to the residents of the Besòs area and particularly to the human talent of the *Consorci Besòs*.

At a personal level, my heartfelt gratitude to my family, their support has been vital, always. Thanks to *Colfuturo* and *Icetex*, Colombian organizations that helped me to consider a self-funded PhD as an option to start this journey, and finishes with the satisfaction of pursuing a postponed dream.

Barcelona, May 20th 2022

Andrea Ramírez-Agudelo

Contributions

This research has contributed to the field of urban sustainability through different academic results: five scientific publications, presentations at congresses and conferences, master-thesis co-supervision, and deliverables for two competitive projects.

Chapters published

This thesis was structured as independent chapters that have been presented to peer-reviewers for their publication as scientific articles. The articles status and impact are presented in Table 1, including the journal's impact factor (IF), the quartile (Q), the category of subject, the publisher and country. Moreover, the citations to date according to Google scholar are presented in the last column (Accessed May 2022 - (https://scholar.google.com/citations?user=dA6lOmoAAAAJ&hl=en).

Table 1. Impact of the included articles

	Impact Factor	**Quartile**	**Category**	**Publisher and country**	**Cit.**
Chapter 4 - Article 1 (published) Sustainability	3.251	Q2	Environmental studies	MDPI, Switzerland	14
Chapter 5 - Article 2 (published) Journal of Cleaner production	9.297	Q1	Environmental Science (Miscellaneous)	Elsevier, United Kingdom	2
Chapter 6 - Article 3 (published) Nature Based Solutions	n/a	n/a	Nature Based Solutions	Elsevier, United Kingdom	
Chapter 7 - Manuscript (under review – 22/01) Environmental Science and Policy	5.581	Q1	Environmental Science and Policy	Elsevier, United Kingdom	

Chapter 4 - Article 1

Ramírez-Agudelo, N. A., Porcar Anento, R., Villares, M., & Roca, E. Nature-Based Solutions for Water Management in Peri-Urban Areas: Barriers and Lessons Learned from Implementation Experiences. *Sustainability*. 2020. Volume: 12. Number: 23. pp.: 12239799-1 ~ 12239799-36. *12*(23), 9799. https://doi.org/10.3390/su12239799

Chapter 5 - Article 2

Ramírez-Agudelo, N. A., de Pablo, J., & Roca, E. Exploring alternative practices in urban water management through the lens of circular economy–A case study in the Barcelona metropolitan area. *Journal of Cleaner Production*. 2021. Volume: 329. Number: 129565. pp.: 129565-1 ~ 129565-11. https://doi.org/10.1016/j.jclepro.2021.129565

Chapter 6 - Article 3

Ramírez-Agudelo, N. A., Badia, M., Villares, M., & Roca, E. Assessing the benefits of nature-based solutions in the Barcelona metropolitan area based on citizen perceptions. *Nature-Based Solutions,* 2022. -Number: 2, *100021.* https://doi.org/10.1016/J.NBSJ.2022.100021

Chapter 7

Manuscript under review - Ramírez-Agudelo, N. A., de Pablo, J., & Roca, E. Brownfield redevelopment in the Barcelona metropolitan area: Implications of a non-binding participatory practice for sustainability transitions. (Manuscript under review submitted in January 2022)

Non-included related articles

Article 5

Ramírez-Agudelo, N. A., Porcar Anento, R., Villares Junyent, M., & Roca Bosch, E. L'EIX BESÒS: Una mirada desde las soluciones basadas en la naturaleza. *QRU: Quaderns de recerca en urbanisme*. 2021. Volume: 11. pp.: 40 ~ 55. https://upcommons.upc.edu/handle/2117/359223

Other contributions

Presentations at congresses and conferences

Congress 1

Ramírez-Agudelo, N.A.; Roca, E.; De Pablo, J. Litoral Besós: sistema técnico y social como soporte inteligente y sostenible. *Congrés Nacional de Medi Ambient*. Technical communication Madrid, 27th of November 2018.

Congress 2

Ramírez-Agudelo, N.A.; De Pablo, J.; Roca, E. Social input for environmental quality assessment: insights of the tool design process supporting the quadruple helix´ integration in the Littoral Besòs. *European Roundtable for Sustainable Consumption and Production*. Oral presentation. Barcelona, October 16th 2019

Congress 3

Ramírez-Agudelo, N.A.; Porcar, R.; Villares, M.; Roca, E. El caso de l'Eix Besòs: lecciones aprendidas de la incorporación de soluciones basadas en la naturaleza en entornos metropolitanos. *Congreso Hispánico ISUF-H / Hispanic International Seminar of Urban Form*. Oral presentation (Online) September 29th 2020

Conference 4

Ramírez-Agudelo, N.A. Barcelona metropolitan waterfront: social dynamics and collaboration in the pathway to urban sustainability. *Network for Early career researchers in Sustainability Transitions Conference*. Oral presentation (Online), April 9th 2021

Conference 5

Ramírez-Agudelo, N.A.; Roca, E. Urban sustainability accounts. Reconfiguration of brownfield redevelopment in Barcelona Metropolitan Area. *IOER - IOER Annual Conference 2021: Space & Transformation*. Oral presentation. Dresden (Germany), September 24th 2021

Co-supervision

Oviedo Ospina, Angelica. Identificación de sinergias a través del metabolismo urbano en la zona Litoral Besòs. Master thesis in Sustainability 2020. Universitat Politècnica de Catalunya

Involvement in competitive projects

This work has been developed and supported by the Pect Litoral Besòs: Territori Sostenible project funded by the European Regional Development Fund (FEDER), and the NATWIP project - Nature-Based Solutions for Water Management in the Peri-Urban: Linking Ecological, Social and Economic Dimensions, partially funded by the Spanish Ministry of Science and Innovation (MCIU/AEI/FEDER) [PCI2019-103674, 2019] financed under the 2018 Joint call of the WaterWorks2017 ERA-NET Cofund of the European Union.

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At a personal level

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Mamá Berthica espero que algún día no muy lejano, estar cerca y compartir los placeres de la vida de la mariposa y el contacto con la naturaleza.

Pa, sé que en estos años tus metas se han cumplido por tu determinación, ¡gracias por tu ejemplo de perseverancia! Me alegra mucho que estés bien y puedas estar conmigo en esta etapa, seguiremos creciendo juntos.

Ma, has sido vital siempre y en este ciclo aún más, ya que tú has hecho parte diaria de esta experiencia ¡gracias por todo! siempre serás mi compañera de luchas y lochas.

Hermanos gracias por el amor y apoyo en esta experiencia, sé que nos quedan muchas historias por vivir y momentos para disfrutar juntos. **Cami** espero compartir muy pronto juntos y disfrutar la vida y sus matices, cómo lo hacíamos antes de iniciar esta experiencia junto con **Clau** y **Tomás**, mi sobrino favorito. **Tom** gracias por el dibujo que me regalaste cuando nos despedimos, ha sido mi paisaje favorito para inspirarme. **Mosk** y **Yuyicita** ha sido bueno tenerles cerca, ¡Gracias por todo! especialmente por las asesorías (técnicas, científicas y psicológicas) y estancias de verano durante este proceso.

Son olarak, sana teşekkür etmek istiyorum **Babək**'im, aşkım, daha doğrusu '*mi amor lindo*', hayatın bana verdiği en güzel hediye olduğun için teşekkür ederim. Bana her türlü zorluğa güçle dayanabilmem için neşe, şefkat ve kahkaha veriyorsun. Birlikte maceralarımızın devam edeceğini biliyorum. Seni çok seviyorum.

Sizə həyatınızı mənimlə bölüşmək üçün qanad verdiyi üçün **Azərbaycandakı ailəmizə** təşəkkür edirəm. **Mama** və **bacılar** mənim üçün xüsusi olduğunuz üçün təşəkkür edirəm.

Contents

Figures

Tables

Appendix

First part – Exploration

1. Introduction

To introduce this thesis and the research developed, this chapter is divided into three sections: Problem statement (section 1.1), Research design and approach (section 1.2), and Thesis organization (section 1.3).

1.1. Problem statement

Cities are under pressure from factors such as climate change, urbanization, or digitalization, all of which are claimed as urgent, long-term, and complex challenges. These societal challenges require skills and capacities to understand cities, their components, and their responses, in order to endorse transformative shifts in urban planning, as a means to enhance the urban governance.

Cities, in their most essential form, are composed of physical and social elements that together change in a dynamic and systemic manner (da Silva et al., 2012). The physical components of these socio-technical systems relate to the specificities of the sectors as urban domains such as transport, energy, or water (section 2.3). These sectoral components have been established as part of the socio-technical systems, in which its transformation depends on innovation as the shifts in the different elements such as technologies, consumption and production patterns, policies, behaviors, lifestyles, attitudes, business models (Geels, 2004).

Thus, a better understanding of cities as socio-technical systems, and of the skills and capacities needed to promote urban change, is a relevant concern for addressing societal challenges. In this concern, urban innovations are developed to underpin fundamental, long-term and systemic changes, which are known as urban sustainability transitions. Accordingly, these transitions are concerned with the sustainability through its dimensional aims of a more socially just, environmentally regenerative and economically redistributive way of shaping cities.

For this purpose, the development of systemic solutions, which serves as a normative standpoint, is a primary concern for addressing these societal challenges. In fact, the fundamental and structural change processes that underpin these systemic solutions are a major field of research within 'sustainability transitions', which pertains to a wide range of disciplines and schools of thought. The strategic aim of this research field is to better understand such transformative change in order to anticipate and adapt to undesirable effects, and to identify how to advance and accelerate the desired sustainability transitions (Loorbach et al., 2017).

This research field makes use of several conceptual constructs. The concept of socio-technical systems, for instance, has been widely accepted as a keystone in transitions scholarship, because it allows for a broader view of the processes of change, and the interlinkages between the elements required to fulfill societal functions (Geels, 2004). Yet, transitions studies have evolved from the use of the multi-level perspective framework proposed by Geels (2004), by the development of a variety of conceptual frameworks and methodologies, as well as empirical evidence through specific case studies in urban sectors and recently in specific locations. In addition, the issue of how technologies, actors, and institutions mutually shaped each other, has received increased attention (Fuenfschilling & Truffer, 2016). Moreover, it has been shown that these (socio-ecological-technical) solutions could be characterized by several factors such as place-based; involved multiple actors; innovative, as urban experimentation is needed; visioning; and problem reframing (Loorbach et al., 2017).

Research field

This thesis is developed within the field of urban sustainability, in which 'Urban sustainability transitions' is a major research topic that recognizes the critical role cities play (urban), in addressing societal challenges (sustainability), and how its deeper understanding is instrumental for facilitating transformative change (transitions). Moreover, urban sustainability transitions are researched for accelerating systemic responses to address societal challenges in different urban systems such as water, energy, mobility.

This thesis focuses on urban sustainability, the process by which societal challenges underpin the need for urgent and systemic solutions, and its endorsement to transitions as fundamental and structural changes (Frantzeskaki et al., 2017). Research examples of urban sustainability as transitions are the shifts in urban farming, decentralized and closed water systems, water reuse technologies (WRT), nature-based solutions (NBS), renewable decentralized energy systems, sustainable urban mobility, adaptable urban planning, social innovation, and cooperative economies. As a multidisciplinary social science research field, transitions research has focused on mechanisms and process explanations for analyzing and understanding sustainable transitions (Loorbach et al., 2017; Truffer et al., 2022).

The explorations of urban-related questions, such as how and why have cities changed allowed the recent emergency of the urban transitions and transformations field (Wolfram et al., 2016). Methodologically, this research field uses the analysis and understanding of fundamental and structural urban change processes, in which the knowledge embedded in case-specificities is evidence that can be linked to global transformative dynamics (Torrens et al., 2021; Truffer et al., 2022).

Research gap

Changes in urban systems are critical for analysis and understanding because they usually are long-term processes; thus, embedded in urban planning practices, whereas the urban responses to societal challenges are delivered typically as short-term initiatives, considered as experimental (Frantzeskaki et al., 2017; Fuenfschilling et al., 2019). Hence, a current debate about the role played by urban planning to support climate adaptation (and mitigation), urbanization, and digitalization is taking place in science, policy, and practice. For instance, to effectively address the challenges related to climate, it has been considered in the latest (sixth) IPCC report that urban planning is somehow a barrier for climate responses. Although, it has been highlighted by the IPCC, how practices in urban planning are central to mainstream climate adaptation through land-uses planning, procuring resilient infrastructure and transportation, supporting health and social services, promoting community-based adaptation, as well as protecting and integrating biodiversity and ecosystem services (Pörtner et al., 2022).

In this context, several questions are open. For instance, it's unclear, whether urban experimentation is addressing long-term challenges in a coherent manner (Torrens & von Wirth, 2021). As this coherence is required to cope with interrelated issues such as the intensity of environment and climate change, the rapid pace of urbanization, and the equity issues, especially related to digitalization. In the context of urban sustainability transitions, a focus on specific interventions as a mechanism that underpins cities' role in facilitating fundamental and structural changes, for example through the lenses of urban experimentation and transformative capacities, could be further investigated. Moreover, the examination of urban interventions provides an opportunity to inform on the specific mechanisms and/or key implications, that enable transformative shifts in urban management, which can provide evidence on the skills and capacities that has allowed advances for a long-term and coherent urban and social transformation.

This 'paradox' of long-term urban change and the transformative potential of short-term initiatives is relevant for the coherence in urban transformations. From an urban planning perspective, this is a significant challenge for the skills and practices in urban management, as it will require creativeness for the anticipation of responses to urbanization, climate and digitalization pressures. This knowledge gap questions the role played by the different actors, the specific mechanisms in the urban planning practice to operationalize a transformative process, including the urban governance for systemic change.

1.2. Research design and approach

This research makes use of a qualitative case study, which is a well-established approach in transitions research, as a means to present detailed analysis of the mechanisms and process explanation (Truffer et al., 2022). For this purpose, the concept of urban sustainability transitions is used as a theoretical framing to identify and characterize the processes, and factors of change in the theory and in a case study. Urban sustainability transitions are characterized by five factors, place-based transitions, multi-actor dynamics, urban experimentation, problem-reframing and visioning importance (Loorbach et al., 2017). Hence, the investigation of a specific urban setting, is a way of gaining in-depth insights into why and how things happen in a particular context to consider interrelated issues (MacCallum et al., 2019; Patton, 2014; Sarvimäki, 2018).

Three key factors were considered of principal interest: i) changes as place-based transition; ii) the multi-actor dynamics, representing the role of different actors, including citizens and simplified as the QH concept; iii) the role of urban experimentation, as alternative practices which are usually short-term as pilots or projects. Consequently, the analysis of a sustainable transition in the *Litoral Besòs* relates to the endorsements for transformative changes within two key factors, which have helped for the emergence of problem reframing and/or urban envisioning for a more sustainable future of the area.

Place-based characterized by the physical elements of place, scale and space, as well as its interrelated social elements (da Silva et al., 2012). The latter as the multi-actor dynamics linked to urban reconfiguration, as the role of citizens in public engagement, and mediating urban sustainability concerns (Chilvers & Kearnes, 2019; Hodson et al., 2017). The role of urban experimentation, as alternative practices primarily related to innovations in urban water systems and its management. Moreover, these endorsements serve to identify whether the shifts characterized have had the potential to shape the *Litoral Besòs*, as an overall urban system in transition.

The case used is the *Litoral Besòs*, which is located in Sant Adrià del Besòs a small municipality in the Barcelona metropolitan area in Spain, Europe (Figure 1). Data for this study is collected using a combination of qualitative research approaches, including a systematic review of literature, desk review, in-depth interviews, surveys, participant observation, and field visits.

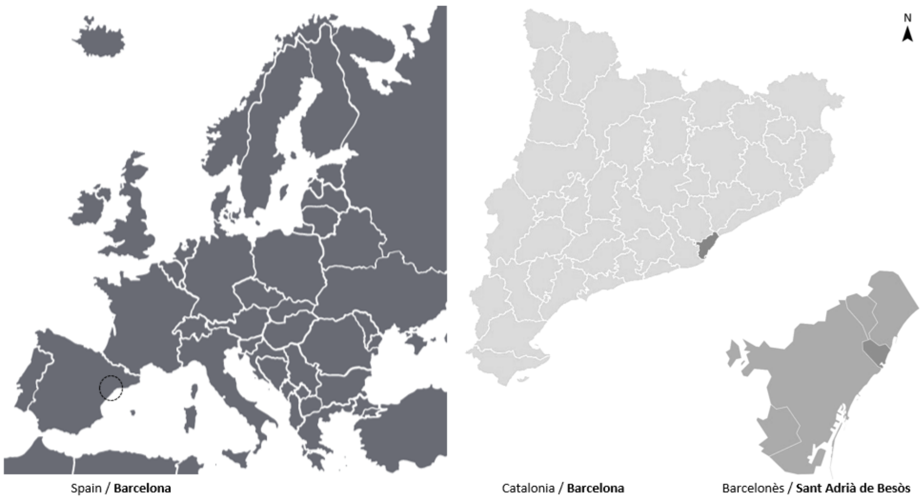

Figure 1. Location of the case study in Europe – Spain - BCN
From left to right, the case study in Sant Adrià de Besòs is located in Spain, and specifically, in the Barcelona Metropolitan area which is the capital of the Catalan autonomous community. Source: Google and Idescat.

Research aims and questions

The aim of this research was to better understand waterfront reconfigurations, and how does the NBS implementation enable transformative shifts toward an urban sustainability transition? The methodological purpose was to better understand the factors that characterize a transition towards urban sustainability with a double aim. First, as **outputs and outcomes** of transformative shifts enabled by innovation as urban experimentation and facilitated by the multi-actor dynamics and the role of citizens. Second, as wide-range **processes** of change that are questioned by their coherence in a context-specific setting.

As a result, this research is structured as an iterative analysis of how the implementations of innovation as alternative practices in water systems has let to physical and social changes in the urban environment. Also, the analysis aimed for the identification of the role played by the various actors, which can be involved or excluded, and the practices that intermediate in their multiple accounts of what a sustainable city. The research aims to provide evidence on how the concept of urban sustainability transitions can be used as a guiding normative aim for a coherent process of change at the urban level.

Guiding questions

The following guiding questions (GQ) were used throughout this thesis different analytical standpoints to develop evidence on the transformative shifts.

Chapter 4
Initially, to establish a standpoint on the usefulness of urban experimentation as alternative practices in water systems, the research asked: (GQ1) - *What lessons are learned, and which barriers are identified, from implementing nature-based solutions (NBS) for water management in peri-urban areas?* This GQ1 addressed the overall questioning of urban experimentation in a specific urban system as NBS for water challenges in peri-urban areas to establish a state-of-the-art that could be useful in the analysis of the *Litoral Besòs*. Accordingly, this guiding question was answered through a systematic literature review, which served to establish the state-of the art.

Following, three guiding questions were used for a comprehensive understanding of the *Litoral Besòs*. For this purpose, different analytical categories have been used, including the results obtained from the literature review, such as lessons learned and barriers from international experimentation experiences, as well as other bodies of knowledge related to the characterization of change and urban systems transformation.

Chapter 5
To investigate the role of urban experimentations as alternative practices, the GQ2 used in this study asked: (GQ2) - *How alternative practices in urban water management contribute to transformative changes towards Sustainable Urban Water Management (SUWM)?* The circular economy principles (Ellen MacArthur Foundation, 2017) were used as analytical categories to answer this GQ2. These principles served as means of change of alternative practices in urban water management, in order to establish the shift toward SUWM that is supported by alternative practices in water reuse, such as NBS and water reuse technologies (WRT).
Following, two guiding questions were used for characterizing the role of citizens (as the QH) to complement this study's exploration of alternative practices as urban experiments by the identification of their insight.

Chapter 6
The GQ3 addressed the role of citizens in the alternative practice of NBS by asking: *What are the usual experiences and nature-based solutions (NBS) practices of citizens?* And, *how do these insights contribute to NBS management?* For this purpose, a survey campaign was used in order to characterize the users and establish the benefits perceived, as their insight can be considered as contributions to NBS management.

Chapter 7
The GQ4 addressed the role of citizens in the participatory processes for the formulation of brownfield redevelopment asking: *Which urban sustainability accounts inform and shape urban reconfigurations*? Accordingly, by the use of the conceptualizations of the procedural formats of public engagement in the (Chilvers & Kearnes, 2019) and the urban sustainability accounts (Hodson et al., 2017), the analysis focuses on the endorsements of the participatory process for urban reconfiguration.

Research scope

The scope of this research was relatively broad, being concerned with the analysis of the changes in the last decades of the case study *Litoral Besòs*. The analysis has been developed as iterative processes of examination with different analytical focuses. The analysis focuses on how this urban area is the context for water innovations for water reuse, which are considered technological niches, and in which the territorial characteristics seem to support the need for protected spaces for innovation development. In terms of multi-actor dynamics, this analysis aids in identifying citizens' involvement and participant role in urban sustainability, as part of the governance features of a sustainable urban management system in which the citizens represent a quadruple helix (QH) for innovation development.

Relevance of this study

The characterization of the different urban change processes is central for the identification of the key factors and mechanisms that can facilitate, or hinder, urban sustainability. In this order, societal challenges in urban areas is a pressing aspect for exploration, and to advance in the understanding of how cities can be better able to address environmental degradation, climate resilience, sustainable urbanization, and a socially just digitalization. This identification of the ‘how’ cities -as socio-technical systems- can better address these challenges at the local level. This is a central issue to be answered as the role of cities are key for a sustainable transition. In the post-COVID world, the future of cities, urban planning and buildings in contemporary transformations is under current debate (Florida et al., 2021).

1.3. Thesis organization

The overall structure of this thesis is developed in three parts, to present a contextualization of the research, the body of the thesis as results, and the discussion and conclusion.

part is concerned with the exploratory phase, as the contextualization of the research, including two additional chapters besides this introduction.

> **Chapter 2** presents the theoretical background and a description of the key concepts used in this research as the state of the art.

Chapter 3 presents the methodology used, as the case study including its historical background and the evolution of its spatial context.

Second part is concerned with the analytical phase, as the results of the research. This section as the body of the thesis is presented in four chapters as:

Chapter 4 presents a systematic literature review (SLR) on nature-based solutions for water management in peri-urban areas, that is as innovations in water systems (GQ1).

Chapter 5 presents the case analysis of alternative practices in urban water by the use of quantitative and qualitative data to assess its fit within the circular economy principles (GQ2).

Chapter 6 presents the analysis of user experiences and practices for insight into management of nature-based solutions (GQ3).

Chapter 7 examines the urban reconfiguration through the analysis of the urban sustainability accounts and the participatory practice in place (GQ4).

Third part is concerned with the explanatory phase, as it ties together the various theoretical and empirical strands on urban sustainability transitions in order to discuss the significance of the results and to conclude this research. This final part is developed in two chapters:

Chapter 8 presents an overall discussion of the findings considering the concept of urban sustainability transitions.

Chapter 9 concludes and emphasizes the contributions, implications and suggestions for future work.

The chapter that follows presents the background and a description of the key concepts as the state of the art.

2. Background

This chapter presents the key theoretical concepts used in this thesis for the 'urban sustainability transitions', as it's a concept that is still relatively new that, in its basic sense, is used to refer to structural and fundamental changes. This chapter is divided into four sections that set the theoretical foundations for the understanding of the concepts of societal challenges and urban sustainability (section 2.1); urban sustainability transitions (section 0); and the directionality to move towards a more sustainable urban water (Section 2.3).

2.1. Societal Challenges and Urban Sustainability

Urban sustainability has been defined as the process by which societal challenges are persistent problems, which underpin the need for urgent and systemic solutions (Frantzeskaki et al., 2017). Addressing the complex and dynamic impacts of these interconnected challenges is highly relevant for defining the role of cities as arenas of change, reflexive learners of the transformative outcomes, or agents of regional and global change (Hölscher & Frantzeskaki, 2021). This aim of urban sustainability could be exemplified, for example, by responding to watershed management, urbanization, and digitalization challenges in order to achieve urban climate resilience.

Changes in climate refers to the planetary pressures on resources and how these pressures endorsed slow changes, irreversible changes in the environment, and the urgent need to be reflexive about consumption and production processes and behaviors. A reflexive understanding of climate-related changes, urban systems and urban governance have been identified as arenas for addressing these concerns from a social, technological and governance perspective (Hölscher et al., 2020). Research has widely acknowledged how the urbanization process is a major and uneven global issue, that causes significant changes such as land-use activities, demands of resources (i.e. water, energy, food), biodiversity, behaviors. As a result, cities, as focal geographical points, are being called upon to promote a comprehensive response to this rapid trend and to transform their contribution to global environmental change.

Current global agendas and paradigms propose to work on this challenge, namely the Sustainable Development Goals (SDG) and the Urban Agenda, on which most governments have clearly agreed on prioritizing the 'what' should be done, by emphasizing the need to alleviate its derived resource needs. In addition, new paradigms such as the circular economy (CE) have endorsed the potential of circular models to regenerate natural capital, keep resources in use, and design-out waste externalities (Ellen MacArthur Foundation, 2017).

Yet, under the paradigm of urbanization and 'ubiquity', digitalization process emerges as a shifting condition for the cities´ planning and design, integrated in the urban development concerns (Townsend, 2013). For instance, as urban systems contribute with vast green-house emissions, population growth is increasing, and ICT-based technologies are disrupting several domains of urban life. Digitalization as a trend affecting the way cities are shaped, is based on the intersection of urbanization and technology, as advanced ICT, relying on an efficient model discourse and the smart cities model (Bibri & Krogstie, 2017). As the processes of enabling or improving by leveraging digital technologies and digitized data, the technological development, and in particular the ICT, has promoted the availability of other resources such as real-time data. A common argument in urban development is that these challenges could be tackled through technological development in urban systems, by improving efficiency and optimization (Angelidou, 2015). However, digitalization seems related to sectoral and top-down decision-making, but not clearly understood as a means for autonomous actions and organizations of a specific location.

Moreover, the societal challenges of a specific location could be anticipated and managed through urban planning. However, the consensus on the 'how' has mainly endorsed the need for short-term responses through experimentation, as a governance approach that supports urban innovation, and which could benefit from learning processes (Bos & Brown, 2012; Evans et al., 2021). In fact, urban planning has historically been the integrative approach for dealing with the complexity of human settlements, and is now regarded as key for climate actions in the IPCC sixth report (Pörtner et al., 2022). Hence, digitalization can serve purposes of information access, decision-making, monitoring, and precaution and adaptation, as well as a cross-sectoral and bottom-up resource to facilitate urban management, and climate resilience.

Nevertheless, the debate over the future of the post-coronavirus city has served to highlight the cities' role in contemporary transformations, as well as the future urban planning and buildings (Florida et al., 2021). In particular, this questioning serves to deal with the societal challenges as the intensity of the climate change, urbanization, or digital gaps; and the cities' capacity to solve equity issues, while shifting from linear models towards more circular ones (Torrens et al., 2021).

Socio-Technical Systems

As previously mentioned, the concept of socio-technical systems is central to the transitions field, because it allows for a broader view of the process of change, and the interlinkages between the elements required to fulfill societal functions (Geels, 2004). Socio-technical systems have emerged as a critical research approach for dealing with the complexities of these effects, as technological innovation is also influenced by a variety of factors, and for gaining a better understanding of systemic change. For example, the urban domains of transport, energy, water have been established as socio-technical systems, in which its transformation relates to the shifts in the technologies, consumption and production patterns, policies, behaviors, lifestyles, attitudes, business models.

Therefore, the systemic nature of innovation addresses the need to move from sectoral systems to systems of innovation, where the traditional supply side (e.g. technology industries) could also be integrated to the demand, introducing the user environment of the technology. In this sense, the citizens have a role as users of urban systems, and their innovations.

The socio-technical concept is examined principally by using the conceptual framework of the Multilevel Perspective (MLP) proposed by Geels (2004). The multilevel perspective (MLP) integrates the various analytical dimensions involved in the socio- technical innovations system, the actors, and the rules and institutions, as a co-evolutionary process of adaptation and feedback dynamics. Through the use of these dimensions, the MLP recognizes three levels macro (socio-technical landscapes), meso (technological regimes) and micro (technological niche) and facilitates the analysis and understanding of transitions as transformative shifts from one system to another, as the opposition to stability (Figure 2).

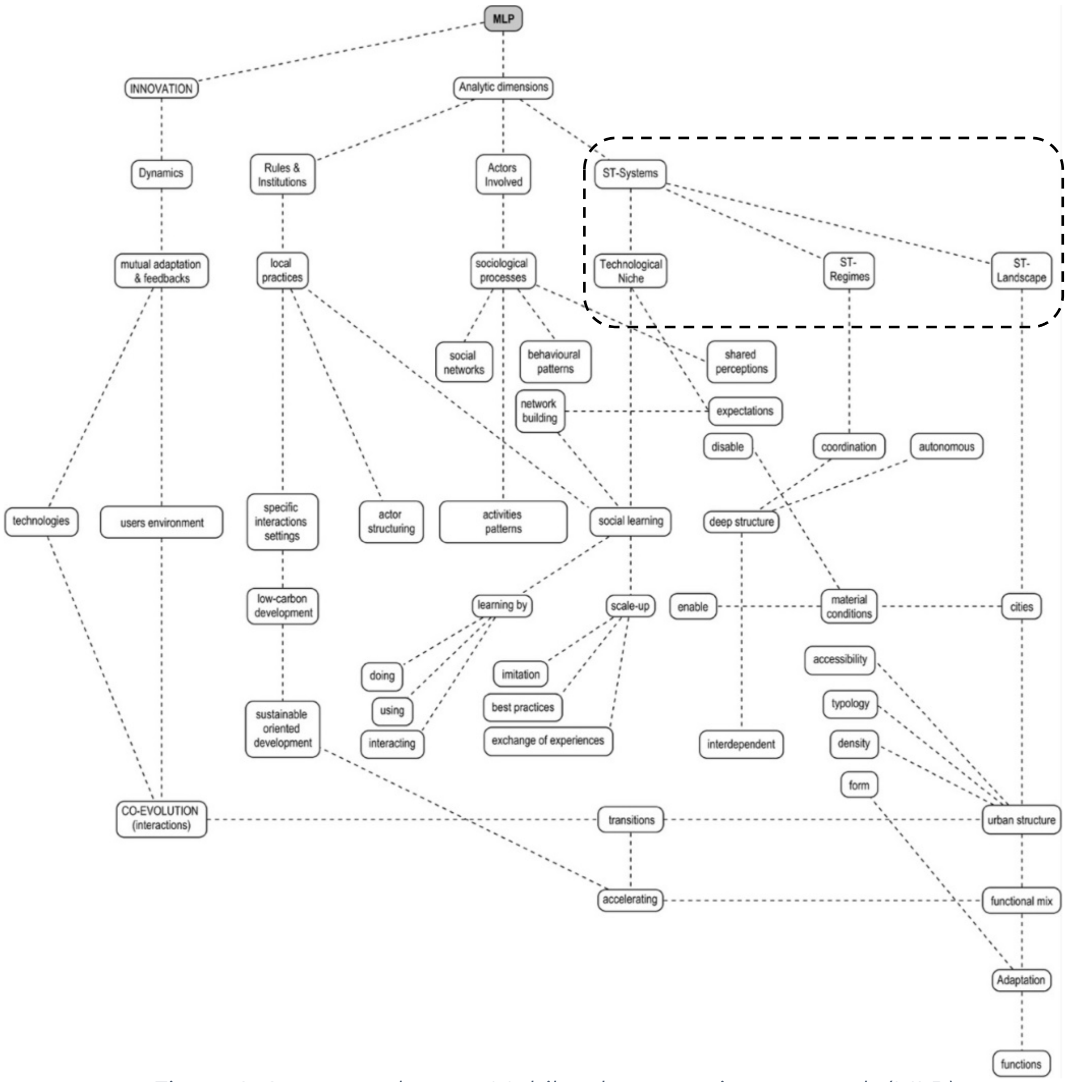

Figure 2. Conceptual map - Multilevel perspective approach (MLP).

The macro-level as socio-technical landscapes refers to aspects of the wider exogenous factors. According to Geels (2004), 'landscape' is the metaphor used to include the material aspect of society, such as the material and spatial arrangements of cities, material and environmental conditions, external agents, larger socio-cultural context. Accordingly, in urban transitions, the socio-technical landscape may refer to the external factors of urbanization, climate change and digitalization.

The meso-level as a technological regime is the 'meta-coordination' aspect (Geels, 2004). As such, the regime is embedded in institutions and infrastructures such as the technological, science, user-market, socio-cultural, policy regimes, expressed as engineering practices, production process technologies, product characteristics, skills and procedures, ways of handling relevant artifacts and persons, as well as ways of defining problems. Specifically, as the regime relates to the set of rules, including the cultural frames, social institutions, interaction norms, reward and cost structures. Thus, the regimes are represented in the 'meta-coordination' of urban systems, which could be for instance, the interaction of urban systems and water systems represented among the interplay of physical and social changes, urban planning, and citizens' engagement in shaping urban change.

The micro-level as the technological niche is the locus of radical innovation (Geels, 2004). Technological niches are often played out as experimental projects, involving heterogeneous actors (e.g. users, producers, public authorities). This level is relevant as locations for learning as processes, e.g. about technical specifications, user preferences, public policies, symbolic meanings. Also, niches provide space to build the social networks which support innovations, e.g. supply chains, user–producer relationships. Accordingly, in urban transitions, the niche refers to the experimental initiatives and projects in a context-specific, which could be related, for example, to alternative practices in specific urban systems such as NBS or WRT for water management, as well as the participatory approaches for urban reconfiguration in a specific location.

The helix approaches

The conventional triple helices approach for innovation development is a concept that shows the actors dynamics of the political stakeholder or government (GOV), economic stakeholder as the market or industry (IND), and science or academic actor (UNI). For this purpose, the quadruple helix approach is used to show the involvement of the public stakeholder or civil society (CIV) is the fourth helix (Figure 3).

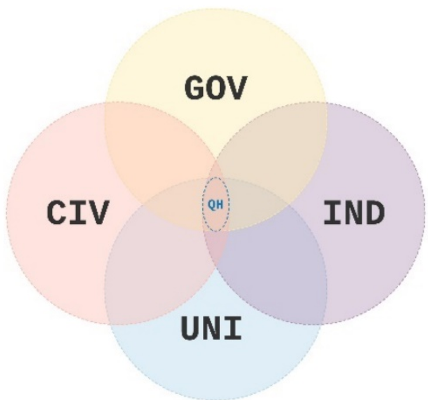

Figure 3. Quadruple helix concept (QH)

Based on Geels (2004, the Quadruple helix (QH) is a concept that includes the citizens, as part of the actors interacting in innovation systems, known as the triple helix (GOV- IND- UNI).

The quadruple helix (QH) is proposed as an extension of the triple helix concept to emphasize the role of the user's environment (demand side) as the fourth helix (Carayannis & Rakhmatullin, 2014). Thus, urban sustainability transitions are characterized by experimentation as innovation in different urban systems which are developed by multiple actors, including the citizens. The QH and its exploratory orientation considers actors as connected through structured and continually evolving coupled networks (Carayannis & Rakhmatullin, 2014). The QH conceptual model, as well as the S3, could be seen as responses to the social dynamics needed for shaping technological innovation, promoting democratic public engagement and learning (Chilvers & Kearnes, 2019; Hollands, 2008; Luederitz et al., 2017). Conceptual tools to analyze actors' concerns are diverse such as the analysis of actors' configuration, network creation, as well as the agency potential for problem-solving, decision-making, or innovation development.

Although, QH has been regarded as an 'imprecise concept' in innovation research, as the fourth helix definition can encompass any role ranging from intermediate innovation enablers to different innovation users (Veldhuizen, 2020). Actors' involvement and participation become a transversal factor for recognizing how urban challenges are not only technological; but integrated and systematic (Fernandez-Anez et al., 2017). Thus, a broader view on the QH exposes the utility of the concept among innovation policy and research, to overcome the concerns on generic users and locations in innovation development. Innovation policy has made efforts to incorporate the QH into place-based strategies for Smart Specialization (S3), to contribute with a means for societal consensus to socio-technical transitions and the governance of sustainable regional development (Veldhuizen, 2020). This research on S3 has described the QH as the role of civil society and the relevance of meaningful engagement with 'sustainability' related issues.

Using a case study in Australia, Veldhuizen (2020) argues that the perception that citizens, as the fourth helix (CIV), have 'no meaningful say' in how the region is governed results from a history of top-down decision-making. The S3 implementation was found to be adaptable in addressing some societal challenges; however, the S3' ability to drive transformational change was constrained by its deployment within timeframes. Moreover, the author argues how citizens' involvement could be an urgent factor 'toward inclusive, bottom-up decision-making, and governance'.

Currently, research, policy and practices debates are centered not only as how cities as socio-technical systems, can also be better understood as socio-ecological-technical systems (SETs) (McPhearson et al., 2016). As such, its solutions to address the societal challenges promote transformative change in these realms. This line of thought follows the argumentation of Carayannis & Rakhmatullin (2014) who explained that from a system's perspective, the triple helix represents the information transition, the QH the knowledge transition, and the quintuple helix the sustainable transition (Figure 4). The quintuple helix is relevant for innovation and knowledge, as one of the frameworks that attempts to account for the natural environment (ENV) as an actor, as well as innovation, knowledge production and use, which must be contextualized by society's natural environment (Baccarne et al., 2016; Carayannis & Campbell, 2013; Carayannis & Rakhmatullin, 2014).

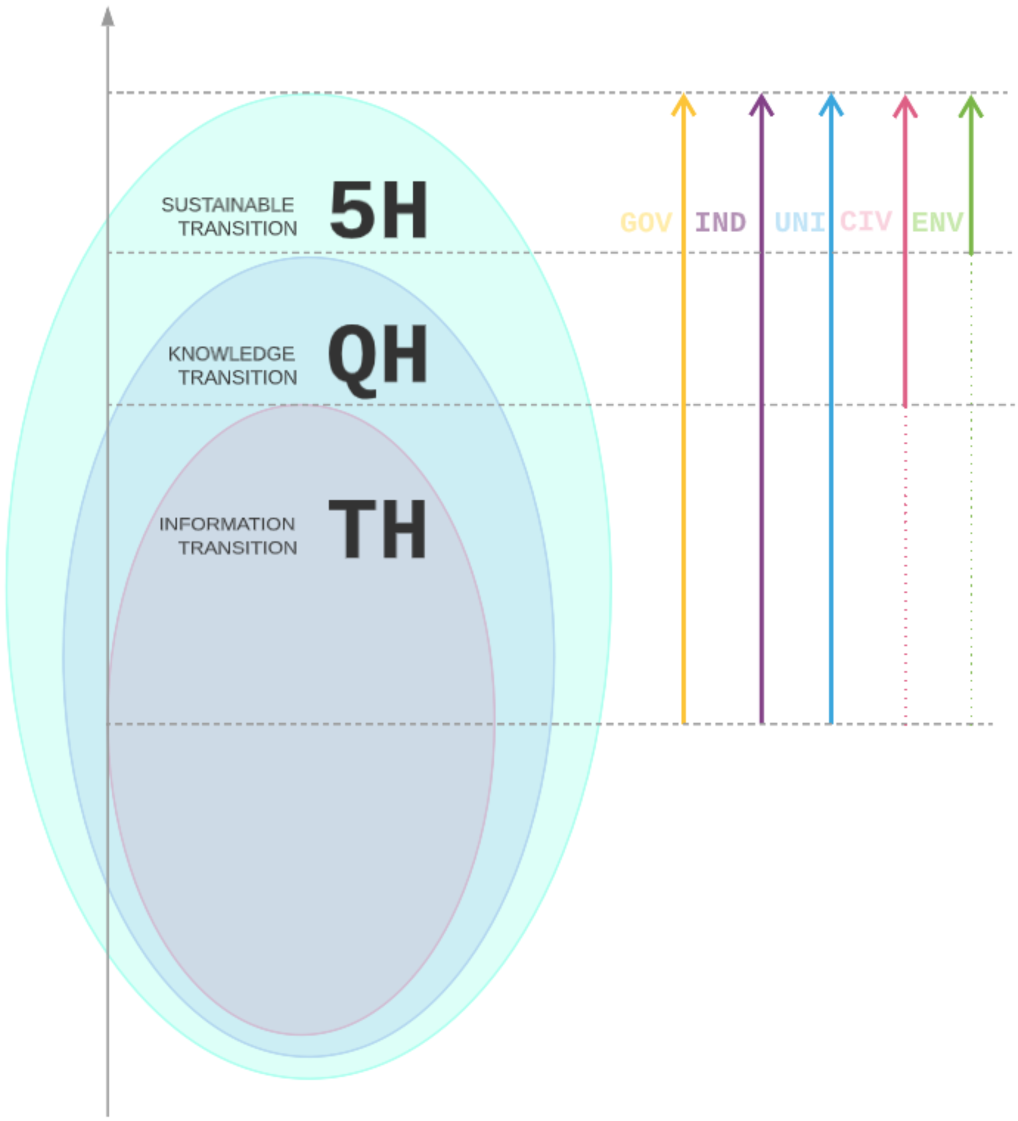

Figure 4. Graphical representation of the helix concept and its extensions.
The quintuple helix concept of Carayannis & Rakhmatullin (2014) as the integration of ENV – environment as an actor for a sustainable transition.

2.2. Urban Sustainability Transitions

Urban sustainability transitions refers to the fundamental and structural changes of addressing persistent societal challenges (Frantzeskaki et al., 2017). Transitions research has contributed through the analysis of historical processes of change, highlighting the drivers, dynamics, and implications behind these processes (Truffer et al., 2022). Advances in this field have recognized that 'urban sustainability' is actively dependent on the delivering actions deployed, supporting the relevance of transformations 'in, by, and for' cities (Hölscher & Frantzeskaki, 2021). Urban sustainability transitions are possible when driven by in-place innovation as a means of experimentation and learning (Luederitz et al., 2017), alongside deeper transformations as urban capacities (Wolfram, 2016), which are supported on more radical, systemic, and accelerated changes (Frantzeskaki et al., 2017; Loorbach et al., 2017; Torrens et al., 2021).

The literature on transformation processes towards sustainability has highlighted how its analysis and understanding has been supported on distinct conceptual approaches such as socio-technical transitions, social-ecological systems, sustainability pathways, transformative adaptation (Patterson et al., 2017). Yet, socio-technical transitions have been a central concept in the overall transitions field as it supports a comprehensive understanding of the fundamental, multidimensional, and long-term changes of socio-technical systems (Geels, 2004; Markard, 2011). Fundamental as disruptive innovation compete, destroy and challenge the different elements of a system (Wolfram, 2016). Multi-dimensional as changes are not only technological, but also organizational, institutional, political and socio-cultural (Geels, 2004). Long-term, because systemic changes are realized after decades (Fuenfschilling et al., 2019).

Research in urban sustainability transitions aims to emphasize on the importance of better understanding of shared characteristics and elements along the processes of change. The '*place-based transitions*', as the changes in the (urban) context as physical configurations of space, place, and scale (Binz et al., 2020; Fuenfschilling et al., 2019).

Also, research on transition governance has proposed that regardless of the conceptual approach (such as urban sustainability transitions), the analysis of societal transitions to sustainability share characteristics and elements summarized as *multi-actor dynamics, problem reframing, the importance of vision, and the relevance of experimentation* (Loorbach et al., 2017). The *'multi-actor dynamics'* refers to the involvement and role of multiple actors along the transition process. '*Reframing the problem*', explores the societal consensus and the actors' ways to understand the need for systemic change. The '*importance of visioning'* denoting the collective value of believing in alternative futures as the potential to take aligned actions. The *'relevance of experimentation'*, explained as the open-ended exploration for ways to adapt, change, and transform existing dominant cultures, structures, and practices.

Place-based transitions

The '*place-based transitions*', as the changes in the (urban) context as physical configurations of space, place, and scale, which is a characterization that urban and geography-related studies have traditionally developed (Binz et al., 2020; Fuenfschilling et al., 2019). A systemic approach to cities is used in urban studies, urban ecology, urban metabolism, and scenario planning, and currently in urban transitions (da Silva et al., 2012). Previous studies have established that a systemic approach helps to understand place-based transitions as how the physical and social elements, as well as their related dynamics shape urban experimentations. Furthermore, a systemic approach can initiate a place-based transition through governance processes that support sustainability innovations (Halbe & Pahl-Wostl, 2019). Therefore, according to the theory, cities as 'socio-technical systems' is a conceptual response to the complexity of systemic approaches (Geels, 2004).

Cities as 'complex -living- systems' capture the multiple dimensions of dynamic exchanges, which are characterized by flows; constantly evolving, responding to internal interactions and external factors (Batty et al., 2006). To cope with societal challenges, city dynamics reveal changes in urban systems as interactions of material infrastructures, various technologies, and social systems as an interdependence of infrastructure development and socioeconomic networks (da Silva et al., 2012).

Lastly, Da Silva et al., (2012) propose that an easy-to-understand manner that does not require complex modeling, is the illustration of urban systems as layers, in which the physical and social components include elements such as infrastructure, technologies, regulatory structures, and formal and informal practices. Therefore, even if social components are characteristics of a place, this component is considered to belong to the multi-actor dynamics in order to facilitate the analysis of the social changes. Thus, simple layers can be used to conceptualize urban systems and its specific sectoral components (e.g. transport, energy, water) as socio-technical systems towards sustainability.

Multi-actor dynamics

The multi-actor dynamics as the involvement and role of multiple actors in innovation development along the transition process. These dynamics include the role of citizens, and which could be represented by the helix concept. Multi-actor dynamics has been proposed as an area of interest to understand how transitions involve multiple actors, who play different roles (Loorbach et al., 2017). These actors may represent various institutional backgrounds such as industry or market, government, academia or science, and civil society. Based on the innovation systems, the quadruple helix concept (QH) is a conceptual model that supports the identification of the actors' role and the interlinkages among the innovation' supply (Carayannis & Campbell, 2012; Geels, 2004).

The visual aid of the QH allows for a simplification of the social aspects, such as the multi-actor dynamics and interaction. This simplification is useful as the social fabric of a city is the result of many intertwined, multi-faceted networks of relations between persons, institutions, and places (Batty et al., 2012). Research on the role of these actors explores how they represent different types and forms of agency, which have influence on the transitions, i.e. speed and direction; as they can be engaged, empowered, and can more effectively contribute to desired transitions (Loorbach et al., 2017). It has been established that shifting power relations and role constellations between different actors is inherent to any transition process. Furthermore, urban innovation could benefit from social innovation through knowledge exchange, actors' empowerment, leadership opening (personal or institutional), and collective action for urban innovation (Avelino et al., 2019).

The understanding of multi-actor dynamics can enrich transitions research, for instance, as how the social elements of a territory are present in sustainability concerns, when referring to place-based social movements, place-making approaches. Previous research established that place-based social movements can facilitate 'unique local heterogeneous' alliances with key actors of the science and technology system (Ramirez et al., 2020). In addition, its deployment as place-based and place-making approaches could be means for greater aims such as more just outcomes (Amorim-Maia et al., 2022).

The role played by the non-usual actors, including civil society (CIV), could be emphasized in sustainability transitions as a complementary bottom-up driver endorsing the 'right to shape the city' (Hollands, 2015). Participatory practices and social innovation, such as consultations, aid in the purpose of a more just and hybrid governance (Toxopeus et al., 2020). This aim behind social innovation is nurtured by opportunities in vis-à-vis encounters, workshops, and meetings, which imply that the encounter of different actors is a first step that allows or constrains collaboration. Conceptual tools such as the procedural formats of public engagement (Chilvers & Kearnes, 2019) could be useful to gather evidence on the models, subjects and objects, and for a better understanding the roles played by these actors in specific conditions. Finally, the social actors are relevant elements for a sustainability transition in science and technology, but also essential participants in urban change.

Urban experimentation

Urban experimentation refers to the governance approach to cope with urban sustainability challenges (Steen & van Bueren, 2017). Also, experimentation are open-ended explorations that allows learning-by- doing and doing-by-learning in order to create ways to adapt, change, and transform existing dominant cultures, structures, and practices (Loorbach et al., 2017). The consideration of experimentation as a characteristic for sustainability transitions means that urban change does not depend only on technological developments but on the multi-dimensional shifts required for fundamental, long-term and systemic transformations.

However, urban experimentation is currently questioned as a means to promote broader transformative dynamics for a coherent sustainable urban transition (Torrens & von Wirth, 2021). Therefore, an open concern in urban sustainability transitions is the potential of cities to escalate and replicate their learnings and solutions, for which is beneficial the integration of reflexive learning and cities capacities (Luederitz et al., 2017; Wolfram, 2016). Reflexive learning means to understand the inputs, processes, outputs and outcomes that need to be in place to promote long-term changes (Luederitz et al., 2017). Thus, experimentation as 'lenses' for governance and agency is aimed to better understand the change processes and influence the speed and direction of transitions (Loorbach et al., 2017).

Experimentation as transformative capacities (and agency) to be in place for the emergence of systemic responses, is a critical component to address the multi-sectoral and multi-scalar issues of societal challenges. This consideration is a response from transitions research theory to the critical claim to the smart cities' discourses. This claim established how the technological innovations, as means for efficiency and optimization tasks, have a limited role in a transition towards sustainability (Hollands, 2015; March, 2016; Martin et al., 2018; Yigitcanlar & Kamruzzaman, 2018).

Cities need to address challenges that are intersectoral and have a multi-level complexity by deploying experimentation as a means for technological, governance, institutional, organizational, political, and socio-cultural innovations (Geels, 2004; Loorbach et al., 2017). This means that cities learnings and capacities serve to address its societal challenges, in which the role of place is shaping the urban transformative potential (Peris-Blanes et al., 2022). Cities as sites of urban reconfigurations are the arena for actors mediation, through mechanisms that expose their consented, non-conflictual, and/or contested multiple urban sustainability accounts (Hodson et al., 2017).

Open-ended explorations can be, for example, the shifts in the governance, institutional, organizational, political, and socio-cultural aspects that underpinned the technological developments or niches, as the micro-level of fundamental change processes (Geels, 2004). Urban experimentations aim for more open-ended governance approaches in real-life contexts. Urban Living Labs (ULL) are concepts that operationalize this aim, which are characterized for its aims, innovation developments, sharing through co-creation activities (Bulkeley et al., 2016; Castán Broto & Bulkeley, 2013; Steen & Van Bueren, 2017).

Problem reframing

Problem reframing insists in the importance of societal consensus, by establishing shared recognitions that can facilitate aligned actions for problem resolution (Loorbach et al., 2017). To better understand this issue, Loorbach et al. (2017) argue that participation promotes the development of a (new) shared discourse for problem resolution. As a result, a comprehensive understanding of the different actors involved in urban systems is required for a systemic identification of the challenge, as a socio-technical system. In fact, a challenge pertaining to a specific urban system may be impacting other systems, thus, for reframing the challenge a better understanding of 'place' is fundamental (Peris-Blanes et al., 2022). Besides the context-specificities of a place, this research argues on the notion of accountability as a feature for urban systems change.

Visioning importance

Visioning importance as the strategic aim of inspiring change. The actors' belief in futures for more sustainable urban living are useful for providing direction and speed of change (Loorbach et al., 2017). The fundamental values that the actors involved aspire to realize with this alternative future is a driver of innovation and experimentation at all levels. Furthermore, these values could be considered as non-prescriptive sustainability principles in order to determine 'what are the essential aspects of the ecological and social systems that need to be sustained in' (Broman & Robèrt, 2017). This alternative vision motivate, coordinate, and empower actions alignment (Loorbach et al., 2017). A variety of tools, including visioning, scenarios, and backcasting, can assist actors and networks in working more strategically on transitions, exploring more radical innovation paths, and developing alternative goals and agendas.

Challenges such as climate neutrality benefits from urban experimentations aimed to promote multi-actor collaborations through problem reframing and visioning. Urban climate governance is an open-ended approach to endorse this purpose, which through vertical and horizontal integration aim to assimilate the multi-dimensionality, multi-sectoral and multi-scale challenge of changes in climate (Hölscher, Frantzeskaki, McPhearson, et al., 2019).

2.3. Towards a more sustainable urban water

Urban water systems are affected by societal challenges exposed in issues such as carbon sequestration, coastal resilience, ecosystem restoration, and watershed management (Ramírez-Agudelo et al., 2020). Urban water systems are in urgent need of fundamental changes due to its characteristics of: i) based on linear management models that center on extraction, use, and disposal; as well as ii) dependent on large-scale and centralized infrastructures and technologies (Heiberg et al., 2022; Hoffmann et al., 2020).

Aims for water sustainability emphasizes prioritizing more sensitive actions in its local management to guarantee resources' availability for its future-proof system (Ferguson et al., 2013). Different approaches are being explored, including reduction and reuse, under the introduction of the paradigm of the circular economy (CE) (Hoffmann et al., 2020). Multiple dimensions of the sustainability challenge(s) in urban water systems need to be addressed to aim for CE and the integration of water systems such as to increase natural capital, close the loops in urban water systems, and avoid negative environmental effects (Fidélis et al., 2020; Nieuwenhuis et al., 2021).

Transformative shifts in water systems are expected by increasing water resources reuse, particularly of alternative resources for non-human consumption throughout a more sensitive management. Urban water balance restoration, multifunctional ecosystems, resource recovery, and water reuse are incremental actions underpinning a more sustainable urban water management (SUWM) (Adem Esmail and Suleiman, 2020). Within this management approach, the reuse of water, energy and nutrients have been established as practices that could promote shifts from households, to cities, to landscape levels (Hoffmann et al., 2020). Urban experimentations as alternative practices in urban water systems are used to deliver technical developments, as well as institutional responses, for an added value by simultaneous and multiple benefits.

Urban water systems are prone to demonstrate higher efficiencies for fresh-resources availability for consumption. The need to reduce drinking-water pressures incentivizes an integrated approach to urban water as a socio-technical system undergoing transformative changes. For example, drinking-water pressures could be reduced through increased awareness of both the pressures on resource availability and consumption patterns. Hence, changes in its production, such as safe access to clean water, are expected; while exploring innovations for efficiency and optimization as new practices, routines, regulations in place, etc. However, even if innovations in water systems can lead to multiple benefits and services, these innovations need to be built up to promote systemic changes, allowing fundamental change in water systems over the long-term (Fuenfschilling et al., 2019; Ghosh et al., 2021).

Although fundamental changes in water systems are likely to be in place over the long-term; alternative practices are typically supported as short-term and/or singular interventions (Fuenfschilling et al., 2019; Fuenfschilling & Truffer, 2014; Hoffmann et al., 2020). The integration of drivers as the circular economy to consider alternative practices, by identifying advances in its sustainable urban transition (Ramírez-Agudelo et al., 2021).

Levels of transformative change in water systems

For Hoffmann et al., (2020), in broad terms, the transformative changes in urban water systems could be distinguished at three levels: micro, meso and macro (Figure 5). *Macro-level* relates to formal and informal rules and regulations and long-term transformations of technological paradigms and societal beliefs. *Meso-level* relates to the spatial organization of technical systems and their governance structures. *Micro-level* relates to technological components, individual actors, and short-term transformations.

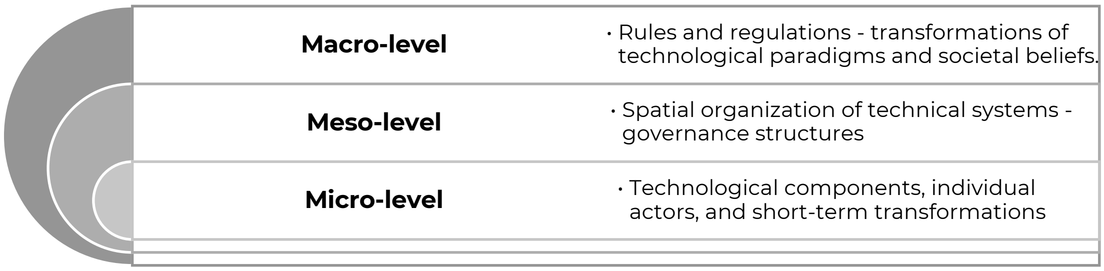

Figure 5. Levels of transformative change in water systems

Similarly, water circularity assessments have used this outline to show how the micro-level could focus at the single components, which are inter-connected at the meso-level, forming a system at a macro-level (Nika, Gusmaroli, et al., 2020). The *macro-level* is concerned with the structural changes promoted by the different approaches, as ways of integrating the technical and biological cycle of urban water systems. The *meso-level* is concerned with the physical changes promoted by alternative practices based on the hybridization, (smaller) scale, modular deployments and decentralization. The *micro-level* is concerned with the specific features delivering additional and multiple benefits and services, which adds value and meaning to the multidimensional responses of alternative practices.

Despite the fact that urban water systems are interconnected, focusing on innovations allows for a better understanding of their implications in a context-specific case. Innovations in water reuse are, at the micro-level, decentralized systems such as water reuse technologies (WRT), which are considered potential technologies for systemic changes in water systems (Hoffmann et al., 2020). Moreover, nature-based solutions (NBS) are alternative practices for water reuse for addressing water challenges through nature-based processes.

This analysis focuses primarily on Nature-based solutions (NBS) as socio-technical innovations for urban sustainability transitions. Even with growing interest in NBS, to operationalize this comprehensive concept is beneficial as a means facilitating the shifts in urban water systems and the characterization of the urban transformative change. This analysis follows guiding questions from different standpoints, which put together clarify the implications of NBS on place-based transitions, multi-actor dynamics, urban experimentation, problem reframing, and visioning relevance. Following, a brief introduction to the NBS concept is presented and a systematic literature review on the concept is presented in chapter 4.

Nature-based Solutions

Nature-based solutions (NBS) represent alternative practices to socio-ecological adaptation and resilience that place equal emphasis on social, environmental, and economic domains (European Commission, 2021). Nature-based solutions (NBS) have been described in the agenda policy of the European Union as "actions that are inspired by, supported by, or copied from nature…" (Bauduceau et al., 2015). Nature-based solutions (NBS) have a place-based transformative potential, because it's a type of urban experimentation that reintroduces nature to address various societal challenges (Frantzeskaki, 2019). Research on NBS has used the term as an umbrella or comprehensive concept, which includes other green concepts such as green infrastructure (GI) and ecosystem services (ES) (Dorst et al., 2019; Escobedo et al., 2019; Hanson et al., 2019).

Green Infrastructure as a strategically planned 'network' of natural, semi-natural, and cultivated areas, with other environmental features -designed and managed- in order to protect biodiversity in urban and peri-urban settings, and to deliver a wide range of ecosystem services (ES) (Escobedo et al., 2019). Ecosystem services are used to identify the different services and benefits provided through nature. These services could be classified as provisioning, regulating, cultural and supporting. (TEEB– The Economics of Ecosystems and Biodiversity, 2011).

Moreover, NBS could be characterized as a comprehensive concept by using its key elements in different outlines or frameworks. In this study, the NBS outline used includes three factors of the urban sustainability transitions as dimensions: (i) Place-based transitions as context, to refer to its specific location; (ii) experimentation, to refer to its problem-solution approach as a technical aspect; and (iii) multi-actor dynamics as the governance and management approach.

First, for **place-based transitions**, the context dimension takes into consideration the spatial and physical conditions of NBS, which can relate to the space, place, and scale as:

- Location as the administrative place considerations, including the GPS coordinates;
- Scales of intervention, which is different from the administrative level of NBS governance;
- Coverage as the longitude and area

Second, for **experimentation**, the NBS problem-solving dimension includes:

- Challenges, as the main issue addressed through nature, in particular related to urban water systems (direct and indirect);
- Ecosystem services (ES), which can follow the TEEB classification (TEEB– The Economics of Ecosystems and Biodiversity, 2011); and

Types, identified as the kinds of NBS implemented, in particular, to address water challenges in peri-urban areas.

Third, for the **multi-actor dynamics** the governance and management dimension include:

- Policy instruments, which differentiates between the level of implementation and the scale of the scope;
- Multi-actors involved which follow the QH concept, and could be used to identify the water-related actors; and
- Financing mechanisms, as the identification of the specific economic means in place, as well as the origin of the funding.

Together, these key elements conform describe NBS in terms of factors (Figure 6).

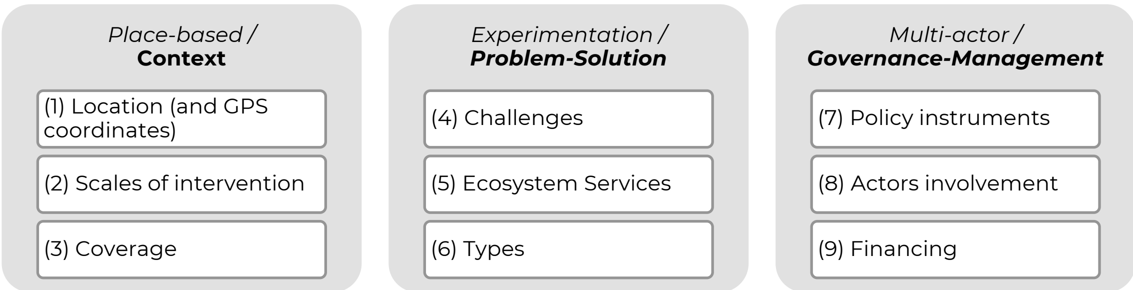

Figure 6. Key elements for NBS characterization

In summary, urban sustainability transitions research has been considered a field of knowledge which could lead to advances in the knowledge on the 'how' and why cities change. Cities , as socio-technical systems, can better address societal challenges such as the pressures of changes in climate, urbanization, and digitalization challenges. In particular, by focusing on change processes, shifts in a specific urban system, such as water systems, could serve to characterize place-based, multi-actor, and urban experimentation dynamics. To identify which aspects at the micro-level, demonstrate advances for a more sustainable water management, and perhaps recognize at the urban level broader dynamics of change, could be further explored through the urban sustainability factors.

The chapter that follows presents the methodology used, as the case study, including its historical background and the evolution of its spatial context.

3. Methodology

This chapter on the specificities of the materials and methods used has 3 sections: Case study research strategy (Section 3.1), Data collection, analysis and interpretation**.** (Section 3.2) and Case Study Overview (Section 3.3).

3.1. Case study research strategy

This research makes use of a qualitative case study, which has been defined as an empirical, in-depth investigation of a contemporary phenomenon in its real-world context (Yin, 2014). Case studies have been considered a well-established approach in sustainability oriented research to support transition's analysis (Truffer et al., 2022). The strength of case study research is its capacity to generalize to theory (Sarvimäki, 2018), in this case urban sustainability transitions. The goal of the case study research is to support a comprehensive understanding of the role of urban sustainability along the change processes, and, in particular, in its urban systems' configuration.

Sarvimäki (2018) identifies several advantages and specificities of the use of a case study for urban research. The author points out how case study research design is a central aspect, as the strategy to present the variables of the setting without control or manipulation; and the methodological goal. For this purpose, a case study relies on multiple sources of evidence, as well as triangulation of methods and data, to answer open research questions ("how" or "why"). As a result, rather than statistical generalizations, a case study draws analytical conclusions from a case study, aiming to generalize to theory.

Furthermore, the use of a holistic case study has been established as a strategy to present detailed analysis in urban studies and research, which have aided in the identification, characterization, and explanation of sustainability transition mechanisms and the processes of change (Truffer et al., 2022). The case study is used to gather empirical evidence from a specific urban (spatial) setting in the Barcelona metropolitan area where alternative practices in urban water systems and management have been implemented.

This research is developed as an iterative process. It started with an exploratory phase, followed by an analytical phase and finishes with an explanatory phase. The exploratory phase aimed for a better understanding of the research intersection of societal challenges and sustainable cities. The analytical phase served for examining the case study to gather evidence for responding to the research guiding questions. The explanatory phase served for identifying the significance of the findings of the case study in relation to sustainable urban sustainability transitions and its characterizing factors. Along this iteration, several thematic standpoints have served to evidence the processes of change and the different features, while the conceptual construct from the urban sustainability transitions has allowed for an integrated knowledge.

The use of a combination of qualitative research approaches supported each phase and its independent presentation.

Exploratory Phase

The exploratory phase started during the initial year of this study (2017 to 2018), in which literature on urban sustainability was revised following a snowball strategy focusing on research on smart and sustainable cities. This preliminary exploration helped two purposes for the research design; first, to identify the key theoretical concerns, and second, to identify a specific case study for the analysis.

For the key theoretical concerns for smart and sustainable cities in the existing literature, the term 'transitions' as the conceptual construct for contemporary concerns was a fundamental identification. In particular, the themes about the social aspects of sustainability were primarily considered, the role of citizens and overall questioning of co-creation and more open approaches to urban management were recognized as key concerns.

The exploratory phase served to identify a potential case study in the Barcelona metropolitan area, in which smart and sustainable concerns were integrated. Then, the research design started by defining a general topic of research, which initially was identified as the 'smart approach'. For this topic, the understanding of the digitalization driver was central to identify its endorsements to sustainable cities. Then, based in the findings of the state-of-the-art, and in particular the critics to the smart approach, the theoretical background developed as the concerns of urban experimentation. Following, an open-ended research strategy was designed, which included the identification of the conceptual background, a (broad and theoretical) research question, as well as the suitable methodological tools to study these concepts, including the selection of a case study.

The literature reviewed served as the conceptual background of this research, including the key theoretical concepts used for the 'urban sustainability transitions', as presented in Chapter 2. Specifically, several concepts were identified as central to the critical appraisal to this research such as socio-technical systems; multi-level perspective (MLP); and the quadruple helix (QH). This process has been useful for emphasizing that the inquiry on the social dimension of urban sustainability transitions is enriched by the myriad of societal challenges, bodies of literature, and research concerns.

This conceptual inquiry used a case study in the Barcelona metropolitan area, as a suitable approach for empirical data gathering for urban transitions. For this purpose, the case study of the *Litoral Besòs* emerged as the location of a smart specialization strategy (S3) research in progress (*Pect Litoral Besòs* in Catalan language). In which, based on the literature, an initial research question focused on the role of multi-actor dynamics in innovation development for this specific innovation project (S3). Accordingly, this case study is presented as a 'single and holistic case study' (Sarvimäki, 2018).

As a result of this phase, the doctoral research proposal was defended, which included a state-of-the art, the research questions, an outline of the methodology and the research design, and a brief introduction of the case study. The findings developed in this phase have been used as the basis of the background (chapter 2), and in the following phases, to emphasize the inquiry on the social dimension of urban sustainability transitions using the *Litoral Besòs* case study. This phase served for establishing the initial concerns, which along the process have changed, to be integrated as concerns related to urban sustainability transitions.

Moreover, these advances have been integrated, and refined, in the following phases of this research, in an iterative process. For example, the reformulation of the unit of analysis in this research, to move from an S3 project and its urban context, to the overall questioning of the waterfronts was made to better characterize the *Litoral Besòs* from different standpoints, as place-based transitions, multi-actor dynamics, and urban experimentation.

Analytical Phase

This phase of the research attempted to analyze the case study through different lenses to develop comprehensive descriptions of the setting, fulfilling the purpose of using single case studies (Sarvimäki, 2018). Along this phase, the conceptual background and the case study have been examined, analyzed, interpreted, and written, from different standing-points, as separate, but related, research parts (chapters 4, 5, 6, and 7).

This analytical phase has advanced as an iterative process of establishing a research question, data collection, data analysis and data interpretation developed per thematic focuses. This iteration has enriched the research, reframing the overall purpose, and improving the specific guiding concerns and the overall research questions. Specific data collection was developed for the identification of additional concepts, presented in each chapter, as operational definitions and measures to use for specific themes (parts) of the study.

Furthermore, the research findings of the study of the *Litoral Besòs* are supported by the description, identification, and explanation of the mechanisms and change process; which emphasizes the complex interrelation of the different urban systems.

Data for this phase is collected using a combination of qualitative research approaches, including a systematic review of literature, desk review, interviews, surveys, and participant observation. Several conceptual tools and guiding questions (GQ) were used progressively in order to be answered independently, and which were formatted as research articles. For the description as a socio-technical system, the MLP perspective is used as a keystone to begin this research(Geels, 2004). The results of this phase are presented in four chapters. Chapter 4 presents the analysis to better identify the concept of NBS and its barriers and lessons learned. The analysis of the case study and its transformative processes is then presented (Chapters 5, 6, and 7), as the *Litoral Besòs* is defined by two waterfronts with important spatial, social, and environmental dimensions.

Explanatory Phase

The analysis of the *Litoral Besòs* as a single case study has focused on different themes, as standpoints responding to the wide-ranging scope of NBS and urban transitions research. Initially, the findings of the analytical phase served for answering the research guiding questions of this study, which aimed to characterize the waterfronts interventions as processes of change, in particular as water systems.

This explanatory phase aimed to enhance the interpretation of the analytical phase, by identifying the change as patterns of transformative shifts in urban reconfigurations and the variables involved. Accordingly, this phase discusses the findings from the previous chapters, as evidence on the key features of change of urban sustainability transitions to respond to the literature a validation and reliability of the research process and results. For this purpose, a conceptual construct is used as an outline for integrating the key findings of the analytical phase under the factors characterizing urban sustainability transitions and NBS.

The explanatory phase to expose how the *Litoral Besòs* relates to the urban sustainability transitions is developed as a two-stage analysis to integrate the findings for each waterfront and the use of the urban sustainability transitions concept and its five key factors as place-based transitions, multi-actor dynamics, experimentation, reframing the problem, and visioning importance.

The discussion focuses mainly on identifying how the findings correspond to the key factors of urban sustainability transitions, as an input on the mechanisms and the explanation of the *Litoral Besòs* process of change (Truffer et al., 2022). The Besòs riverfront and the Mediterranean seafront are different transformative change processes. The river waterfront is a historical intervention, while the seafront is an ongoing urban reconfiguration process. Together, the *Litoral Besòs* is explained as a more reflexive process, in which these factors are identified to explain the interrelated processes of change and transformation. This research closes by restating the practical applications and call to action as a means for considering this analysis as an input, and proposing a basis for future research.

In summary, the research phases have been developed as an iterative process to allow the integration of the different parts, for a better understanding of urban change as urban sustainability transitions (Figure 7).

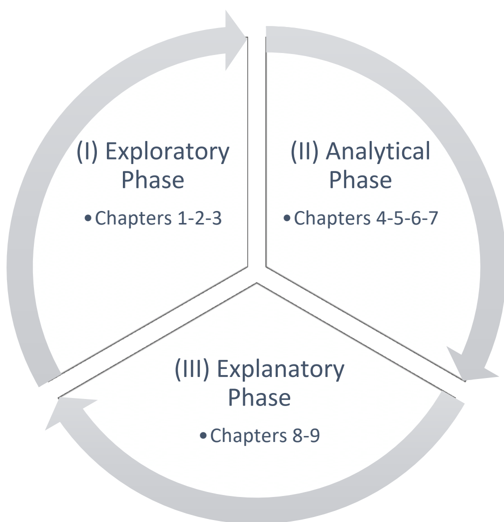

Figure 7. Research strategy phases

3.2. Data collection, analysis and interpretation.

For data collection and analysis, the information was collected using a combination of qualitative research approaches. The use of different tools served to purposefully appraise from different standpoints the richness of the case study in the Barcelona metropolitan area to support the analysis of the urban sustainability transition.

Data collection and analysis

This research makes use of different qualitative research tools, which have been used to achieve specific purposes in the study. The research was design as an iterative process, which require different standpoints and independent analysis of the single case study.

Tools such as desk and literature reviews, the development of in-depth interviews, a survey campaign, as well as field visits and participant observation have been used for data collection, to have different inputs for the case analysis. Data analysis was mainly based on the data identified during the interviews, surveys analyses, accounts from observations. In this sense, the case study provided evidence which was used thoroughly (presented in italicized text).

This section includes a case study overview as a comprehensive presentation of the *Litoral Besòs*. However, the research was developed as an iterative process, as it was developed as separate analysis with specific research focuses and approaches. Therefore, this section contains only a brief summary of the conceptual tools used for the analysis, the guiding questions, and the procedural means for data collection. Moreover, each of the four chapters included in the analytical part present a detailed methods and materials section, which provides a context of the research focus, the concepts used, and the specificities of data collection and analysis (Table 2).

Table 2. Data analysis and integration in the case study analysis

Research focus - Approach	**Key themes and topics**	***Aspects for data collection***	**Scientific literature**	**Desk review**	**Surveys**	**In-depth interviews**	**Field and active observations**
(Chapter 4) Nature-based solutions for water management	NBS Concept, definition, key features, implementation experiences	Lessons learned and barriers in NBS implementations in peri-urban areas	X (SLR)				
(Chapter 5) Water reuse towards circularity	Alternative practices	Context of the case study, emergence conditions and outcomes of the NBS and WRT	X	X		X	X

Research focus - Approach	**Key themes and topics**	***Aspects for data collection***	**Scientific literature**	**Desk review**	**Surveys**	**In-depth interviews**	**Field and active observations**
	Sustainable urban water management – SUWM Circular Economy - CE	Study area - Historical background implementation process CE principles (Nature preservation and enhancement; minimizing pollution; maximizing the use of water; resources value maintenance; environmental and social impacts; resources efficiency)					
(Chapter 6) Citizens perceptions on the use of NBS	NBS Concept and features, relation to other green concepts (NBS-GI-ES)	citizens use perception	X		X		X
(Chapter 7) Citizens participation in urban reconfiguration	Urban reconfiguration accounts Public engagement formats	Opposing, non-conflictual, reinforcing Models, subjects, and objects	X	X			X

Case study data collection

Referring to the case study, this research makes use of tools such as desk review, in-depth interviews, surveys, participant observation and field visits. Desk research was used to have an initial understanding of the *Litoral Besòs* as a territory in terms of the historical evolution, the planning instruments in place, and the indicators. In-depth interviews were used to gather the multiple actors' perspective, first as part of the exploratory phase, and then as experts' interviews on the NBS implementation.

Surveys were used to collect citizens perceptions in a campaign on the riverside waterfront. Participant observation was used principally, to better understand the participatory approach for the seafront masterplan formulation. Field visits were an important activity to understand the place-based context, in particular, for the activities and use of the riverside front, as well as the plans for the spatial reconfiguration of the seafront.

The socio-technical systems concept aided in the identification of the elements involved in the change processes (Geels, 2004). For the case study analysis, the MLP served for an initial and systemic identification of the three analytical dimensions (Table 3). The socio-technical landscape refers mainly to the external pressures of urbanization, climate change and digitalization. The regime refers to social rules, such as cultural frames, social institutions, interaction norms, reward and cost structures when related to water systems in challenges. As well as to urban planning, citizen engagement, and sustainable urban water management. The technological niche relates to the urban experimentation developed as the alternative practices in urban water systems and management. The *Litoral Besòs* is the territory representing technological innovation in urban water systems, e.g. as the socio-ecological innovation of NBS, as well as the S3 as a smart initiative for WRT.

Table 3. Summary of the key elements of the case study of the Litoral Besòs

MLP	Main Focus	Secondary focus
Socio-technical landscape	General understanding of the societal challenges, and with a main focus on the urban water systems	Climate change and resilience
		Urbanization
		Digitalization
Technological regime	Urban planning, urban water management and participatory processes in city planning (in particular) for SUWM- Sustainable urban water management	Water Systems and Circular economy (CE)
		Urban planning
		Citizens participation and engagement
Technological niches	Urban (water) innovation	Nature-based solutions - NBS (S-E-T inn)
	Experimentation and learning	Smart technologies - WRT (ST inn)

Data validation

The tools and the conceptual constructs used as part of the procedural analysis facilitated the research triangulation, validation and its substantive significance (MacCallum et al., 2019; Patton, 2014; Sarvimäki, 2018). Usually, results were validated by triangulation, with the various data sources integrated. Then, each process of analysis followed the themes identified as analytical categories of an outline or framework. Moreover, the analysis presented in the analytical part (chapters 4, 5, 6, and 7) have been submitted to peer-reviewers as part of the research process. As a result, these chapters have already been published in scientific journals.

Following, the next section presents the case study, exposing the objective of this research, the unit of analysis and its key elements.

3.3. Case Study Overview

As mentioned, the case study used corresponds to the *Litoral Besòs*, located in the Barcelona metropolitan area. This case study consists of an urban area within two waterfronts, the Besòs river waterfront and the Mediterranean seafront. The *Litoral Besòs* is described in terms of place-as the context, location and site; and second, in terms of its evolution, which includes a brief introduction to the urban waterfronts and the sustainability concerns.

Litoral Besòs: Context, location and site description

The '*Litoral Besòs*' is an urban area bounded by two waterfronts, the Besòs river waterfront and the Mediterranean seafront in Sant Adrià de Besòs (Figure 8). Symbolically, the *Litoral Besòs* is the territory that corresponds to the riverfront in the area of influence of the Besòs river's restoration which is an 'axe' of green infrastructure (AMB, 2020). In addition, the seafront of the Three Chimneys, in the missing (and last) plot for the reconfiguration of a metropolitan littoral.

Figure 8. Location of the Litoral Besòs in Barcelona Metropolitan area

The top image corresponds to the location of the case study in the Barcelona metropolitan area. In terms of waterfronts, the image below shows the two waterfronts: The Besòs River waterfront as a peri-urban axe while the Mediterranean waterfront correspond to the last plot in the configuration of the metropolitan littoral.

Furthermore, the use of the available indicators allows for a comparison within the metropolitan area. The Barcelona metropolitan area (AMB) accounts for 43 percent of Catalonia and indicates a significant growth as it has more than doubled in less than 70 years (AMB, 2020). Because of its advantageous location, the Barcelona metropolitan area is relevant as it is ranked as the eighth largest metropolitan area in Europe. According to the Metropolitan area authority, this is attributed to the fact that the metropolitan area occupies a strategic position in southern Europe, in the middle of the Mediterranean corridor that connects Spain to the rest of the continent, thus, it has become the epicenter of Catalonia.

In terms of territory, the Barcelona metropolitan area (*Àrea Metropolitana de Barcelona*, AMB) has 636 km^2, with a population of 3,247,281 inhabitants and a population density of 5093 inhabitants per square kilometer in 2017. Barcelona city (BCN) has an area of 101.35 km^2, and holds nearly half of the metropolitan population, with 1,660,314 residents as of the beginning of 2021, and a population density of 16,149.3 inhabitants per square kilometer. In contrast, Sant Adrià de Besòs, which is the location of the case study, is a municipality of 3.82 km^2 and 37,282 inhabitants, and a population density of 9,760 inhabitants per square kilometer (Table 4).

Table 4. Basic territory indicators. Data source: INE, Idescat.

Dimension	Indicator Name	Definitions	AMB	BCN	SAB
Territory	Administrative area	Geographical (surface) area of the city in km^2	636	101,35	3,82
	Total population	Number of inhabitants in administrative area (2021)	3'247281	1´660314	37283
	Population density	Number of inhabitants per km^2	9760	16149,3	9600

AMB, Barcelona metropolitan area; BCN, Barcelona; SAB, Sant Adrià de Besòs

For the socio-economic dimension, several differences between Catalonia, Barcelona, and SAB were identified. In particular, SAB has a lower overall income (expressed in GDP per capita), GDHI, and a significant number of unemployed inhabitants. No specific data were found for BCN and SAB to reveal differences compared to Catalonia for life expectancy or the Gini index. In this sense, as a general perspective, SAB is a more socially vulnerable area (Table 5).

Table 5. Socio-economic indicators. Data source: INE, Idescat.

Dimension	Indicator Name	Definitions	CAT	BCN	SAB
Socio-economic	Population growth	Total growth (annual average) (rate per 1,000 inhabitants 2001-2011)	16,98 (CAT)	7,33	6,88
	GDP per capita	GDP per capita (thousands of euros €)	29,11 (2020)	42,6 (2020)	27,7 (2019)
	GDHI	Gross disposable household income per inhabitant (thousands of euros €) –	17,6	21,5	14,8

Dimension	Indicator Name	Definitions	CAT	BCN	SAB
		(Based on 2019 Benchmark revision. 2018)			
	Unemployment registered	Number of inhabitants registered as unemployed. (Annual averages, 2021, % on total population)	437165 (10.4%)	81103,7	3113,2
	Life expectancy	Life expectancy at birth. (2018) (Years, women (w), men (m))	86 (w) 80.4 (m)	-	-
	Gini index	0 to 100 Inequality indicators of the distribution of income.	31,7	-	-

CAT, Catalonia; BCN, Barcelona; SAB, Sant Adrià de Besòs. These indicators follow the dimensions proposed for Green City developed by (Brilhante et al., 2018). Indicators. Data source: INE.

This metropolitan configuration, in which the population concentration in BCN city exposes the difficulty of a 'greater city,' in terms of unbalanced demands and capacities to address it. For instance, these differences are exposed in terms of environmental quality as green and open space, water resources availability, besides the traditional needs of transportation, housing, jobs; as well as the city's benefits in terms of capacities to cope with the functional complexity in comparison to neighboring settlements. Thus, the articulation through the metropolitan area is key, because this ‘imbalanced’ situation is difficult not only with SAB, but within the 36 municipalities.

Furthermore, the *Litoral Besòs* in Barcelona metropolitan area is located in a context that can be considered as an urban and peri-urban area context, in the understanding that different types of activities, or logics, are mixing. This area is facing challenges related to its environmental degradation, including soil, air, nature, and water. Water, in particular, is the focus of this research.

The key aspects that can be highlighted to describe the area’s processes of change are: i) evolution of the *Litoral Besòs*, as an anthropized landscape in close proximity to Barcelona; ii) Besòs riverside waterfront, as the restoration through NBS as coping approaches to deal with the industrialization effects; and iii) Mediterranean seafront, as the contemporary littoral reconfiguration.

Evolution of the *Litoral Besòs*

The *Litoral Besòs* is an anthropized landscape in close proximity to Barcelona city. Initially, the River Besòs was considered a natural limit within these urban centers, in which the placement of industrial activity generated a human-made coastline and river waterfront. Together, these activities and the interest to configurate the metropolitan area motivated the development of massive transport infrastructures (Figure 9).

Figure 9. Evolution of the industrial areas in the Litoral Besòs.
The evolution of the industrial areas in the *Litoral Besòs* in Barcelona Metropolitan area (1957 – 2016) was developed in the LESEC research group based on https://www.icgc.cat/ (Institut Cartogràfic i Geològic de Catalunya, 2022)

Although industrial activity on the waterfront is declining, there are still some active industrial polygons that still operating, which are dedicated to logistics and the metabolic infrastructures. Indeed, the latter may be identified as a cluster dedicated to the metropolitan metabolic infrastructures, which comprise an essential urban component in the *Litoral Besòs* the location and local impact of the urban fluxes' management (Figure 10).

Figure 10. Location urban metabolic infrastructure in the area. Source: Google

The urbanization process of the *Litoral Besòs* has been inextricably linked to the urban metabolism infrastructures, as part of the industrial type of economic activities that serve the overall Barcelona metropolitan area. This placement of infrastructures supporting urban systems, especially in the domains of water, energy and waste (urban metabolic), is also recognized as an effort towards urban sustainability due to significant investments in these infrastructures (Figure 11).

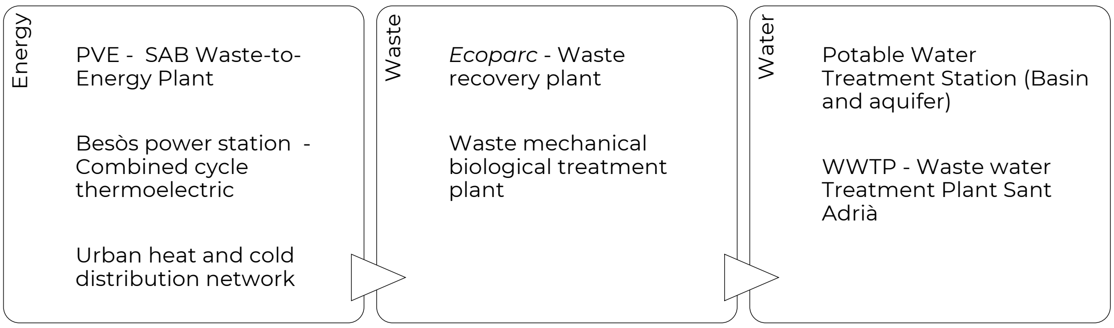

Figure 11. Urban Metabolic Infrastructures in the Litoral Besòs

As a result, the urban development of the *Litoral Besòs* is conditioned by the location of these activities and its compatibility with other urban land-uses. The key spatial elements of this analysis are the Besòs river waterfront and the Mediterranean seafront, as the urban infrastructures that can expose the understandings and concerns underpinning its urban sustainability transitions.

Besòs River waterfront

The analysis of the area of the Besòs riverside park using a chronological approach exposes two decades of changes, addressing environmental degradation through the use of nature.

At the end of the 20th century, the challenges for the Besòs river were related to mitigating the poor water quality and the relatively high risks of flooding (Santasusagna Riu, 2019). A Besòs river intervention was needed to address the environmental degradation of water resources caused by heavy pollution from industrialization-related activities that were performed in the area. To respond to this, a river restoration project began in 1996 that lasted until 2006, with the goal of improving the riverbed's environmental conditions, including its hydrology as a natural system, and to allow recreational use of the river banks (Pol Masjoan et al., 1999; Santasusagna Riu, 2019). This intervention was mainly supported by European funds, resulting in a significant investment in the Besòs river and the metropolitan area (Martín-Vide, 2015).

Here, the nature-based solutions were implemented by: i) constructing wetlands, as a first section, around the Montcada i Reixac wastewater treatment plant (WWTP); this was completed in 2003; and ii) creating a 22-hecter, 9-km-long riverside park (of which 5-km-long is a public use area) as a second section, completed in 2006. Currently, the intervention of the river's delta is a pending action (2022), which will correspond to a third section ().

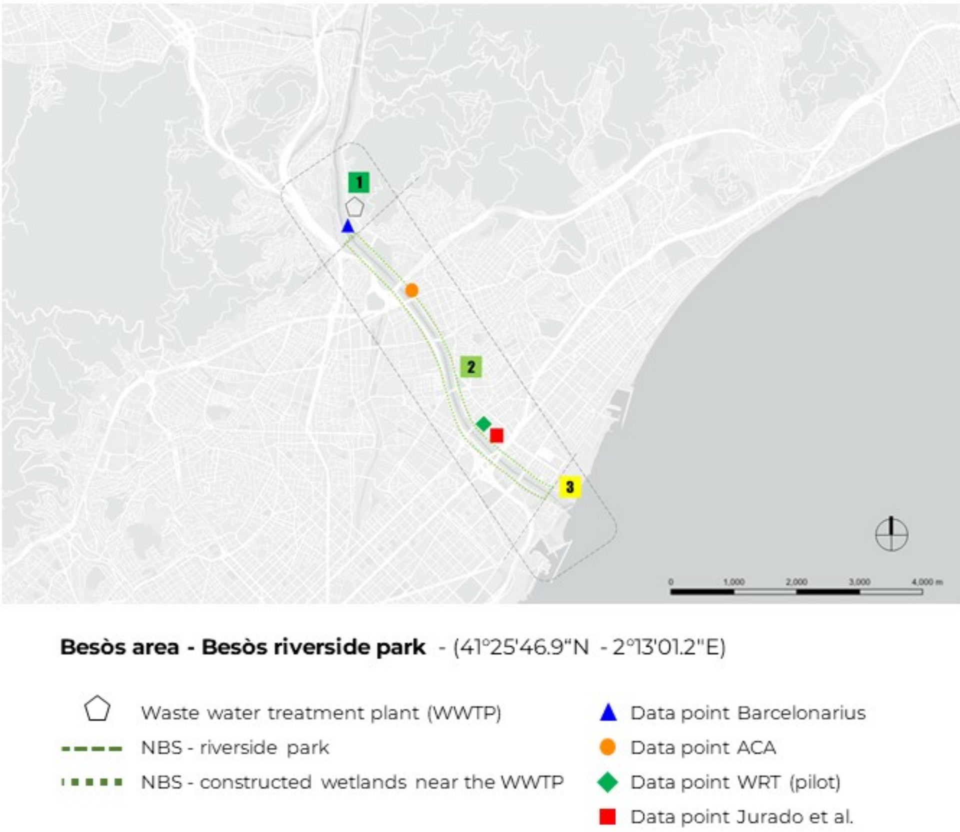

Figure 12. Sections along the Besòs River intervention

Besòs riverside park' three sections: Section 1 - Location of the constructed wetlands. Section 2 - Besòs riverside park, Section 3 Restricted area. The conventions represent the location of observation points for water quality, included in the analysis of alternative practices.

This characterization of the Besòs sections and supported activities (Figure 13) reveals how the NBS has effects at the scale of the metropolitan area of Barcelona, as the river's right bank corresponds administratively to Barcelona (BCN), while the river's left bank connects the municipalities of Montcada i Reixac (MiR), Santa Coloma de Gramenet (SCG), and Sant Adrià de Besòs (SAB) as a continuum (MiR/SC/SAB).

Figure 13. Characterization of the Besòs sections and supported activities

A pilot on WRT was implemented in the Besòs river area to improve the reuse of water pumped from the aquifer, as well as to explore the potential demand and supply coupling of water resources via a fit-to-purpose strategy. This intervention developed through the 'Pect *Litoral Besòs*' (RIS3 project) (2017-

2021) was based on a quadruple helix consortium of a regional innovation strategy based on smart specialization (RIS3) for urban sustainability research (https://www.besossostenible.cat/), (Pect Litoral Besòs, 2017).

This intervention has addressed the challenges related to water quality as a result of industrial pollution; to water quantity due to flooding risks (torrential storms), water-stressed flows; and hydrology as a natural system. The water quality difficulties were induced directly by the substantial industrial pollution of the area. In addition, water quantity issues were the result of unexpected water volumes such as insufficient flow or flooding, which could be associated with the conditions of climate and its variability. Specifically, its water challenges have been linked to freshwater withdrawals and reduced river flow in the river Besòs area, as well as to flooding due to torrential rains (or flash floods) and inundating risks in underground infrastructures (Pol Masjoan et al., 1999; Tubau et al., 2017).

Sustainability challenges in the *Litoral Besòs*

As previously mentioned, the key spatial elements of the *Litoral Besòs* analysis are the waterfronts, the Besòs riverfront and the Mediterranean seafront. These waterfronts are urban infrastructure that are shaped through the sustainability understandings and concerns.

The Besòs riverfront, in particular, has attracted researchers' interest due to its transformation as a river restoration addressing various water challenges which has been proven as successful. However, the seafront reconfiguration is an ongoing process of change, in which the urban reconfiguration is aimed as a brownfield reconfiguration (presented in detail in chapter 7). As a result, research can be beneficial in identifying how the learnings from the river intervention can provide a critical perspective on how to advance the seafront reconfiguration in a coherent manner (Torrens & von Wirth, 2021).

Research in the area has established that this intervention addressed the challenges that motivated its implementation, with steps towards a more sustainable peri-urban area. Key advances in the river water quality and the biodiversity of the area have been documented, for instance by an academic initiative (termed the Barcelonarius) that has been consistently monitoring its environmental progress and establishing the overall balance status of the river (Universitat de Barcelona, 2021). From an NBS standpoint, the intervention has helped to regenerate natural capital and keep resources in use, contributing to more sustainable urban water management; however, further efforts should be made to endorse the circularity paradigm and avoid waste externalities (Ramírez-Agudelo et al., 2021).

Currently, along the discussion for a new metropolitan masterplan (2020-2021), the Besòs area has been highlighted as strategic for the metropolitan water cycle, which is interrelated to the green and blue metropolitan infrastructure goals of renaturalization (AMB, 2021). Therefore, the understanding of the area as an interrelated littoral can benefit with the provision of evidence for supporting this purpose.

Following, the second part presents the analytical part of the thesis, in which the chapters included present the research findings .

Second part - Analysis

4. Nature-based solutions for water management

Nature-based solutions for water management in peri-urban areas: Barriers and lessons learned from implementation experiences (Art 1).

Abstract

Nature-based solutions (NBS) are defined by the European Commission as "actions that are inspired by, supported by, or copied from nature…" and that solve societal challenges and multiple benefits. As a result, NBS are often promoted as alternative responses that solve complex societal challenges such as watershed management, while delivering a systemic approach of multiple benefits for well-being, human health, and sustainable use of resources. Despite rising interest in NBS, further identification of experiences implementing NBS could advance our understanding of the operationalization of this comprehensive concept. For this purpose, we analyzed 35 peer-reviewed articles on implementation experiences of NBS for water management in peri-urban areas, on aspects related to (i) NBS problem–solution: water challenges, ecosystem services, scales, and types; (ii) NBS governance and management. From the insights of the analysis, this paper asks what lessons are learned, and which barriers are identified, from implementing NBS for water management in peri-urban areas? As a result, this study presents a detailed analysis of each aspect. We conclude by highlighting accountancy, monitoring, and communication as potential success factors for integration and development while diminishing the overall barrier of complexity, which leads to technical, institutional, economic, and social uncertainty.

Keywords

NBS; sustainable water management; ecosystem services; problem-solution; governance

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4.1. Introduction

Societal challenges such as carbon sequestration, coastal resilience, ecosystem restoration, and watershed management underpin the need for systemic ways to address them. In this sense, nature-based solutions (NBS) enable natural processes into the technical response to address these challenges, with the aim of creating multiple benefits for society (Escobedo et al., 2019), well-being, human health, and the sustainable use of resources. NBS are delivering the benefits through open green spaces (e.g., urban parks), green/blue infrastructures (e.g., wetlands, river parks, rain gardens), and at a building level with elements such as green roofs or green walls. For example, addressing water challenges through NBS, i.e., flood risks, droughts, water pollution, freshwater withdrawals, or difficulties related to stormwater and urban water management, promotes the development of multifunctional landscapes, e.g., river parks that could benefit human well-being and physical and mental health. Dealing with the complex and dynamic impacts of urbanization processes and climate changes through NBS could be particularly relevant in areas that combine rural and urban dynamics, identified as peri-urban areas, peripheries, sprawls, and suburbs, among others (D. I. A. Wandl et al., 2014).

NBS has been defined as solutions inspired and supported by nature to face societal challenges while delivering benefits that are ecological, social, and economic (Bauduceau et al., 2015). There are plenty of arguments about the concept's novelty and its operationalization within well-established concepts or 'old tools' as 'natural capital', which could limit its potential (Hanson et al., 2019). For instance, the implementation of alternative responses as NBS are 'Low Impact Development' (LID) in North America (Kim, 2019); 'Water Sensitive Urban Design' (WSUD) in Australia (Furlong et al., 2018); 'Sponge City' in China; 'Sustainable Urban Drainage Systems' (SUDS) (La Rosa & Pappalardo, 2020); Integrated Urban Water Management (IUWM); and Edible Cities (Säumel et al., 2019).

The links between NBS and other green terms frame NBS as an 'umbrella' concept (Dorst et al., 2019; Escobedo et al., 2019; Hanson et al., 2019), an aspect that was originally coined by IUCN (Cohen-Shacham et al., 2016) and is commonly cited (Albert et al., 2019; Dallimer et al., 2020; Dhyani et al., 2018; Dorst et al., 2019; Gómez Martín et al., 2020; Loiseau et al., 2016). The nexus of NBS with other terms has been studied by setting out how the concepts depict a metaphor (Escobedo et al., 2019). Within this framing, NBS is mainly linked to terms such as ecosystem services (ES), green infrastructure (GI), and ecosystem-based adaptation (EbA) (Escobedo et al., 2019).

NBS promotes a comprehensive approach to contribute to human well-being, where ES are regarded as the specific benefits that humans derive from the ecosystem functions delivered through GI, as a 'network' of natural and semi-natural areas. Similarities among these concepts are its systemic approach to challenges (Kabisch et al., 2016), but differentiating in the problem-solving feature. For example, some authors have established a link between other GIs and ecosystems-based adaptation EbA, arguing that EbA is more solution-oriented than ES (Dorst et al., 2019). Whilst EbA is also associated with disaster risk reduction (DRR) to argue on its response to the impacts of urbanization processes (Dhyani et al., 2018), and climate changes, i.e., NBS for flood risk reduction (Pagano et al., 2019).

NBS is considered a 'European' concept (Dorst et al., 2019; Escobedo et al., 2019; Hanson et al., 2019), after being introduced by the European Commission. NBS has been supported through a definition, prioritization areas, and financing by research and development. For the first time, NBS was mentioned by the World Bank in 2008 (Hanson et al., 2019). IUCN refers to NbS in 2009 at the United Nations Framework Convention on Climate Change (COP 15) (Escobedo et al., 2019; Hanson et al., 2019), and was adopted in 2012 as part of the IUCN program (2013–2016) (Hanson et al., 2019). In 2015, NbS was introduced as a research area within H2020, a major source of research funding for Europe, and NBS has thus 'recently entered the scientific sphere' (Hanson et al., 2019). Scientific publications have increased significantly since 2017, led by authors with European affiliations, albeit slightly from other locations.

NBS is a compound term in which 'nature-based' describes the bond with nature and natural processes (Ronchi et al., 2020), and the 'solution' refers to the feature of tackling a problem by providing multiple benefits in a resource-efficient manner (Bauduceau et al., 2015). This idea is exposed in a review that defines NBS while exploring the two-part concept, as based on nature and the solution feature (Dorst et al., 2019). NBS are mainly related to urban contexts, yet in their search for a resource-efficient and adaptable solution, the challenges that NBS addresses, such as sustainable water management, also pertain to rural and peri-urban areas.

Therefore, the analysis of NBS implementation in peri-urban areas as hybrid territories combining urban and rural dynamics (D. I. A. Wandl et al., 2014), is an opportunity for advancing on the identification of the derived barriers and lessons learned. Nevertheless, peri-urban areas are subject to variability across countries and regions (Shaw et al., 2020). In its conceptualization (A. Wandl & Magoni, 2017), similar concepts to peri-urban could be fringe, peripheries, suburbs, sprawls, and territories in between, among others (Shaw et al., 2020; D. I. A. Wandl et al., 2014). In this sense, peri-urban areas are recognized as transition spaces that have some degree of intermingling of urban and rural uses (A. Wandl & Magoni, 2017). This consideration highlight the pressures of urbanization processes and climate changes in local and spatial aspects such as shifts in land cover, land use, land management, and planning (Shaw et al., 2020). Also, in the socioeconomic criteria and cultural context for its demarcation (Mortoja et al., 2020), where the multifunctional character of peri-urban expose changes in socio-economic aspects between stakeholders sharing the area, which could lead to some conflicts because of different perspectives or interests.

These areas expose the place-based and social dynamics of neither-rural-nor-urban territories, which could condition the potential development of NBS. First, in terms of the spatial transition, peri-urban act as urban buffer zones, surrounding the urban boundary and limited by the rural one, e.g., comprising two boundaries, an inner (urban) and an outer (peri-urban) one (Mortoja et al., 2020). Second, these areas are strategically relevant to ecosystem services (ES), integrating and responding to natural and built-up dynamics by acting as a multi-functional landscape. This relevance is based on the argument of proximity to natural landscapes of biodiversity habitats, woodlands, farmlands, and built-up areas; such as urban subdivisions and transport infrastructures (Mortoja et al., 2020). Third, peri-urban areas expose the community consensus, or the lack of it, for the support and up-take of NBS as an innovation development.

Purposely, NBS and peri-urban concepts have been used as keywords in this literature review, and the references that exposed case studies were selected as implementation experiences of 'NBS' for water management in 'peri-urban areas'. The analysis followed an outline structure (i.e., social, environmental, economic, and governance) to gather the descriptors that could be supporting the comprehensive approach of NBS. Specifically, we examined NBS as a problem-solution relating to the analysis of physical and spatial aspects, and NBS governance and management to identify the actors involved and the policy instruments supporting the implementation. What lessons learned and barriers are identified in implementing NBS for water management in peri-urban areas? This article identifies the characteristics of implementing NBS in peri-urban areas as actionable knowledge in lessons learned, and the barriers as observed limitations or negative aspects.

4.2. Materials and Methods

The multi-methods research is qualitative-focused and comprises a literature review in combination with, content analysis, and descriptive research. The SLR helps to collect, examine, and integrate the different scientific contributions under the keyword combination ''nature-based solutions' + water + peri-urban'. An initial search of peer-reviewed articles was conducted in December 2019. Two databases have been used, Scopus and Web of Science for the search of the keywords combination. As the exclusion criteria, we used the date to limit it to sources from 2015, type to gather only articles in peer-review journals and because of language limitations, we excluded references when not written in English. As the inclusion criteria, we selected articles that explicitly expose case studies of NBS and its implementation experiences. The Systematic Literature Review (SLR) was developed with the purpose of review and analysis of 'NBS implementation', dealing with water management in 'peri-urban areas', recognizing that these terms are mainly used in the European context, while other terms are used globally for similar purposes.

A literature search using digital databases to find experiences in implementing NBS, using selected keywords presented 160 references, of which 3 references were excluded because of the lack of access or they were not written in English. Of the 157 peer-reviewed publications, we first read the title and abstract to search for the terms, "water" and "case study"; 66 references mentioned case studies and were included. The excluded 91 references were related to literature reviews, conceptual, modeling, and assessment publications. We then read the 66 articles to determine their proper fit as a case study, to conduct a more intensive review and selected 35 references (Figure 14). The examination followed an outlined structure of aspects including location, environment, economics, social dimensions, and descriptors about governance, instruments, actors involved, and its financing. To support the systematic documentation of the lessons learned and barriers highlighted in the experiences, the analysis and synthesis strategy was assisted by NVivo (Qualitative Analysis Software). In terms of the review criteria, the references excluded were out of the scope of NBS implementation; because of not using cases dealing with water or to the concept of NBS, e.g., not mentioning water in the process as input, output, or benefit, or not mentioning NBS or other green terms, such as ES, GI, EbA.

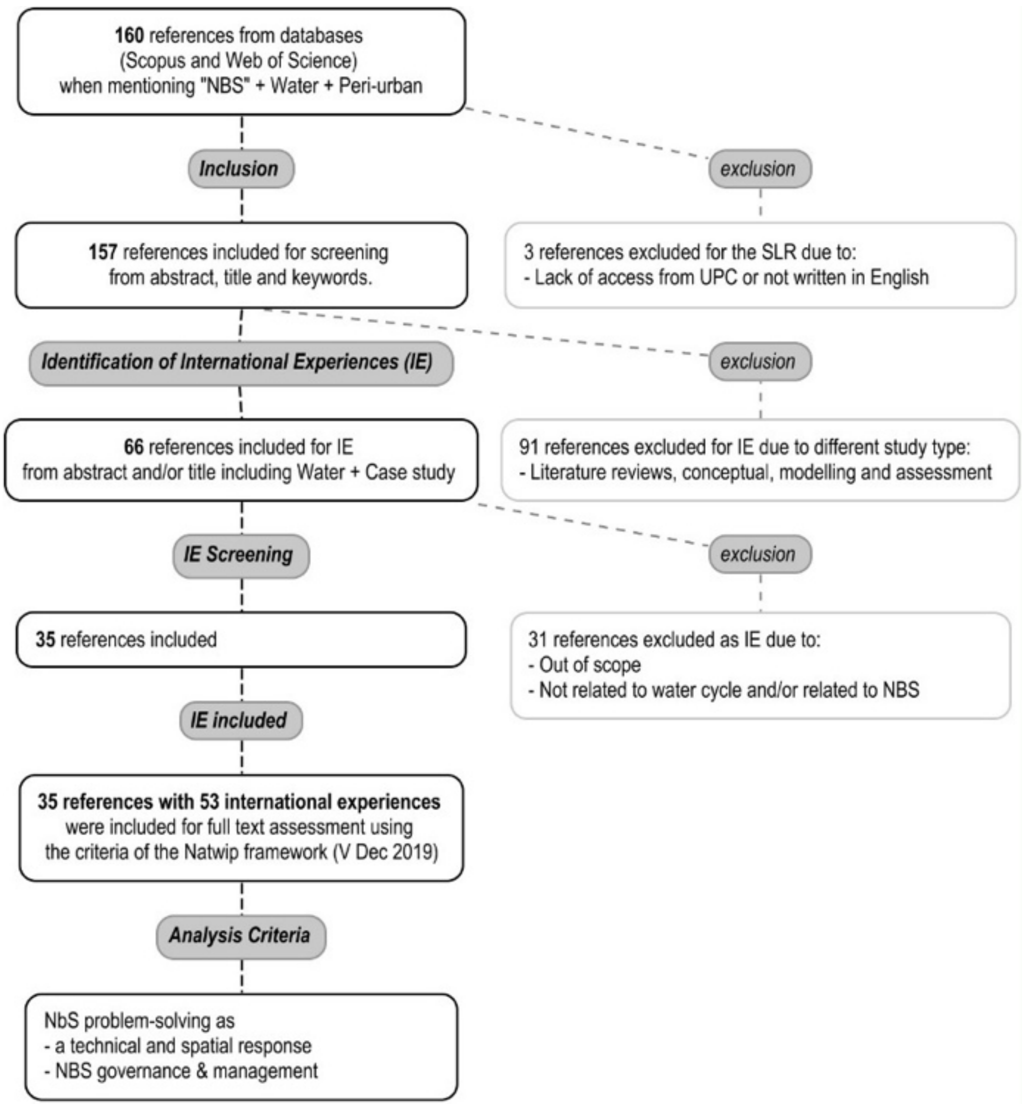

Figure 14. Literature review process.

Data were gathered from 35 references published in 2016 (1), 2017 (6), 2018 (6), 2019 (15) to 2020 (7), detailed information and codes for the references are presented in Appendix A, Table A1. The references present studies in different locations, but mainly from Europe where the 'NBS concept' is promoted and funded, followed by Asia, America, Africa, and Oceania. Yet, it is acknowledged that due to the concepts used, the review is predominantly focused on European experiences. Besides, even if the specific search including 'peri-urban' as a criterion; some case studies are linked to urban and rural areas, reinforcing the idea of interlink among built environments, beyond the administrative borders.

The analysis of NBS has been structured as (i) NBS problem–solution: Water challenges, ES, types, and scales, for the technical and spatial response; and (ii) NBS governance and management, for identifying the specific factors that support NBS implementation. As the search strategy required an iterative process to determine if the case studies were included or excluded in each criterion, the case studies mentioned in each sub-section might vary. To facilitate the analysis, each aspect is included along the results using codes and references, while detailed information on each implementation experience is presented in Appendix A. The barriers and lessons learned emerged from these insights, identifying the positive descriptions in the collected evidence of the implementation as 'lessons learned' or actionable knowledge; and the negative aspects as 'barriers' or observed limitations for operationalizing NBS as a comprehensive concept.

4.3. Results

The dominant discourse of NBS as a comprehensive approach is to achieve systemic interventions, delivering multiple benefits to multiple stakeholders in a resource-efficient manner (Bauduceau et al., 2015). As an integral feature of the concept, NBS link the problem addressed to the solution, within the aim of sustainable development—in other words, facing social, environmental, economic, and institutional barriers (Dorst et al., 2019). Thus, when referring to complex challenges, the aim for systemic interventions is to deliver results at different environmental–technical, and social levels. In this sense, we analyzed NBS implementation for water management to identify the specificities of the systemic response. The next sub-sections present NBS examined from two standpoints. The first search criteria aimed to examine the NBS problem-solving feature from the technical and spatial aspects (Section 3.1), responding to the ecological dimension of the concept. Second, the NBS governance and management (Section 3.2) to identify the socio-economic aspects that support NBS implementation.

NBS Problem-solution: Challenges, ES, Scales, and Types

This section will explore NBS by focusing on the technical and spatial factors of NBS implementation for water challenges, the ES delivered, the scales of the solutions, and types implemented. To close this section a representation of the links among NBS types, challenges, and ecosystem services is presented. This section is complemented by Appendix A, with detailed information on each implementation experience.

Challenges

In terms of challenges, the experiences describe a variety of issues related directly and indirectly to water, reporting pressures on water resources, and the system management (Table 6). The direct challenges are flood risks, urban water systems management, freshwater withdrawals, climate regulation, freshwater supply, stormwater management, climate change mitigation and/or adaptation, water pollution purification/filtration, and drought/water scarcity. Indirect challenges are related to the effective-incorporation of socio-cultural services when mentioning concerns as recreation, human well-being, and social cohesion. See also Appendix A Table A2.

Table 6. Nature-based solutions (NBS) Challenges description.

Challenges	Description	Codes	References
Flood risks	Climate change or urbanization causing higher occurrence of flooding	4, 8, 10, 12, 14, 21, 22, 23, 30	(Arabameri et al., 2019; Dhyani et al., 2018; Gunnell et al., 2019; Kim, 2019; La Rosa & Pappalardo, 2020; Pagano et al., 2019; Reynaud et al., 2017; Ronchi et al., 2020; Tomao et al., 2017)
Urban water systems management	Black, gray, storm- and/or freshwater management	7, 16, 20, 26, 32, 33, 34, 35	(Bricker et al., 2017; Capotorti et al., 2019; Furlong et al., 2018; Hazbavi et al., 2018; Herslund & Mguni, 2019; Jia et al., 2019; Mulligan et al., 2020; Pedersen Zari et al., 2020)
Freshwater withdrawals	Related to freshwater supply/ withdrawals	4, 7, 9, 20, 29, 34, 35	(Brunetta & Salata, 2019; Capotorti et al., 2019; Furlong et al., 2018; Hazbavi et al., 2018; Pedersen Zari et al., 2020; Thompson et al., 2019; Tomao et al., 2017)
Climate regulation	Capacity of water bodies to regulate micro-climate, e.g., mitigation of urban heat island (UHI) and heatwaves	4, 6, 8, 13, 18, 24	(Belčáková et al., 2019; Dhyani et al., 2018; Fung & Jim, 2020; Marando et al., 2019; Ronchi et al., 2020; Säumel et al., 2019; Tomao et al., 2017)
Freshwater supply	Pollutants discharge	25, 27, 28, 30, 32	(Carrard et al., 2019; Castelli et al., 2017; Herslund & Mguni, 2019; Kim, 2019; Yang et al., 2020)
Stormwater management	Created as a separate category for its frequency in the case studies Flood prevention, runoff control, drainage, and filtration, etc.	3, 15, 31, 33	(Belmeziti et al., 2018; Langemeyer et al., 2020; McFarland et al., 2019; Mulligan et al., 2020)
Climate change mitigation and/or adaptation	CO^2 reduction	12, 13, 18	(Belčáková et al., 2019; La Rosa & Pappalardo, 2020; Säumel et al., 2019)
Water pollution purification/ filtration	Pollutants purification/filtration	10, 11, 16	(Bricker et al., 2017; Liquete et al., 2016; Reynaud et al., 2017)
Drought/ Water scarcity	Related to droughts and water scarcity	22, 28	(Castelli et al., 2017; Dhyani et al., 2018)
Effective-incorporation of Socio-cultural services	Includes recreational opportunities, esthetics, human well-being, social cohesion	1, 2, 5, 14, 17, 18	(Beery et al., 2017; Cortinovis et al., 2018; Jerome et al., 2017; Pagano et al., 2019; Riegels et al., 2020; Säumel et al., 2019)

The literature on NBS usually explains water challenges as results of the pressures from the climate influence and/or urbanization effects, and as causal mechanisms of interdependence among other challenges. This is observed, for example, on the hydrological impacts of urbanization processes, such as a reduction in perviousness, infiltration, and surface retention, which could be the causal mechanism for increasing storm rainfall going to a runoff, leading to floods (Kabisch et al., 2016). Thus, flood risks are linked to stormwater management, not only by runoff and peak flows but also by conveying pollutants to nearby surface waters (Pagano et al., 2019). In this order of ideas, shifting natural landscape in peri-urban areas, towards an urbanized one, diminishes the natural land previous cover, its infiltration, and its retention capacities. This shift could increase environmental risks, not only locally but also in other areas, which will require higher investments in infrastructure, services, and management over the long-term.

In fact, the literature frequently mentioned NBS for risk management, including floods, droughts, heatwaves, sea-level rise, and earthquakes. Figure 15 shows the relations between water challenges and risk management addressed in the literature. The thickness of the edges (nexus) are proportional to the number of articles that relate to both vertices (nodes). The strongest relations show more publications that relate risks to water challenges are 'flood', which relates to flood risk, urban water systems and pollutants purification/filtration, and "climate change" (climate change mitigation/adaptation, climate regulation and flood risk). Consequently, integrating changes in land covers and flows controls, while maintaining a certain water quality and flow, is a multi-level challenge for water management in peri-urban areas. In this sense, it is relevant to notice that water systems are also influenced by the dynamics of urban and rural systems, and decisions in other sectors as risk management.

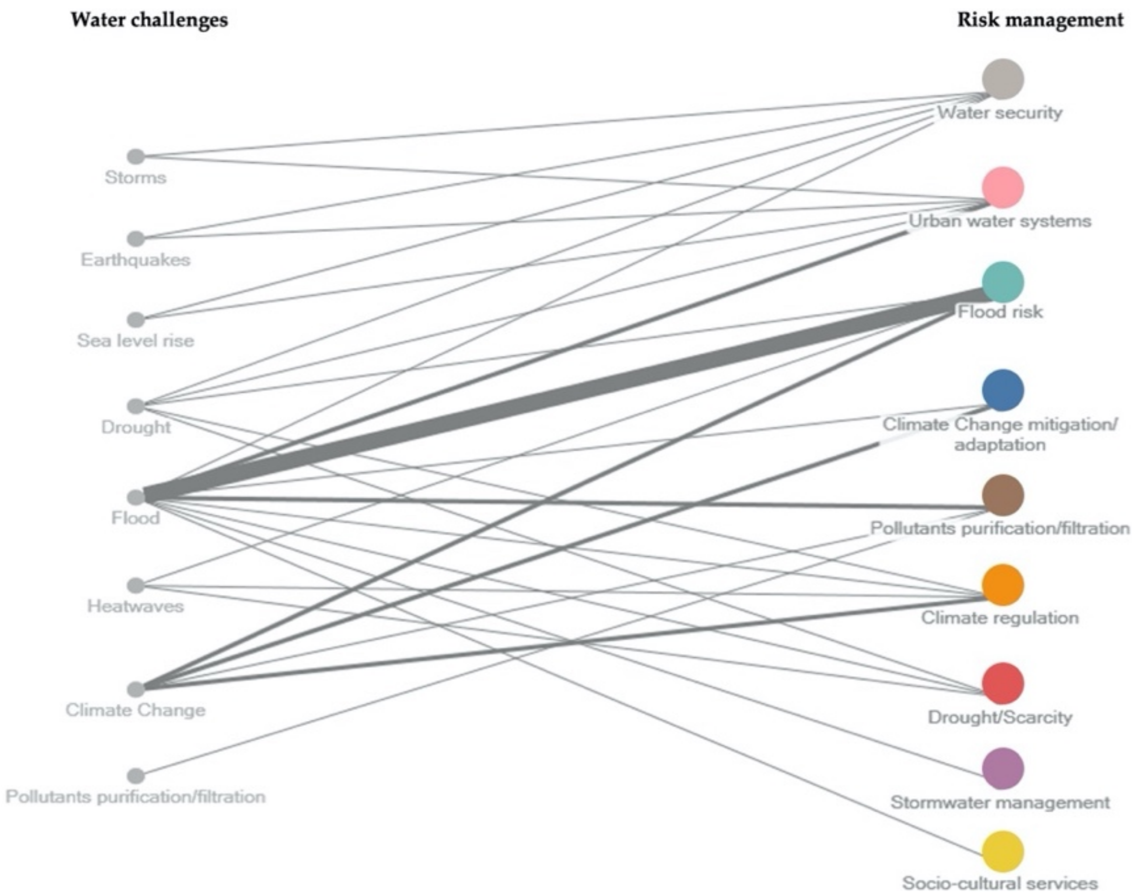

Figure 15. Relation between Water challenges (left) and Risk management (right).

NBS and ES

NBS implementation as a solution addressing, primarily, the issues related to water challenges; has the potential of delivering multiple benefits in a resource-efficient manner and adaptable manner. In this review, these benefits are identified through ES and its categorization of provisioning, regulating, cultural, and supporting services (Table 7). The regulating services that are frequently mentioned are the moderation of extreme events, waste-water treatment, among others. Cultural services are mainly related to recreation, mental, and physical health. Provisioning services are mainly represented through freshwater. Supporting services expose the habitat for species. See also Chapter 4 - Appendix A,

Table A3 and Table A4.

Table 7. Ecosystem services description

ES	Description	Codes	References
Provisioning Services	Food	4, 15, 18	(Langemeyer et al., 2020; Säumel et al., 2019; Tomao et al., 2017)
	Raw materials	11	(Liquete et al., 2016)
	Freshwater	8, 9, 16, 22, 25, 27, 28, 32	(Bricker et al., 2017; Brunetta & Salata, 2019; Carrard et al., 2019; Castelli et al., 2017; Dhyani et al., 2018; Herslund & Mguni, 2019; Ronchi et al., 2020; Yang et al., 2020)
Regulating Services	Local Climate Air Quality	3, 5, 8, 15, 22, 24	(Belmeziti et al., 2018; Cortinovis et al., 2018; Dhyani et al., 2018; Fung & Jim, 2020; Langemeyer et al., 2020; Ronchi et al., 2020)
	Carbon sequestration and storage	8, 22	(Dhyani et al., 2018; Ronchi et al., 2020)
	Moderation of extreme events	2, 3, 6, 8, 10, 11, 15, 21, 22, 23, 31	(Arabameri et al., 2019; Beery et al., 2017; Belmeziti et al., 2018; Dhyani et al., 2018; Gunnell et al., 2019; Langemeyer et al., 2020; Liquete et al., 2016; Marando et al., 2019; McFarland et al., 2019; Reynaud et al., 2017; Ronchi et al., 2020)
	Waste-water treatment	1, 3, 7, 10, 11, 16, 25, 31	(Belmeziti et al., 2018; Bricker et al., 2017; Capotorti et al., 2019; Liquete et al., 2016; McFarland et al., 2019; Reynaud et al., 2017; Riegels et al., 2020; Yang et al., 2020)
	Erosion prevention and maintenance of soil fertility	7,8	(Capotorti et al., 2019; Ronchi et al., 2020)
	Regulation of Water Flow	1,4,9	(Brunetta & Salata, 2019; Riegels et al., 2020; Tomao et al., 2017)
	Pollination	7	(Capotorti et al., 2019)
Cultural Services	Recreation and, mental and physical health	1, 2, 3, 5, 8, 10, 11, 15, 22	(Beery et al., 2017; Belmeziti et al., 2018; Cortinovis et al., 2018; Dhyani et al., 2018; Langemeyer et al., 2020; Liquete et al., 2016; Reynaud et al., 2017; Riegels et al., 2020; Ronchi et al., 2020)
	Aesthetic appreciation and inspiration for culture, art and design	8, 22, 24	(Dhyani et al., 2018; Fung & Jim, 2020; Ronchi et al., 2020)
	Spiritual experience and sense of place	3, 15	(Belmeziti et al., 2018; Langemeyer et al., 2020)

ES	Description	Codes	References
Supporting Services	Habitat for species	1, 3, 7, 11, 15	(Belmeziti et al., 2018; Capotorti et al., 2019; Langemeyer et al., 2020; Liquete et al., 2016; Riegels et al., 2020)

Although, the multiple benefits and services provided through nature are recognized; the debate in the literature is more oriented to the proper assessment of these services, and its integration into different sectors, to recognize the added value of NBS. In the policy sector, advancement by the European Commission established NBS priority areas as: the regeneration and well-being in urban areas, carbon sequestration, coastal resilience, watershed management, and ecosystem restoration, to enhance the insurance value of ecosystems and to foster sustainable use of matter and energy (Bauduceau et al., 2015).

NBS Scales

NBS implementation for water management in peri-urban areas respond to different spatial scales from site to national level (Table 8). Cases are mentioned as sites (6), neighborhood (6), municipality (20), metropolitan area (7), regional–basin level (10), and national level (1). In some cases, no explicit reference was found, thus, the category 'other' was applied (3). Implementation experiences were mainly on a municipality scale, which is associated with the level of urban planning competencies.

Table 8. NBS spatial scales description.

Spatial Scale	Codes	References
Site	2, 3, 17, 24, 31, 33	(Beery et al., 2017; Belmeziti et al., 2018; Fung & Jim, 2020; Jerome et al., 2017; McFarland et al., 2019; Mulligan et al., 2020)
Neighborhood	4, 5, 17, 32, 33, 34	(Cortinovis et al., 2018; Furlong et al., 2018; Herslund & Mguni, 2019; Jerome et al., 2017; Mulligan et al., 2020; Tomao et al., 2017)
Municipality	1, 2, 4, 5, 8, 10, 11, 12, 13, 14, 15, 18, 19, 20, 22, 28, 29, 30, 31, 32	(Beery et al., 2017; Belčáková et al., 2019; Castelli et al., 2017; Cortinovis et al., 2018; Dhyani et al., 2018; Fan et al., 2017; Hazbavi et al., 2018; Herslund & Mguni, 2019; Kim, 2019; La Rosa & Pappalardo, 2020; Langemeyer et al., 2020; Liquete et al., 2016; McFarland et al., 2019; Pagano et al., 2019; Reynaud et al., 2017; Riegels et al., 2020; Ronchi et al., 2020; Säumel et al., 2019; Thompson et al., 2019; Tomao et al., 2017)
Metropolitan area	4, 6, 7, 9, 16, 27, 29,	(Bricker et al., 2017; Brunetta & Salata, 2019; Capotorti et al., 2019; Carrard et al., 2019; Marando et al., 2019; Thompson et al., 2019; Tomao et al., 2017)
Regional (Basin level)	9, 14, 20, 21, 23, 25, 26, 28, 31, 35	(Arabameri et al., 2019; Brunetta & Salata, 2019; Castelli et al., 2017; Gunnell et al., 2019; Hazbavi et al., 2018; Jia et al., 2019; McFarland et al., 2019; Pagano et al., 2019; Pedersen Zari et al., 2020; Yang et al., 2020)
National	26	(Jia et al., 2019)
Other	9, 24, 25	(Brunetta & Salata, 2019; Fung & Jim, 2020; Yang et al., 2020)

Despite, the spatial scale of intervention cannot address or control the overall impact of the water challenges; it is a recognition of the limits of the NBS and the need for articulated responses at different spatial scales. This shows the role of the governance level of decision-making, that the type of NBS could determine the sectors involved, and that there must be instruments allowing the required integration of governance and management for supporting NBS implementation.

NBS Types

As technical responses, different types of NBS are presented in the implementation experiences (Table 9). NBS are wetland-related approaches, such as natural wetlands, constructed wetlands, and purpose-built wetlands (15); sustainable urban drainage systems (SUDS) (11); green-roofs/walls (11); river parks (9); agroforestry (9), parks (9); permeable pavement (4); Phytorid sewage treatment (3), which is a wastewater treatment using a specific variety of plants in constructed wetlands (Dhyani et al., 2018); rain gardens (3); bioswales (2); and others (24). In this review, the solutions are differentiated elements, since there is no clear boundary between what is conceptualized as SUDS in the literature. Specifically, solutions referring to SUDS for their drainage or filtration functions could be permeable pavement, rain gardens, bioswales, green roofs, detention and retention basins, wetlands.

Table 9. NBS types description.

NBS Types	Codes	References
Wetlands-related	2, 4, 5, 10, 11, 12, 13, 14, 16, 18, 21, 25, 29, 31, 33	(Beery et al., 2017; Belčáková et al., 2019; Bricker et al., 2017; Cortinovis et al., 2018; Gunnell et al., 2019; La Rosa & Pappalardo, 2020; Liquete et al., 2016; McFarland et al., 2019; Mulligan et al., 2020; Pagano et al., 2019; Reynaud et al., 2017; Säumel et al., 2019; Thompson et al., 2019; Tomao et al., 2017; Yang et al., 2020)
SUDS	7, 9, 12, 13, 16, 18, 28, 29, 31, 32, 33	(Belčáková et al., 2019; Bricker et al., 2017; Brunetta & Salata, 2019; Capotorti et al., 2019; Castelli et al., 2017; Herslund & Mguni, 2019; La Rosa & Pappalardo, 2020; McFarland et al., 2019; Mulligan et al., 2020; Säumel et al., 2019; Thompson et al., 2019)
Green-roofs/walls	3, 8, 9, 12, 13, 15, 16, 18, 28, 29, 31	(Belčáková et al., 2019; Belmeziti et al., 2018; Bricker et al., 2017; Brunetta & Salata, 2019; Castelli et al., 2017; La Rosa & Pappalardo, 2020; Langemeyer et al., 2020; McFarland et al., 2019; Ronchi et al., 2020; Säumel et al., 2019; Thompson et al., 2019)
River parks	4, 5, 9, 10, 11, 13, 16, 18, 29	(Belčáková et al., 2019; Bricker et al., 2017; Brunetta & Salata, 2019; Cortinovis et al., 2018; Liquete et al., 2016; Reynaud et al., 2017; Säumel et al., 2019; Thompson et al., 2019; Tomao et al., 2017)
Agroforestry	5, 7, 9, 13, 16, 18, 28, 29, 30	(Belčáková et al., 2019; Bricker et al., 2017; Brunetta & Salata, 2019; Capotorti et al., 2019; Castelli et al., 2017; Cortinovis et al., 2018; Kim, 2019; Säumel et al., 2019; Thompson et al., 2019)
Parks	5, 7, 8, 9, 13, 16, 18, 29	(Belčáková et al., 2019; Bricker et al., 2017; Brunetta & Salata, 2019; Capotorti et al., 2019; Cortinovis et al., 2018; Ronchi et al., 2020; Säumel et al., 2019; Thompson et al., 2019)
Permeable pavement	3, 8, 12, 31	(Belmeziti et al., 2018; La Rosa & Pappalardo, 2020; McFarland et al., 2019; Ronchi et al., 2020)
Phytorid sewage treatment	8, 22, 25	(Dhyani et al., 2018; Ronchi et al., 2020; Yang et al., 2020)
Rain garden	8, 31, 33	(McFarland et al., 2019; Mulligan et al., 2020; Ronchi et al., 2020)
Bioswales	12, 31	(La Rosa & Pappalardo, 2020; McFarland et al., 2019)

NBS Types	Codes	References
Others	1, 2, 3, 4, 6, 7, 8, 9, 17, 19, 20, 21, 22, 23, 24, 25, 26, 27, 30, 31, 32, 33, 34, 35	(Arabameri et al., 2019; Beery et al., 2017; Belmeziti et al., 2018; Brunetta & Salata, 2019; Capotorti et al., 2019; Carrard et al., 2019; Dhyani et al., 2018; Fan et al., 2017; Fung & Jim, 2020; Furlong et al., 2018; Gunnell et al., 2019; Hazbavi et al., 2018; Herslund & Mguni, 2019; Jerome et al., 2017; Jia et al., 2019; Kim, 2019; Marando et al., 2019; McFarland et al., 2019; Mulligan et al., 2020; Pedersen Zari et al., 2020; Riegels et al., 2020; Ronchi et al., 2020; Tomao et al., 2017; Yang et al., 2020)

NBS are not implemented independently but are combined within hybrid approaches of green, blue, and/or gray infrastructures. NBS as place-based interventions shifts the approach to landscape management, compared to traditional infrastructural projects. This is done by emphasizing the link among the green (vegetation), and blue (floodable areas, water) areas; and the influence of changes in land covers, and land uses. To illustrate this aspect using flood risk management, some publications claim that the hybrid approach is the most widely used, followed by a green approach and then by a blue approach (Sahani et al., 2019). In contrast, others argue that the green approach, represented as a green storage, is modified and influenced by land cover and land-use change; thus, it is more vulnerable than the blue approach (Gunnell et al., 2019). Despite its vulnerability, NBS proposes a shift from the design and use of gray flood control infrastructure or NBS planning for water management (La Rosa & Pappalardo, 2020).

In addition, other types of NBS could be regarded as linked to natural landscapes or to build-up landscapes (Table 10). The first solutions refer to integrating soil, vegetation, floodable areas, and water, while the latter is related to vegetation, floodable areas, and water.

Table 10. NBS Types and Landscapes.

	Soil	Vegetation	Floodable Areas	Water
Built-up Landscapes		Street trees	Retention/detention basins	Ponds
		Private gardens		
Natural Landscapes	Wildlife crossings	Riparian corridors	Drainage corridors	Wet meadows
		Coastal vegetation	Semi-natural waterways	Other water bodies
		Forests	Floodplains	

To close this sub-section, NBS is represented (Figure 16) as a simplified scheme flowing from problems or challenges (left) towards a response delivering benefits (right). In the literature, the analysis of the ES supports how NBS might deliver reinforced benefits through several and simultaneous ES. Thus, this scheme exposes the problem-solving feature in the spatial and technical aspects of the NBS, as the response addressing the interconnected water challenges and delivering a multiplicity of services; rather than establishing a causal link for a fixed categorization. See also Chapter 4 - Appendix A, Table A5 and

Table A6.

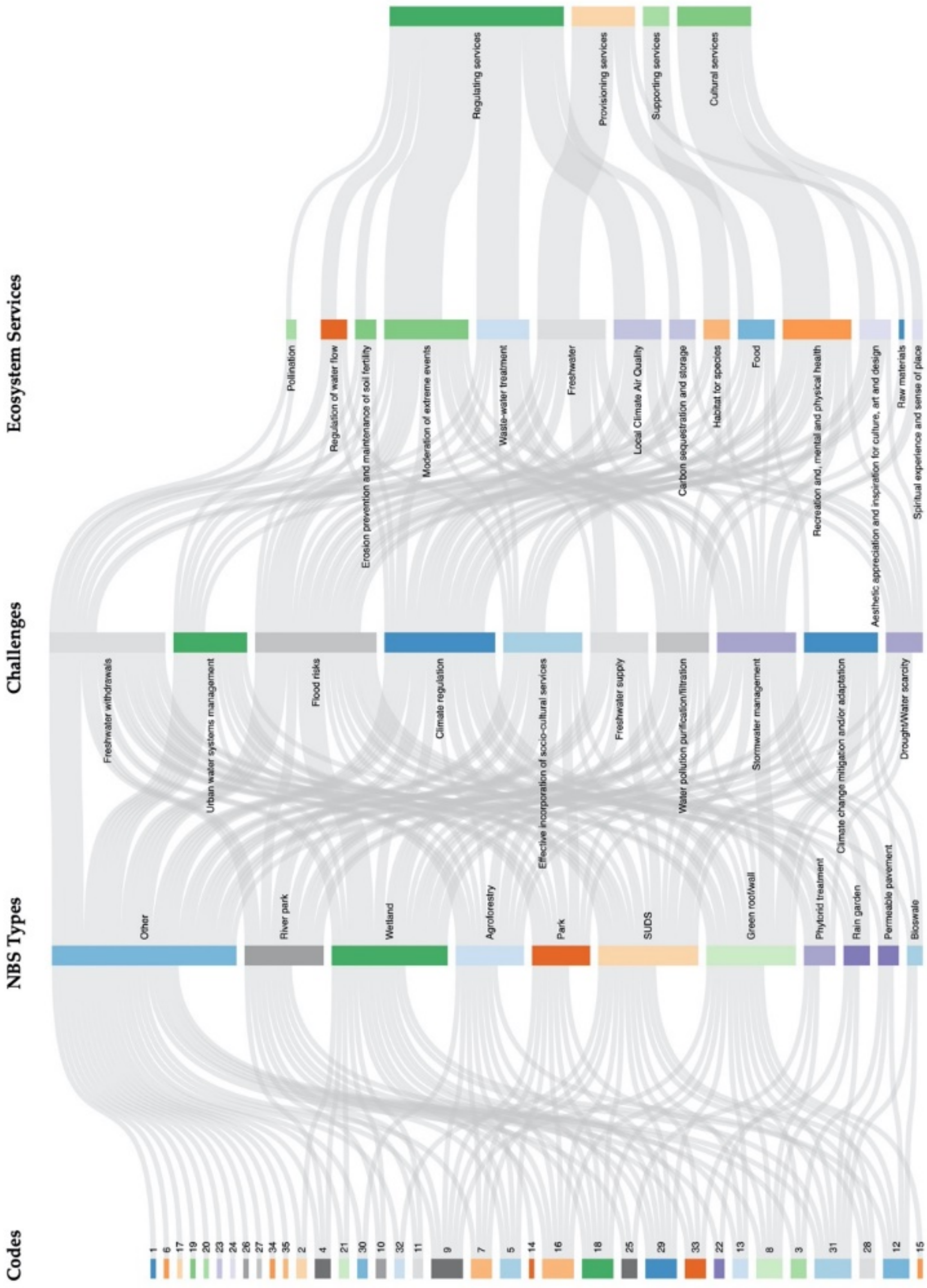

Figure 16. NBS types, challenges, and ecosystem services.

NBS Governance and Management

This section continues the analysis of NBS by identifying the governance and management factors that are supporting NBS implementation in peri-urban areas as the policy instruments , the involvement of stakeholders, and financing. This section is complemented by Chapter 4 - Appendix A,

Table A7 with detailed information on each implementation experience.

Policy Instruments

Most of the implementation experiences mentioned some kind of policy instrument (27) supporting its implementation, such as projects, programs, and plans (Table 11). When analyzing the governance level of these instruments, the regulations could link supra-national regulations to national, regional, or municipal initiatives. Most instruments correspond to local regulations and initiatives at the municipal level, which complements the findings of the spatial scale of the projects (See subsection on Involvement of Stakeholders). In the European Union context, the multi-level link is often developed under the EU Water Framework directive, which exposes the vertical coordination or agreement on NBS implementation. In addition, these regulatory frameworks cover long-term and cross-sectoral agendas, such as Sustainable Development Goals (SDGs); and sectoral documents, such as water planning, water management, risk management, and urban planning, displaying the interrelation among sectors for NBS while promoting specific supporting tools.

Table 11. Policy instruments mentioned.

Level	Policy Instrument	Scale	Codes	References
International	Sendai Framework for Disaster Risk Reduction (2015-2030)	Global	22	(Dhyani et al., 2018)
	Kyoto protocol	Global	13	(Belčáková et al., 2019)
	WaterWorld Policy Support System	Global	21	(Gunnell et al., 2019)
	UNESCO Biosphere Reserve" protection	Global	2	(Beery et al., 2017)
	UNESCO Groundwater resource sustainability indicators	Global	26	(Jia et al., 2019)
	UN's SDG 17	Global	20, 27	(Carrard et al., 2019; Hazbavi et al., 2018)
	UNICEF Joint Monitoring Program	Global	27	(Carrard et al., 2019)
EU Directives	EU Water Framework Directive (2000/60/EC)	Regional	1, 10, 11, 14	(Liquete et al., 2016; Pagano et al., 2019; Reynaud et al., 2017; Riegels et al., 2020)
	EU Flood Directive (2007/60/EC)	Regional	14	(Pagano et al., 2019)
	EU FP7 -Demonstrating Ecosystem Services Enabling Innovation in the Water Sector (DESSIN)	Regional	1	(Riegels et al., 2020)
	EU Biodiversity Strategy for 2020	Regional	7	(Capotorti et al., 2019)
	EU Strategy on Adaptation to Climate Change" (2013)	Regional	13	(Belčáková et al., 2019)
	6th Research Framework Program of the EU	Regional	30	(Kim, 2019)
Laws/ Policies	Green Highways Policy (2015)	National	22	(Dhyani et al., 2018)
	Regional law (R.R. n.3 from 24 March 2006)	Regional	10, 11	(Liquete et al., 2016; Reynaud et al., 2017)
	Act No. 17/1992, Collection of Laws, On the Environment	National	13	(Belčáková et al., 2019)
Plans	River basin management plan from *Autorità di Bacino del Fiume Po*	Sub-national	10, 11	(Liquete et al., 2016; Reynaud et al., 2017)
	Barcelona's Green and Biodiversity Plan (2012-2020)	Municipal	19	(Fan et al., 2017)
	Air Quality Plan (2011-2015)	Municipal	19	(Fan et al., 2017)

Level	Policy Instrument	Scale	Codes	References
	Finger Plan (1947)	Municipal	2	(Beery et al., 2017)
	19 different Canadian urban or city plans	Municipal	29	(Thompson et al., 2019)
	Italian National Plan of Adaptation to Climate Change (PNCC, 2016)	National	9	(Brunetta & Salata, 2019)
	Action Plan for Adaptation to the Adverse Effects of Climate Change on Territory, the Capital City of the Slovak Republic Bratislava, 2017-2020	Municipal	13	(Belčáková et al., 2019)
	The Woodlands Masterplan (citing McHarg, 1970s)	Municipal	30	(Kim, 2019)
	River Basin Catchment Management Plans	Sub-national	16	(Bricker et al., 2017)
	Support Program for the Natural Area of Integrated Management of Rio Grande (ANGIRG)	Municipal	28	(Castelli et al., 2017)
	Secretariat of the Pacific Regional Environment Program (SPREP)	Regional	35	(Pedersen Zari et al., 2020)
Programs	China Major Science and Technology Program for Water Pollution Control and Treatment	National	25	(Yang et al., 2020)
	One Water Supply, Sanitation and Hygiene (WASH) National Program (OWNP)	National	32	(Herslund & Mguni, 2019)
	Kibera Public Space Project (KPSP)	Municipal	33	(Mulligan et al., 2020)
	NAIAD Project	Municipal	14	(Pagano et al., 2019)
	Pacific Ecosystem-based Adaptation to Climate Change (PEBACC)	Regional	35	(Pedersen Zari et al., 2020)
	Joint Innovative and Technological Research Projects from the Ministry of Science and Technology of the People's Republic of China	National	25	(Yang et al., 2020)
	Mapping and Assessment of Ecosystems and their Services (MAES)	Regional	7	(Capotorti et al., 2019)
	Jawaharlal Nehru National Urban Renewal Mission (JNURM)	National	22	(Dhyani et al., 2018)
	Atal Mission for Rejuvenation and Urban Transformation (AMRUT)	National	22	(Dhyani et al., 2018)
	Greening the West initiative (GTW)	Municipal	34	(Furlong et al., 2018)
	Community-Scale Green Infrastructure (CSGI)	Local	17	(Jerome et al., 2017)
	Piano paesaggistico regionale (PPR)	Sub-national	8	(Ronchi et al., 2020)
Others	*Piano di governo del territorio* (PGT, 2012)	Municipal	8	(Ronchi et al., 2020)
	Municipal Natural Assets Initiative (MNAI)	Municipal	29	(Thompson et al., 2019)
	Peri-urban Land Use Relationships–Strategies and Sustainability Assessment Tools for Urban-Rural Linkages (PLUREL)	Regional	30	(Kim, 2019)
	Conservation Design for Subdivisions: A practical guide to create open space networks	Local	30	(Kim, 2019)
	UK National Ecosystem Assessment (2014)	National	16	(Bricker et al., 2017)
	Multifold instruments (mentioned for different cases)	Municipal	18	(Säumel et al., 2019)

Involvement of Stakeholders

In NBS development, complex societal challenges reveal the efforts of different actors (Table 12). However, a key aspect of its implementation is the cooperation between stakeholders to address sectoral barriers, fragmentation at different governance levels, and multidisciplinary consensus. In terms of stakeholders, the categories implemented correspond to representatives of public authorities, academics and researchers, the business and private representatives, the citizens and community, including NGOs, and other water-related actors. In the review, academic and public authorities were the most mentioned actors in the case studies reviewed in this study (22), followed by the civil society (16), water-related actors (10), and business and private representatives (5).

Table 12. Actors mentioned in the case studies.

Actors	Description	Codes	References
Public authorities	Local governments (municipalities, planning authorities, etc.), regional governments, ministries or departments, national governments or even supra-national institutions.	2, 7, 8, 9, 10, 11, 13, 14, 15, 16, 18, 19, 22, 25, 26, 28, 29, 30, 32, 33, 34, 35	(Beery et al., 2017; Belčáková et al., 2019; Bricker et al., 2017; Brunetta & Salata, 2019; Capotorti et al., 2019; Castelli et al., 2017; Dhyani et al., 2018; Fan et al., 2017; Furlong et al., 2018; Grizzetti et al., 2016; Herslund & Mguni, 2019; Jia et al., 2019; Kim, 2019; Langemeyer et al., 2020; Liquete et al., 2016; Mulligan et al., 2020; Pagano et al., 2019; Pedersen Zari et al., 2020; Ronchi et al., 2020; Säumel et al., 2019; Thompson et al., 2019; Yang et al., 2020)
Civil society	Citizen associations, community groups, advocacy organizations, environmental associations, friend groups, volunteers, NGOs, etc.	7, 10, 11, 13, 14, 15, 16, 17, 18, 22, 28, 29, 32, 33, 34, 35	(Belčáková et al., 2019; Bricker et al., 2017; Capotorti et al., 2019; Castelli et al., 2017; Dhyani et al., 2018; Furlong et al., 2018; Herslund & Mguni, 2019; Jerome et al., 2017; Langemeyer et al., 2020; Liquete et al., 2016; Mulligan et al., 2020; Pagano et al., 2019; Pedersen Zari et al., 2020; Reynaud et al., 2017; Säumel et al., 2019; Thompson et al., 2019)
Academic and research bodies	Scientific and technical experts, consultants, university departments, research groups, etc.	1, 3, 4, 6, 7, 8, 9, 10, 11, 12, 13, 15, 18, 20, 21, 22, 23, 25, 26, 27, 28, 31	(Arabameri et al., 2019; Belčáková et al., 2019; Belmeziti et al., 2018; Brunetta & Salata, 2019; Capotorti et al., 2019; Carrard et al., 2019; Castelli et al., 2017; Dhyani et al., 2018; Gunnell et al., 2019; Hazbavi et al., 2018; Jia et al., 2019; La Rosa & Pappalardo, 2020; Langemeyer et al., 2020; Liquete et al., 2016; Marando et al., 2019; McFarland et al., 2019; Reynaud et al., 2017; Riegels et al., 2020; Ronchi et al., 2020; Säumel et al., 2019; Tomao et al., 2017; Yang et al., 2020)
Water-related actors	Water management authorities, water utilities, hydro-geologists, water-sources investors, etc.	3, 5, 10, 11, 22, 25, 26, 27, 32, 34	(Belmeziti et al., 2018; Carrard et al., 2019; Cortinovis et al., 2018; Dhyani et al., 2018; Furlong et al., 2018; Herslund & Mguni, 2019; Jia et al., 2019; Liquete et al., 2016; Reynaud et al., 2017; Yang et al., 2020)
Industry, business and private sector	Private landscaper, wastewater treatment companies, water vendors, etc.	5, 15, 16, 22, 26	(Bricker et al., 2017; Cortinovis et al., 2018; Dhyani et al., 2018; Jia et al., 2019; Langemeyer et al., 2020)

The public sector is leading the NBS implementation effort to address the challenges described, and it takes on technical and economic leading roles.

Scientific interest is reflected in the effort when research opportunities are available. The involvement of private actors and industry depends on the development of business models. The role of citizens is related to users and recipients of the benefits. However, a limitation of this study is that only peer-reviewed publications in scientific databases were considered, which may explain also the importance of the academic actors. Accordingly, further research could include the analysis of other literature sources, to complement the actors and roles.

The articles exposed different social and/or cultural values when implementing NBS. Whilst some case studies (16) involved the civil society, only one-third of them (10) explicitly mentioned its role: in the participatory process (Pedersen Zari et al., 2020); participatory modeling (Pagano et al., 2019); and personal interviews and collective meetings (Belmeziti et al., 2018). Also, cultural values were mentioned with terms such as recreation (Beery et al., 2017; Belmeziti et al., 2018; Cortinovis et al., 2018; Dhyani et al., 2018; Langemeyer et al., 2020; Liquete et al., 2016; Reynaud et al., 2017; Riegels et al., 2020; Ronchi et al., 2020); aesthetics (Dhyani et al., 2018; Fung & Jim, 2020; Riegels et al., 2020); social cohesion (Langemeyer et al., 2020); educational and therapeutic activities (Jerome et al., 2017); and cultural and historical heritage (Ronchi et al., 2020). Local knowledge was slightly mentioned in educational activities (Reynaud et al., 2017); in activities to increase awareness (Liquete et al., 2016); and in bottom-up initiatives (Mulligan et al., 2020).

Financing NBS

For financing, almost half of the studies in the reviewed literature mentioned sources (Table 13). NBS is mostly funded by the public sector (14), the private sector (9), and few mentioning public–private partnerships (6). Public funding comes from local governments (municipalities), regional governments, ministries or departments of national governments or supranational institutions, such as the European Union. Research funding at the supranational level is a key aspect of this European context. Private funding comes mainly from sources such as foundations, non-profit organizations, and private corporations; or by conducting before–after simulations (McFarland et al., 2019; Riegels et al., 2020).

Table 13. Funding sources mentioned in the case studies.

Financing source	Countries	Codes	References
Public sector	Italy, Poland, Slovakia; Slovenia, United Kingdom, Spain, China, India, Ethiopia, Tanzania, Australia, Vanuatu	8, 10, 11, 13, 14, 16, 19, 22, 25, 32, 34, 35,	(Belčáková et al., 2019; Bricker et al., 2017; Dhyani et al., 2018; Fan et al., 2017; Furlong et al., 2018; Herslund & Mguni, 2019; Liquete et al., 2016; Pagano et al., 2019; Pedersen Zari et al., 2020; Reynaud et al., 2017; Ronchi et al., 2020; Yang et al., 2020)
Private sector	Italy, Poland, Slovakia, Spain, China, India, Bolivia, Ethiopia, Tanzania	10, 11, 13, 19, 22, 28, 32	(Belčáková et al., 2019; Castelli et al., 2017; Dhyani et al., 2018; Fan et al., 2017; Herslund & Mguni, 2019; Liquete et al., 2016; Reynaud et al., 2017)
Public-Private partnerships	Italy, Poland, Slovakia, India, China, Ethiopia, Tanzania	10, 11, 13, 22, 26, 32	(Belčáková et al., 2019; Dhyani et al., 2018; Herslund & Mguni, 2019; Jia et al., 2019; Liquete et al., 2016; Reynaud et al., 2017)

NBS has been developed as an amenity supported by public interest or through a non-profit aim, rather than through specific business models. The lack of identification of innovative business models behind NBS, reveals an open arena for identifying who is involved in the development of NBS for water management, and which roles they play. Although some references mentioned aspects related to the economic feasibility of NBS, specifically through aspects as life-cycle costs, cost-benefit analysis, or operating and maintenance costs, there were not included as part of this study; but, it should be covered in research by others. In fact, the economic feasibility of NBS is a barrier in its implementation, especially for avoiding uncertainty in its operationalization.

In summary, the results in this section indicate that implementation experiences of NBS in peri-urban areas are addressing different challenges, at different spatial scales, but mainly at the municipal level, and are executed through several types as hybrid approaches. The governance and management aspects of the cases suggest that NBS is linked to municipal, metropolitan and regional basin scales, i.e., by interventions across administrative borders, and delivered through agreements and consensus supported by policy instruments. The recognition of the actors involved indicates the leading role of public authorities, although, in some cases, other actors as academia and industry are involved. Funding schemes executed by privates are rarely mentioned. Finally, the implementation of NBS could be considered a process of a participatory nature. NBS as a socio-technical innovation needs to advance in the economic aspects. As a further barrier, none of the case studies examined referred to the gender perspective, which could be seen as a knowledge gap in sustainable development and the NBS–well-being relationship. The next section, therefore, moves from these insights on to discuss the barriers and lessons identified.

4.4. Discussion

This paper analyzes NBS for water management in peri-urban areas, using peer-reviewed literature on the implementation experiences, with a detailed view on specific spatial and technical aspects; and more general information on the governance, and management aspects. It supports in particular a previously cited barrier of NBS: there is still a need for NBS to be operationalized to be able to collect evidence on its effectiveness (Kabisch et al., 2016). The added value of NBS in terms of measuring the technical performance is presented in the literature through the recognition of ES, although, the debate is more oriented on the assessments, classifications, and scenario planning. In this review, the added value of NBS in the management and governance focused on the policy instruments and involvement of stakeholders, and economic aspects are only examined by the funding sources; but is an aspect to be researched by others, since it is equally relevant for informed cost-benefits, assessments on life-cycle costs, or operating and maintenance costs.

What lessons were learned, and which barriers were identified, by implementing NBS for water management in the peri-urban?

Lessons Learned

Water challenges expose pressures due to climate, risks, and urbanization. These challenges are interdependent, dynamic, and linked to the quality and quantity of the resource, revealing the complexity of water management in peri-urban areas. A common aspect is addressing water challenges through a mix of green/blue, green/gray, and green/blue/gray infrastructure approaches. NBS in the peri-urban area ranges from macroscales, such as river basins and agroforestry, to buildings as a microscale. Although there is not a fixed spatial scale, it is understood that peri-urban areas could tend to municipal levels for their planning competencies or bigger scales for implementations linking rural and urban systems. The multiple benefits delivered could be regarded as interrelated services, influencing different fields as landscape management; risks and climate regulation; recreation, physical and mental health, and well-being (Belčáková et al., 2019). This approach is open to contextualization as various GI and ES are mentioned when referring to implementation experiences, e.g., in the use of NBS or other green terms such as GI, ES, Eb; also, its open to adaptation, since NBS could be known under other terms such as LID, WSUD, SUDS, IUWM.

NBS delivers structural physical changes, exposed as spatial elements enhancing water management in different material manners while being resource-efficient. These changes result from integrating different fields, instruments, and mechanisms to promote shifts in the practices of cross-sectoral expertise, e.g., infrastructure design and water management. These new practices shift different domains, for example in landscape management (Albert et al., 2019), to support built-up landscapes or natural landscapes; as well as improvements in the spatial resources, risk management, and social well-being. Specific examples are the identification of flood-prone areas and influencing factors for flood occurrence, such as distance, slope, and land cover (Arabameri et al., 2019); design green infrastructure for increasing awareness of previously unnoticed natural features, such as sudden incidental nature experiences (Beery et al., 2017); and improve multifunctionality of the urban green space (Belmeziti et al., 2018).

NBS as an alternative practice, to enhance the dominant culture of gray infrastructure with interventions and experiments of blue and green approaches, could increase the potential of a peri-urban area to support human well-being. NBS implementation can deliver multiple benefits at multiple aspects; depending on the involvement and support of different levels of responsibility, territorial scales, and sectors. The operationalization of NBS could be enhanced by developing frameworks for capturing its comprehensive approach, considering it as a process, and including the multiple dimensions of its solution (e.g., spatial, technical, ecological, social, economic, etc.).

Finally, accountancy on the multifunctionality and the benefits delivered could be a critical success factor to involve cross-disciplinary approaches into NBS for water management. In this sense, monitoring NBS as a process is crucial for integrating the different scales of NBS: the spatial scale of the implementation, the scale of the challenge, and the scale of the impacts. Besides, communication about NBS could support the involvement of different actors, and the integration of sector, at different levels of decision-making to improve infrastructure planning and assessments of multiple benefits.

Barriers

NBS cannot control the overall impact of water challenges (Pedersen Zari et al., 2020), nor can it meet all needs (e.g., high runoff volumes, high contaminant loads, etc.), that could be related to high technical uncertainty (McFarland et al., 2019). To avoid uncertainty, systemic implications of NBS require taking into account the benefits, services, and the potential risks or unintended consequences of their up-take (Gómez Martín et al., 2020). Limitations to this purpose could be financial but could also extend to the lack of technological capacity or deficiency in infrastructure, as shown by the region-wide gap in groundwater monitoring systems and data (Carrard et al., 2019); or that affect institutional capacity (Herslund & Mguni, 2019; Mulligan et al., 2020). These also affect the NBS market uptake and the creation of alternative business models and practices that support it, and thus, limiting partnerships and involvement. For instance, market uptake of NBS benefits as a field still requires legal regulations (Säumel et al., 2019).

Even if NBS implementation involves different stakeholders, the promoting role is mainly done, and funded, by the public sector. The lack of interactions among the different actors involved compromises the perception of NBS, which could be negative for aspects such as costs, benefits in the short- and long-term, and impact of the solution (Raymond et al., 2017). This could lead to difficulties due to inhabitant resistance to changes (Belčáková et al., 2019; Herslund & Mguni, 2019), passive involvement, and insignificant increase of social cohesion (Säumel et al., 2019), fear of the unknown, and uncertainty (Kabisch et al., 2016; Pagano et al., 2019). Some NBS functions could lead to disservices, which are perceived negatively or affect safety perceptions, i.e., fire risks on green spaces or drowning risks in SUDS (Mulligan et al., 2020). In this sense, the cases revealed how social dynamics in terms of behavior and practices are shaped through socio-cultural values, traditions, and perceptions (Kabisch et al., 2016; Mulligan et al., 2020); and how they influence the uptake and use of NBS (Bricker et al., 2017). Study cases revealed that NBS increases individual and public awareness for lifestyle shifts (Säumel et al., 2019). Major aspects to consider for precaution in implementing NBS are displacement, gentrification commodification, social justice regarding access to nature and human well-being, among others (Albert et al., 2019; Escobedo et al., 2019; Kabisch et al., 2016).

A common aspect of the lessons learned and barriers is the knowledge demand, associated with the NBS uptake or decision-making for long-term and co-benefits (Kabisch et al., 2016), and on its effectiveness for comparison to conventional approaches. Therefore, NBS as a process should also be open to monitoring, i.e., for its maintenance and operation, and for examining ES and disservices. A crucial factor is to account for NBS perceptions throughout its implementation, e.g., costs, benefits; while acknowledging that both positive and negative perceptions need to be managed (Raymond et al., 2017).

Limitations of this review are related to the use of European promoted terms; the lack of economic aspects related to cost-benefits, maintenance, and operation, and that none of the case studies examined referred to the gender perspective, which could be seen as a knowledge gap in the NBS–well-being relationship. To provide greater insight into the novelty and comprehensive approach of NBS, further research could work on these gaps.

4.5. Conclusions

NBS address different water challenges, produced by urbanization processes, changes in climate, and risks while allowing the delivery of other services. Through a systematic review, in combination with content analysis, and descriptive research, this study examined 35 articles of experiences with NBS implementation in peri-urban areas. The review presented NBS from two standpoints, first from the spatial scale and technical aspects of its problem-solving feature, to respond to the ecological dimension of the concept. Second, from the governance and management, to identify the socio-economic factors that support its implementation.

Based on the insights of this analysis, we identified lessons learned and barriers. Mainly, accountancy, monitoring, and communication could be a potential success factor in NBS for water management. In this sense, accountancy to involve cross-disciplinary approaches on the multifunctionality and the benefits delivered. Monitoring on NBS as a process for integrating the different scales of NBS: the spatial scale of the implementation, the scale of the challenge, and the scale of the impacts. Communication about NBS could help to implicate different actors at different levels of decision-making. In a second order, this work identified that NBS could deliver multiple benefits, regardless of the type, scale, and location. However, in its implementation as a systemic response, its benefits are usually acknowledged as ES, which are integrated at multiple spatial scales and social aspects beyond the green infrastructure (GI). Since NBS cannot meet all needs, neither control the overall impact of water challenges, its implementation should be supported on different levels of responsibility, territorial scales, and sectors. This means that physical changes in water management should be supported on social consensus established among different stakeholders, sectors, and organizations.

Yet, a major barrier for NBS implementation is the complexity of a comprehensive approach, which leads to technical, institutional, economic, and social uncertainty. Limitations could be the lack of technological capacity or deficiency in infrastructure, as shown by the region-wide gap in groundwater monitoring systems and data (Carrard et al., 2019). Even if public authorities are playing a vital role in the promotion of NBS, by funding it, promoting research and policies; limitations could be related to the institutional capacity (Herslund & Mguni, 2019; Mulligan et al., 2020); and extend to economic aspects, e.g., to promote legal regulations required for the market uptake of NBS benefits (Säumel et al., 2019). This weakness in the creation of alternative business models and practices could restrain partnerships and the support of NBS by private actors. Further NBS uptake is depending on the enhancement of technical, institutional, and financial capacities, but also on the involvement of the different actors, including lay citizens. In fact, the interaction between the different actors involved could promote greater advances to actionable knowledge, perspectives, and discourses on this solution.

Nevertheless, the effort in identifying the systemic implications of NBS, in terms of benefits, services, potential risks, and unintended consequences aids to manage the negative perceptions around NBS implementation, which could be an advancement for overcoming alternative practices as NBS. In this sense, water management requires addressing its related challenges and social aspects in an integrated way. The cases reviewed have implemented NBS as an environmental and socio-technical system, which provides a feasible approach to managing water challenges and their associated pressures. As the research focused on NBS for water management in peri-urban areas, it is limited in identifying meaningful influential factors among NBS types, ES, or built-up context. Water management in peri-urban areas could be further explored to understand the influence of urban boundaries on NBS types.

As a systematic review, this paper has different limitations. First, `NBS' and 'peri-urban' terms used in inclusion criteria are mostly used in Europe. Although, other relevant experiences may be found under similar concepts for NBS such as LID, WSUD, SUDS, IUWM, or to peri-urban areas as suburbs, fringe, peripheries, suburbs, sprawls, etc. Second, the literature selected only covered peer-reviewed articles, and there may be significant evidence of experiences, lessons, and barriers, in other bodies of literature as NBS is in the intersection of science-policy-innovation. Third, the analysis has a wide-spread view of the implementation of NBS reported in the scientific literature, which usually focuses deeply on a specific discipline, therefore further analysis could advance in the operationalization of NBS in terms of frameworks for capturing its comprehensive approach. Further analysis could contrast this 'NBS in peri-urban areas' to other bodies of literature, including other terms, and explore this alternative approach from complementary concerns as the economic aspects (e.g., cost-benefits, life-cycle costs, operating and maintenance costs).

Despite these limitations, this review offers a widespread overview of the comprehensive approach of NBS regarding implementation experiences of NBS for water management in peri-urban areas. The contribution of this paper is the analysis of NBS in its different aspects throughout the implementation, identifying the lessons learned and barriers behind them. The results are describing each of the aspects analyzed in the selected references, to provide an overview of what is considered the problem-solving feature of NBS. Furthermore, complementary information of the cases (location, challenges, ES, types, scales) is used to report the specificities of the implementation experiences. There are still many opportunities and knowledge gaps to facilitate NBS operationalization, such as the different narratives around NBS and the local search for collaborations as processes that not only reveal the technical effectiveness of the challenges addressed but also the advances to the solution as a fixed vision or as a cross-boundary scheme that requires cross-sectoral dialogues.

5. Water reuse towards circularity

Exploring alternative practices in urban water management through the lens of circular economy (Art 2)

Abstract

Urban water management has recently been questioned because of the fragmented nature of the urban water system and its linear model. The integration and management of water systems are currently recognized as a socio-technical challenge that must be addressed for a more sustainable urban water management. In the short term, a key factor for its transition will be integration of alternative practices that allow for experimentation, learning, and scaling up. This study aims to identify potential shifts supported by two alternative practices for water reuse: nature-based solutions and water reuse technologies, using circular economy principles as analytical categories. The research uses a case study, the Besòs river of the Barcelona metropolitan area, to show that: i) improving biodiversity and water quality helps to regenerate natural capital; ii) water reuse for streamflow augmentation keeps resources in use and promotes synergies, which benefits social livability; and iii) risk management and a potential fit-to-purpose strategy can marginally help to avoid waste externalities. This research has shown that the CE principles are applicable as a framework for identifying the interconnected shifts promoted by water systems. A reflexive understanding of the alternative practices provides deeper insight into the experiences, barriers, and shifts that allow innovative interactions in specific urban contexts and can deliver additional benefits for society. This knowledge can be useful for integrated urban management; however, further integration of cross-sectoral collaboration and flexibility are required.

Keywords

Sustainable urban water management; circular economy principles; nature-based solutions; water reuse technologies; Besòs river area

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5.1. Introduction

There is growing concern about urban water systems being i) based on linear management models that center on extraction, use, and disposal, and ii) dependent on large-scale and centralized infrastructures and technologies (Heiberg et al., 2020; Hoffmann et al., 2020). This linear model of urban water systems is being challenged for its environmental sustainability, as it may cause the deterioration of water and other resources due to the influential presence of pollutants and waste stocks in the environment that are affecting human and ecosystem health (Fuenfschilling & Truffer, 2014; Nika, Vasilaki, et al., 2020). Addressing these issues—for instance, by overcoming the fragmented nature of water management—presents a complex challenge, as urban water systems are socio-technical systems that involve not only actor practices but also the interactions between infrastructures, institutions, and regulations (Fuenfschilling & Truffer, 2014; Nieuwenhuis et al., 2021).

Moving toward an integrated water system has multiple sustainability challenges, such as how to increase natural capital, close the loops in urban water systems, and avoid negative environmental effects (Fidélis et al., 2020; Hoffmann et al., 2020; Nieuwenhuis et al., 2021). The aim of technical, environmental, and social shifts is to integrate the urban water cycle and system management and thereby create a more sustainable urban water management (SUWM) (Adem Esmail & Suleiman, 2020; Fuenfschilling & Truffer, 2014). As compared to traditional approaches, SUWM is an overarching concept that promotes additional benefits gained through innovation, such as incorporating new ways of addressing water challenges from alternative practices in urban water systems (Adem Esmail & Suleiman, 2020; Marlow et al., 2013).

The term alternative practices is used in this study to refer to the practices that deliver added benefits (such as technical developments and institutional responses) that are typically supported as short-term, singular interventions (Fuenfschilling & Truffer, 2014; Hoffmann et al., 2020). Conditions that support alternative practices include protected sociotechnical spaces/niches, funded implementation, and research and development; in these conditions, new approaches, technologies, and routines can be tested, and any added benefits of these tests can be determined. Alternative practices may need to be built up to promote systemic changes, such as the emergence of new rules and systems, which would allow fundamental change in water systems over the long-term (Fuenfschilling et al., 2019; Ghosh et al., 2021).

In the short term, implementing alternative practices provides insights about the experiences, barriers, and shifts to be endorsed; this knowledge can help to advance the sociotechnical challenge of system integration and urban water cycle management. Consideration of alternative practices as a means for experimentation, learning, and scaling as proposed by Luederitz et al., (2017) could facilitate operationalization of SUWM. The search for novel approaches and technologies could support new paradigms, such as circular economy (CE), which has been proposed for achieving non-linear systems and transitioning to SUWM (Cipolletta et al., 2021; Hoffmann et al., 2020). Based on the CE paradigm, sustainability of water systems is analyzed based on three guiding principles: i) it regenerates natural capital; ii) keeps resources in use, and iii) it designs out waste externalities (Arup & Ellen MacArthur, 2018).

The gray literature discusses the benefits of CE derived from the value created at synergies between urban systems (Arup & Ellen MacArthur, 2018), and as key building blocks required for a utility to transition (Jazbec et al., 2020). Previous research has reported a link between water systems and CE, leading to the proposal that adopting the CE model could be a potential response to the linear model for a water system transformation (Nika, Gusmaroli, et al., 2020). Focusing on SUWM also seems to help to incorporate urban water management into the emerging CE paradigm, by highlighting the role of water reuse on the services that urban water systems are expected to provide (Hoffmann et al., 2020). Specific opportunities for water reuse as substitutions of water resources could include streamflow augmentation, recreational and ecological purposes, greening and cooling, and agricultural irrigation, among others (Hoffmann et al., 2020; Jazbec et al., 2020).

The literature is lacking reports of concrete cases that operationalize the CE principles, actions, and potential circularity features, yet this is needed for identifying incremental shifts towards integration and management of urban water system. The aim of this research is to identify contributions of alternative practices to SUWM by using a case study that implements two alternative practices addressing water reuse—namely, nature-based solutions (NBS) and water reuse technologies (WRT)—in the Besòs river area of Barcelona metropolitan area (Àrea Metropolitana de Barcelona; AMB) (Figure 17).

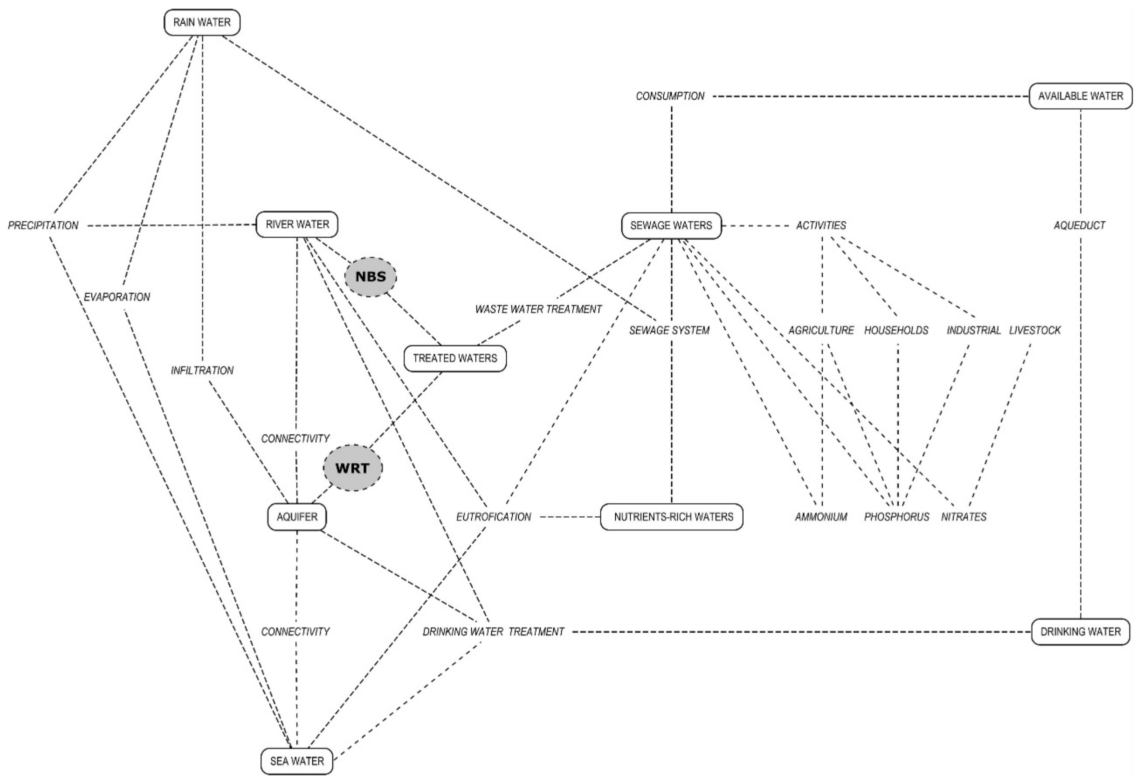

Figure 17. Graphical representation of the case study and the alternative practices

The data collection process for the case study included interviews with different stakeholders, field observation, and a desk review of secondary sources on the alternative practice performance on water reuse. Data analysis was conducted using the CE framework. The case study revealed: i) alternative practices that gave an added benefit to the specific urban context, and ii) the practicality of the proposed framework for identifying the incremental shifts promoted in water systems.

5.2. Background of alternative practices and CE principles

Alternative practices in water management have been implemented to address climate change and urbanization pressures for a more sustainable urban water management (Adem Esmail & Suleiman, 2020). These practices can lead to multiple benefits and services, such as urban water balance restoration, multifunctional ecosystems, resource recovery, and water reuse. Similar to water reuse, energy and nutrient reuse could promote shifts at different spatial scales, ranging from households, to cities, to landscape levels (Hoffmann et al., 2020).

Challenges identified for the integration and management of water systems include comprehensively assessing the CE, reintroducing nature, and decentralizing infrastructures. In particular, an overall model establishing what needs to be measured and how to do this has been proposed, which designs a framework for a comprehensive CE assessment (Nika, Gusmaroli, et al., 2020; Nika, Vasilaki, et al., 2020). However, practical applications based on comprehensive CE assessments (that use various methodologies and indicators) may be difficult to report due to high levels of complexity (e.g., information flow, economic valuation, feedback loops, and sectoral interdependence) (Nika, Vasilaki, et al., 2020).

Research on reintegrating nature into human-managed water systems has focused on the potential of implementing nature-based solutions (NBS) to address different water challenges (Nika, Gusmaroli, et al., 2020). NBS are defined as actions inspired and supported by nature that deliver benefits (ecological, social, and economic) (Bauduceau et al., 2015). In urban water management, NBS address diverse issues, such as flood risks, droughts, stormwater management, and freshwater withdrawals, as well as challenges related to water pollution (e.g., phytoremediation). Various types of NBS for water management in peri-urban areas have been implemented, including wetland-related approaches (based on natural, constructed, and/or purpose-built wetlands), sustainable urban drainage systems (SUDS), and river parks (Ramírez-Agudelo et al., 2020).

Decentralized systems for water reuse with new technological elements, such as water reuse technologies (WRT), could promote changes at the micro-, meso-, and macro-level of water systems (Hoffmann et al., 2020). Elements of WRT include features that provide benefits through digitalization (such as wireless monitoring, membranes for reverse osmosis, and waste-to-value technologies) and that allow interventions to be embedded into the grid-dominated infrastructure (such as data monitoring, sensors, and smart controls) (Hoffmann et al., 2020). NBS and WRT as alternative water management practices may support the use of the CE paradigm in water systems (Hoffmann et al., 2020; Nika, Gusmaroli, et al., 2020).

At the strategic level, these alternative practices use a general rationalization principle in water resource use and recovery, and emphasize using new management logics, such as sensitive or hydraulic logic (Fuenfschilling & Truffer, 2014). For instance, a sensitive logic could be related to a socio-ecological approach to urban water management (e.g., by incorporating NBS), and a hydraulic logic could be related to a socio-technical approach (such as the efficiency and optimization objectives of WRT). The socio-ecological approach of NBS encourages multidimensional responses, including ecosystem services, risk management, and urban amenities, positioning NBS as a priority for urban sustainability in European policy (Bauduceau et al., 2015). In terms of ecosystem services, NBS are recognized to promote human well-being, of both physical and mental health (Raymond et al., 2017). The socio-technical approach of WRT is represented in a variety of environmental technologies and includes the smart tactic resolving specific technical challenges, while involving the users in "fit-to-purpose" strategies for water demand management (Domènech et al., 2015).

CE could enable shifts in water systems by following three principles: 1) regenerate natural capital, 2) keep resources in use, and 3) design out waste externalities (Arup & Ellen MacArthur, 2018; Nika, Gusmaroli, et al., 2020; Nika, Vasilaki, et al., 2020). The 'CE concept' functions as a connecting link, ensuring functional environmental flows and stocks, closing resource loops, and increasing the economic efficiency of waste reduction in water systems (Nika, Gusmaroli, et al., 2020; Nika, Vasilaki, et al., 2020). The literature on CE in water systems describes that the CE principles may be associated with specific actions and examples of potential circularity features, thereby promoting shifts in the water systems, as these individual features are interconnected and contribute to SUWM.

Regenerating natural capital aims to prevent pollution and restore natural capital, and thereby ensure functional environmental flows and stocks. Recommended actions supporting this principle are related to natural capital preservation and enhancement, and to processes in which human interactions/use cause the minimum disruption to natural water systems (Arup & Ellen MacArthur, 2018; Nika, Gusmaroli, et al., 2020; Nika, Vasilaki, et al., 2020). Potential circularity features include ecosystem health support and improving the quality of discharge effluents (e.g., improving biodiversity, greening and cooling properties, water quality of the effluents, waterways, and urban landscapes) (Jazbec et al., 2020; Nika, Gusmaroli, et al., 2020; Nika, Vasilaki, et al., 2020). This principle endorses the regeneration of the natural and urban environments to contribute to SUWM.

Keeping resources in use aims to maximize water use by i) keeping it in the landscape, ii) close resource loops, and iii) preserve its value as long as possible through recovery, reuse, and up-/recycling. Benefits are derived from the value generated at the water systems' interfaces with other systems, as well as by optimizing resource yields within water systems and management (Arup & Ellen MacArthur, 2018; Nika, Gusmaroli, et al., 2020; Nika, Vasilaki, et al., 2020). Potential circularity features include reducing water use and optimizing resources, which are exemplified by reducing use in water consumption and non-consumption, streamflow augmentation by returning wastewater to waterways, maximizing environmental flows, and best use when operating water systems with other systems (which should optimize water, minerals, chemicals, and energy) (Nika, Gusmaroli, et al., 2020; Nika, Vasilaki, et al., 2020). To contribute to SUWM, this principle endorses synergies among urban systems that better support livability and the local community, and thus the social dimensions of livability (Arup & Ellen MacArthur, 2018; Jazbec et al., 2020).

Designing out (waste) externalities targets environmental and social impacts, as well as the economic efficiency of waste reduction. The recommended actions address i) the negative impact on both environmental and social dimensions, and ii) how to improve the economic dimension by resource efficiency in terms of the right assessment of the amounts and the value of resources. Potential circularity features include risk management, efficiency of resource use in services and benefits, and assessment for best value of water use. Risk management—for example, through stormwater attenuation—contributes to reduced discharge in the environment, reduced atmospheric emissions, and lower social exposure. Actions that target resource efficiency aim to use the least amount of (fresh) resources to deliver services and benefits, and to establish best value for water use of not only economic efficiency and cost-effectiveness but also through non-market methods (including assessments in terms of natural, human, and social capital) (Arup & Ellen MacArthur, 2018; Jazbec et al., 2020; Nika, Gusmaroli, et al., 2020; Nika, Vasilaki, et al., 2020). To contribute to SUWM, this principle endorses the correct valuation of the waste reduction in terms of social and environmental impacts.

To summarize, each CE principle can be associated with specific actions, potential circularity features, and examples (Table 14). Moreover, these analytical categories are interconnected; when viewed as a set, they can give information about the incremental shifts that contribute to system integration and urban water cycle management towards SUWM.

Table 14. Framework of the CE principles in water systems:

CE Principles	Actions	Potential Circularity Features
Regenerate natural capital Preventing pollution and restoring natural capital, to guarantee functional environmental flows and stocks.	Natural capital preservation and enhancement	Support the ecosystem's health (biodiversity, greening and cooling properties)
	Minimize disruption from human interactions and use of natural water systems	Improve the quality of (and reduce) discharge effluents (water quality, waterways, or urban landscapes)
Keep resources in use Maximize water use by maintaining water in the landscape, close resource loops, and preserving its value as long as possible through recover, reuse, upcycling, and recycle.	Benefits from the value generated in the interface of water systems with other systems	Reduce water use (streamflow augmentation by returning treated wastewater to waterways, maximizing environmental flows, consumption and non-consumption)
	Optimize through resource yields obtained within water systems	Optimize resources via use and extraction of nutrients (N, C, P), minerals, chemicals, and energy

CE Principles	Actions	Potential Circularity Features
Design out (waste) externalities Design out waste disposal by targeting environmental and social impacts and the economic efficiency of waste reduction.	Address the negative environmental and social impacts	Risk management (via stormwater attenuation, reduced discharge to the environment, reduced atmospheric emissions, and lower social exposure)
	Improve efficiency of resources	Target the most efficient amounts of (fresh) resources to be used in to deliver services and benefits
		Best value for water use (economic efficiency, cost-effectivity, and non-market methods as natural, human, and social capital)

5.3. Materials and methods

This research was conducted using a case study of water reuse experiences through NBS and WRT, aiming to present a detailed analysis of how alternative practices in urban water management contribute to transformative changes towards SUWM. For illustrating advances through NBS and WRT implementation in a specific urban context, the CE principles were used as analytical categories to examine each category as a linear-analytical approach (Van Der Blonk, 2016). This analysis identifies the CE principles in terms of evidence for related actions, and potential circularity features; however, a limitation is the increased complexity of findings due to the interconnectedness of these actions.

Study area

To avoid redundancy, the study area description has been omitted. Please see the overview of the research area (Section 3.3).

Data collection

This study is based on a mixed approach of quantitative and qualitative data, using data collected through interviews, complemented with field observations, and a desk review of secondary sources. Between 2019 and 2020, four in-depth interviews were conducted to acquire perspectives from different stakeholders, who are either directly or indirectly involved with the alternative practices: i) in academia, a person involved in the development of the WRT; ii) in government, a member of the local consortium involved in NBS and WRT; iii) for civic society, an environmental activist and resident of the area; and iv) in industry, a person involved with the area's urban metabolic infrastructure. Field observations were conducted during multiple visits between 2019 and 2021 to gather the infrastructure's various spatial aspects.

Data analysis

Analysis was for the interaction of two key themes: i) the CE principles and ii) the historical context of implementation of alternative practices (Table 15). The CE principles are used as analytical categories to build evidence for related actions and potential circularity features based on the framework presented in the background section. Results were validated by triangulation, with the various data (such as quantitative data on water quality) integrated; the themes identified during the interview analyses (including quotes), accounts from observations, and established ideas in the literature are presented. This style of reporting is intended to highlight that examining the support of the CE principles also jointly addressed the question of how alternative practices contribute to SUWM.

Table 15. Data analysis and integration of data through the case study

Key themes	**Data collection**		**Data sources**			**Input for alternative practices**	
	Topics from the literature	*Aspects searched*	*Desk review*	*Interviews*	*Field observations – (NBS)*	*NBS*	*WRT*
Alternative practices	Study area - Historical background implementation process	Context of the case study	X		X	X	X
		Conditions for its emergence	X	X		X	X
		Outcomes	X	X	X	X	X
CE - SUWM	Natural capital preservation and enhancement	Ecosystems health - Biodiversity	X		X	X	
		Greening and cooling properties				No info.	N.A.
	Minimizing pollution	Water quality – nutrients presence, regulatory limits for reuse purposes	X			X	X
	Maximizing the use of water	Water quantity - Streamflow	X	X	X		
	Maintenance of resources value	Nutrients optimization				No info.	No info.
	Tackling environmental and social impacts	Water challenges - flooding risks	X	X	X	X	X
	Targeting efficiency of resources	Best value for water use				No info.	No info.

The topics aiding the analyses of natural capital regeneration principle were natural capital preservation and enhancement and pollution reduction. Topics illustrating 'how to keep resources in use' included maximizing water use and maintaining resource value. The analysis of 'designing out (waste) externalities' was supported by the topics of tackling environmental and social impacts, as well as targeting efficiency of resources.

Regenerating natural capital is presented as the advances in the support of the ecosystem's health towards capital preservation and enhancement of nature through the NBS using data related to biodiversity monitoring, including the IBMWP index from an academic observer (e.g., the Barcelonarius project; Universitat de Barcelona, 2021). Actions oriented to minimizing disruption from human interactions and to improving the quality of the effluent discharge are related to water quality, using NBS for the Besòs river and potentially WRT for the aquifer (See details on data and references in the Appendix).

5.4. Results and discussion

How do alternative practices contribute to SUWM? For the case study of the Besòs river area, alternative practices were implemented through several actions and (potential) circular features along the three CE principles: biodiversity and water quality improvements, through NBS supporting natural capital regeneration; water reuse for streamflow augmentation and multi-functional infrastructure, which keep resources in use; and management of flooding risks and a potential fit-to-purpose strategy for avoiding waste externalities.

Regeneration of natural capital

The Besòs river area aims to prevent pollution and restore natural capital, to ensure functional environmental flows and stocks; this is developed through two actions: 1) preserve and enhance natural capital, and 2) minimize disruption due to human interactions with and use of natural water systems.

Environmental degradation and pollution of the Besòs river area was first addressed with an alternative practice for water reuse in a restoration project that included NBS (1996–2006). NBS were implemented by i) creating a 22-hectare, 9-kilometer-long riverside park; and ii) constructing wetlands around the Montcada i Reixac waste water treatment plant (WWTP) in 2003. These solutions not only promote biodiversity but also support the ecosystem health, improve the water quality of the Besòs river and aquifer, and promote improvement of the discharged effluents.

Various biological indicators were used to measure biodiversity, such as the invertebrate benthic fauna index IBMWP (Figure 18), for which the Catalan Water Agency (ACA, *Agència Catalana de l'Aigua*) provided data that showed an overall increase in biodiversity in the area, from 1996 to 2017 (from 0 in 1996, to 3 in 1999, to 48 in 2017). Both NBS programs contributed to this increase, as evidenced by the positive results for the biological quality measured by the Barcelonarius project (Universitat de Barcelona, 2021) and the Water Agency data (ACA, *Agència Catalana de l'Aigua*). Nevertheless, it has been argued that if forest quality is considered with the overall ecological status, the ecological state of the lower Besòs river area remains negative (Fortuño et al., 2020).

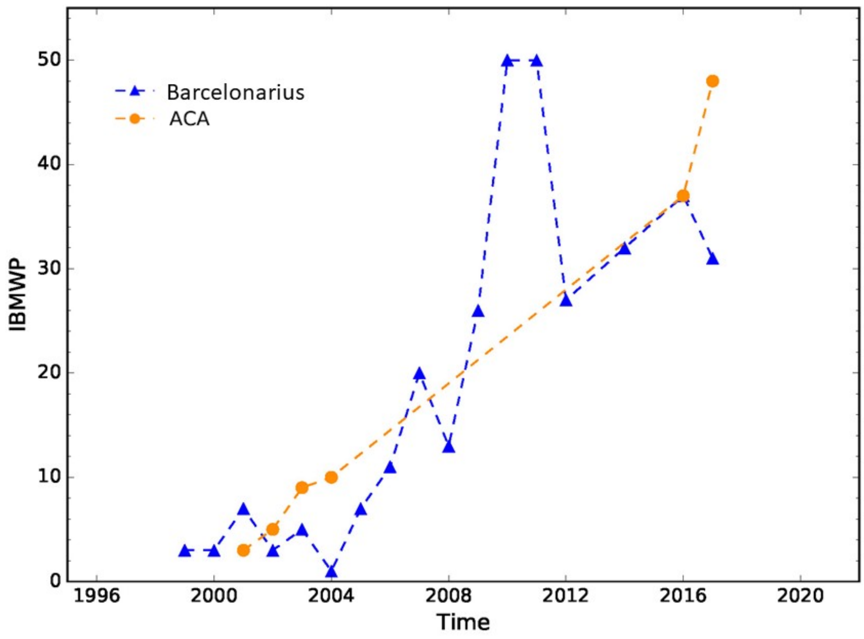

Figure 18. Biodiversity index IBMWP - Besòs river 1999-2017

Nitrate concentrations in the river were less than 25 mg/L until 2013, which is the accepted limit set by the river quality directive as good/moderate (Figure 19). Since 2014, seasonal fluctuations have increased these nitrate levels, even though the levels have remained below the accepted limit of 50 mg/L required by drinking water regulation and the river's ecological flow maintenance. These results seem to show that using the NBS wetland in the river (since 2003) has not decreased nitrate concentrations.

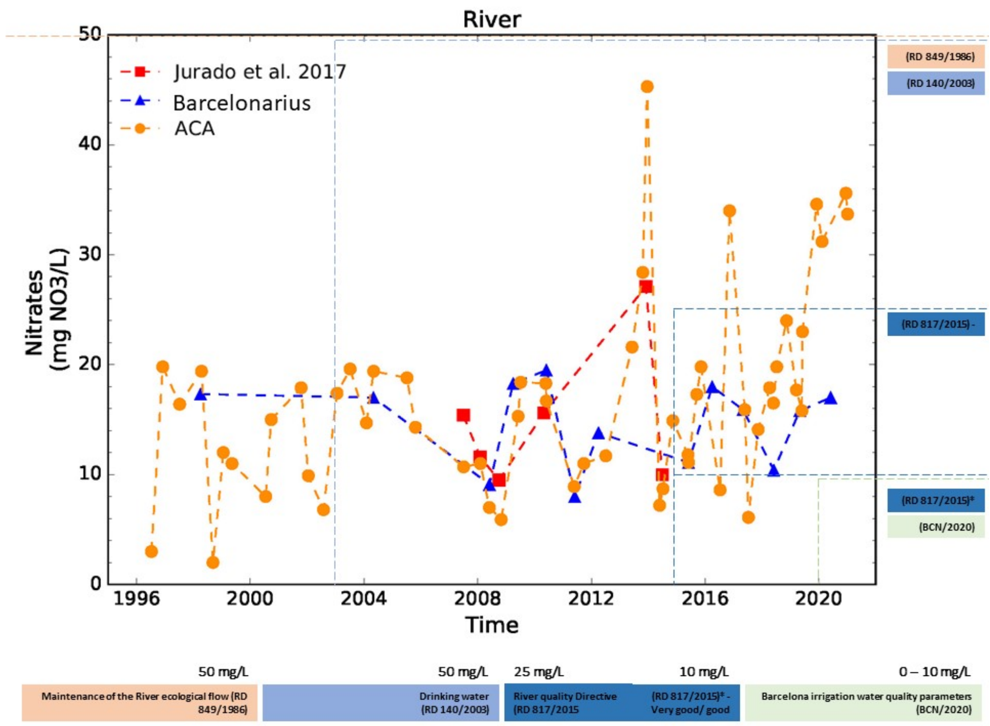

Figure 19. Nitrate concentrations (mg/L) in the Besòs river 1996–2021

The phosphate concentrations in the river exceeded the established limits until 2015. However, since 2017, it has remained below the 2 mg/L limit established by the Barcelona irrigation water parameter (Figure 20). This decrease in phosphate concentrations could be due to an improvement in the treatment at the WWTP, which uses chemical reagents that favor the phosphate precipitation.

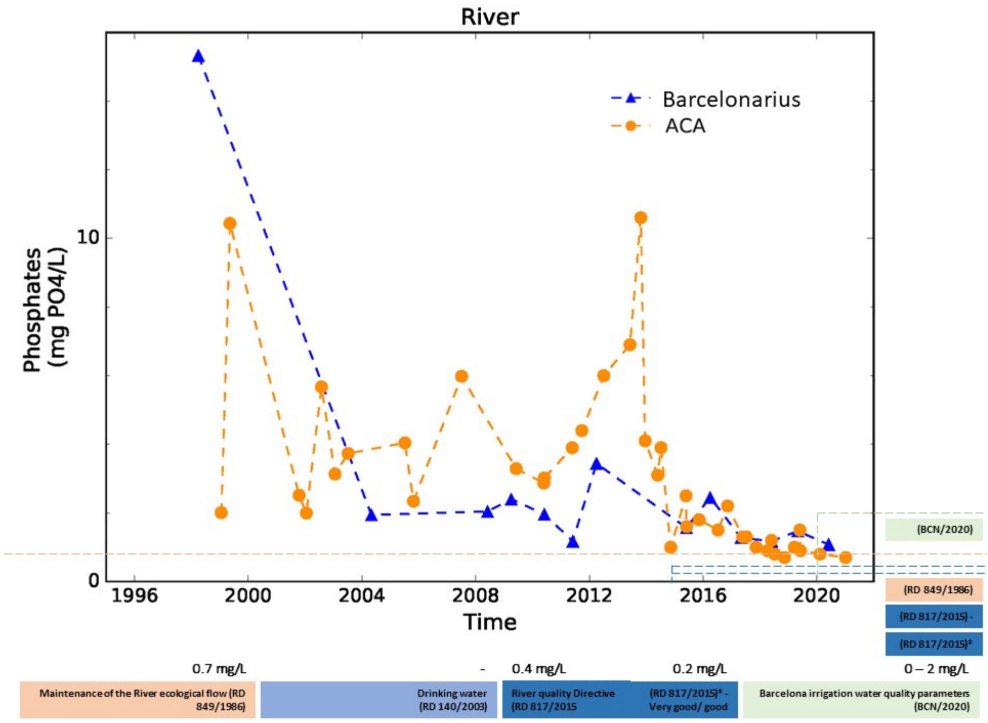

Figure 20. Phosphate concentrations (mg/L) in the Besòs river 1999-2021

Disturbingly, the ammonium concentrations have fluctuated between 30 mg/L and 5 mg/L from 1998 to 2009 (Figure 21). Since 2008, it has ranged between 20 mg/L and 1 mg/L. Currently, the upper established limit for ammonium is 5 mg/L, established by the Barcelona irrigation water parameter, and the lower limit is 1 mg/L for ecological flow maintenance. It is important to consider that, depending on the pH, part of the ammonium can be transformed to ammonia, which is toxic to certain species, including fish.

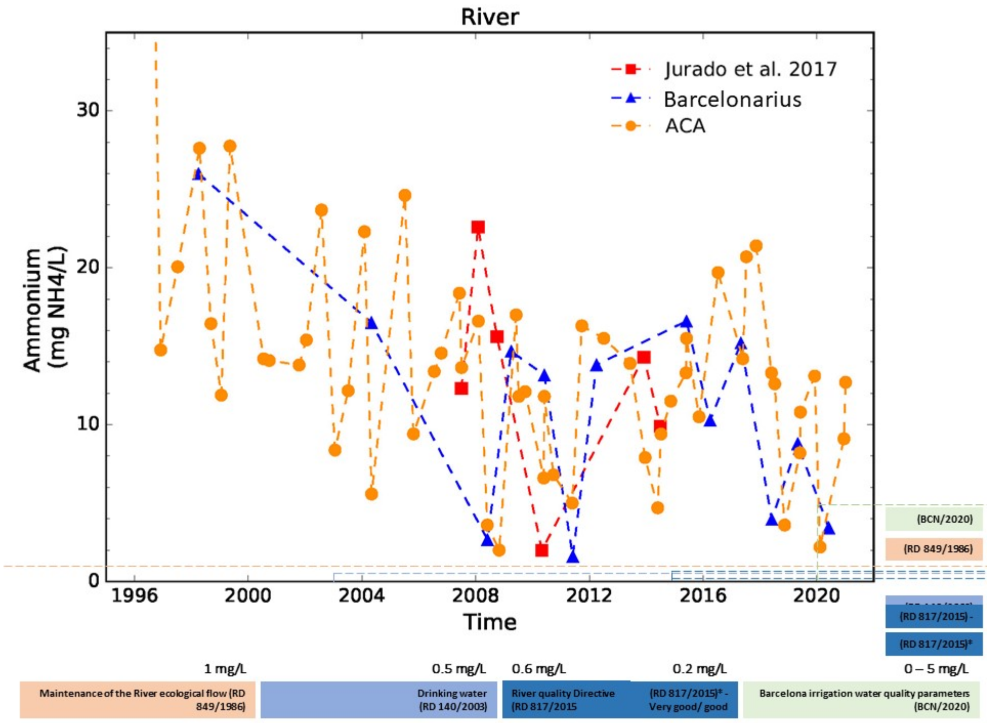

Figure 21. Ammonium concentrations (mg/L) in the Besòs river 1996-2021

The constructed wetlands (NBS) have served as an integrated solution for natural purification to the WWTP by reusing some of the treated water on cultivated land, thereby maintaining the existing vegetation of the Besòs river reedbeds. NBS have served for enhancing and preserving the river's water quality. The effluent quality has improved because of the constructed wetlands, which assist in purifying the used waters. However, nitrate and ammonium concentrations are insufficiently assimilated, both in the river and in the aquifer; this reflects the connection between the two water bodies. Environmental preservation of groundwater-dependent ecosystems, such as riparian areas and wetlands, has been critical for maintaining nitrogen assimilation rates (Mas-Pla & Menció, 2019).

In contrast, we could determine (despite the scarcity of data on nutrient concentrations in the aquifer) that, until 2011, nitrate concentrations of the aquifer were less than 10 mg/L (Figure 22). This level is very low compared to levels in aquifers affected by agriculture and livestock activities. After 2011, it remained between 10 and 25 mg/L, which is also lower than the levels found in the most contaminated areas of Catalonia (Mas-Pla & Menció, 2019).

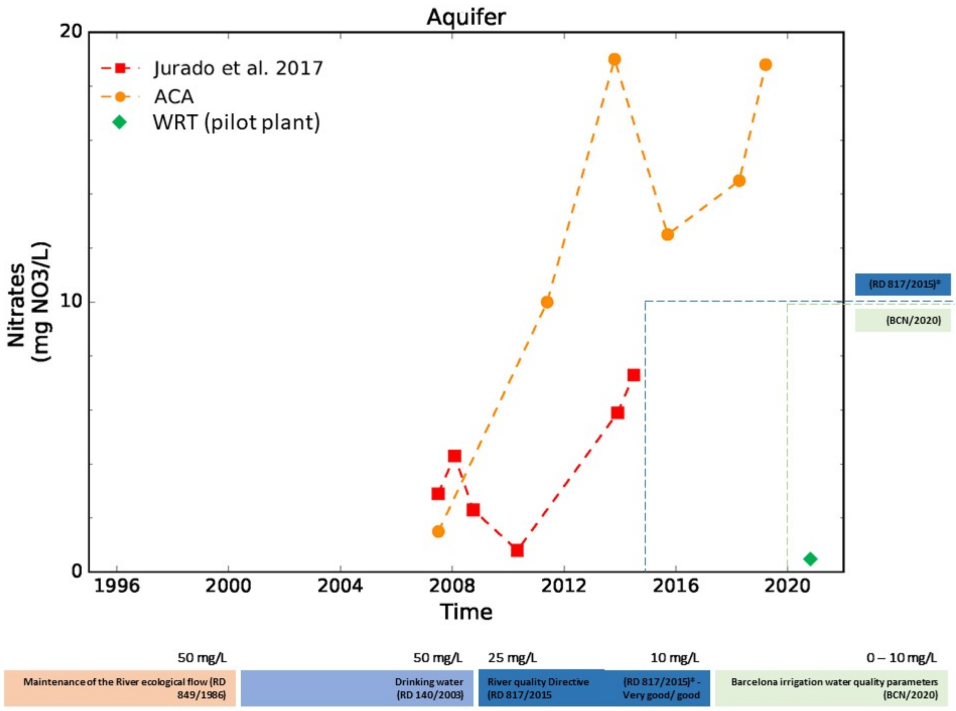

Figure 22. Nitrate concentrations (mg/L) in the Besòs aquifer 2007–2021

No data on phosphates in the aquifers were identified, which could also indicate that its concentration was below the detection limit.

Until 2008, ammonium levels in the aquifer exceeded 5 mg/L; from 2010 to 2014, they ranged from 2 to 4 mg/L (Figure 23). These values pose a problem for groundwater reuse, as its concentration must be less than 1 mg/L, except for irrigation purposes. To achieve this limit, osmosis membrane technology (among others) should be considered.

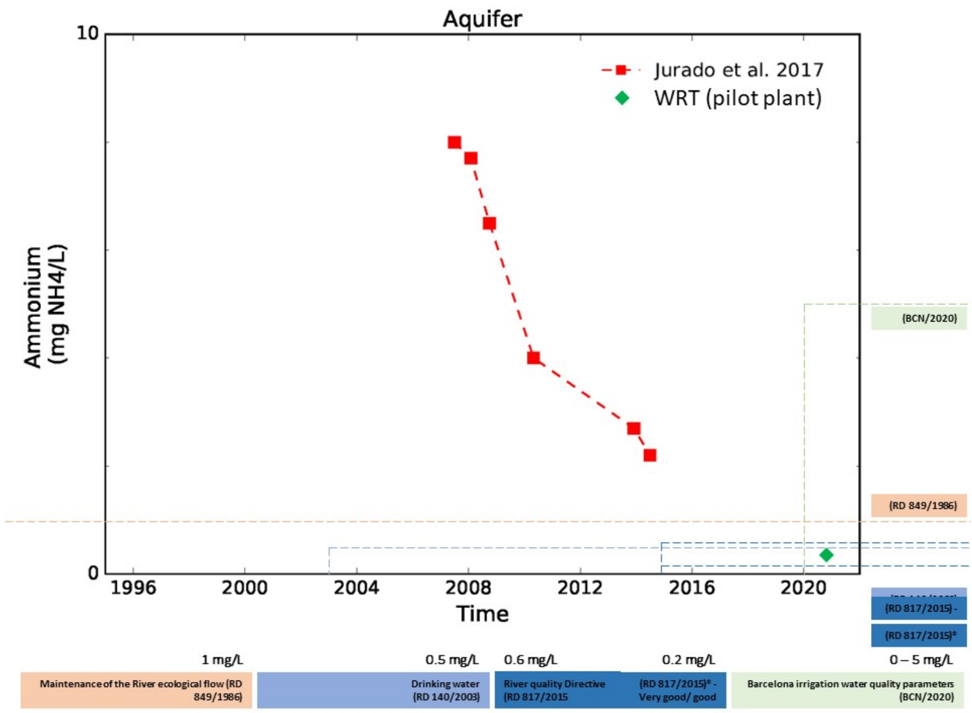

Figure 23. Ammonium concentrations (mg/L) in the Besòs aquifer 2007-2014

The Ammonium concentrations have been measured with the WRT pilot during 2020

Implementing the WRT reduced nitrates and ammonium to allowed concentrations, confirming its capacity to improve the reuse of water pumped from the aquifer. Despite this, it is still unclear how best to minimize disruption to natural water systems caused by human interactions and use, as ammonium concentrations in the river and aquifer exceed the maximum limit of 5 mg/L. Progress in complementary treatments, such as WRT based on reverse osmosis, may increase the potential to reduce ammonium concentrations.

To summarize restoration of the Besòs river has been documented as advances towards natural capital preservation and enhancement. The availability of data from water quality analyses help to monitor the quality of the effluent discharge. At present, according to the AMB, the wetlands currently act like a tertiary treatment of the WWTP (AMB, 2021). The Besòs river area is considered a strategic area for the metropolitan water cycle, as it is connected to the green and blue metropolitan infrastructure goals of renaturalization (AMB, 2020).

These findings demonstrate that the described actions are linked as a sequential process: the circularity features initially prevented pollution, then natural capital was restored, and thus functional environmental flows and stocks currently guarantee the regeneration of the natural capital and the urban environment of the Besòs river area.

Keeping resources in use

Keeping water in the landscape supports the purpose of maximizing water use, which highlights the benefits from the value generated in the interface of water systems with other systems. The analysis identified that water reuse served as an input for streamflow augmentation by returning wastewater to the Besòs river (Figure 24). The data present descriptions of the effects of streamflow augmentation that distinguish the benefits obtained as NBS, such as the constructed wetlands and the riverside park along the Besòs River, and the potential benefits of WRT for the aquifer.

Figure 24. NBS - Besòs river park in the Barcelona metropolitan area

This case study presents how a challenge related to reduced river flow has improved significantly after the goal of an integrated river basin management was established in 1995, incorporating 25 WWTPs in the Besòs basin area (1038 km^2) (Boada et al., 2018). For instance, WWTPs in the Besòs area currently treat an average of 259.37 hm^3 of wastewater per year, which is nearly half of the AMB total volume (532.29 hm^3), and this ultimately flows into the Mediterranean Sea. The Montcada i Reixac WWTP can treat 72 million liters per day, equivalent to the water consumption of 360,000 inhabitants and associated economic activities (AMB, 2021).

NBS keeps resources in use, as it receives 1 hm^3/year of regenerated waters from the WWTP through the constructed wetlands. As it was mentioned by the government interviewee: "*the wetlands that were built… are taking advantage of the water that comes out of the WWTP, to provide a biological treatment, which shows that a natural solution… can improve the quality of the area that goes in the river*". This integration has benefited the WWTP as a key intervention space for preserving water as a raw material (Nika, Gusmaroli, et al., 2020), the wastewater quality, the Besòs river, and (indirectly) the aquifer. This fact has improved the hydraulic capacity, which is significant in the overall urban water management, as this represents a substantial physical change for the area's landscape.

The riverside park has benefited from the streamflow augmentation, allowing recreational use of the river's banks and fostering synergy between urban public space and urban amenities (Bauduceau et al., 2015). As an added value to urban water systems, streamflow augmentation is based on the interface of a natural process with the WWTP and integrated as a hybrid scheme (Hoffmann et al., 2020). This NBS has served not only for recreational purposes by integrating the urban waterfront with its natural areas, but also to create a public space for contemplation and mobility along the river. The landscape's high multifunctionality results in nearly million visits per year and delivers social benefits, such as physical health (Vert et al., 2019).

For the aquifer, overexploitation was identified as part of a diagnosis of the main environmental effects on the Besòs area in the 1990s (Santasusagna Riu, 2019). According to the entity responsible for integrated water cycle management (*Aigües de Barcelona,* the Barcelona water provider), the aquifer provides 6–10 hm^3/year of the 283 hm^3 required for the metropolitan area. This resource involves the removal of excessive salts and organic matter, which the Besòs water treatment plant accomplishes via nanofiltration and reverse osmosis (Aigües de Barcelona, 2021). In the case of the WRT, according to the academic interviewee: "*the river is the major source of groundwater origin and that interaction of the river, with all the contributions of the treated wastewater discharges from the entire Besòs basin. The 'Pect Litoral Besòs'* (RIS3 project) *is the interface between groundwater and the river.*"

These findings demonstrate that the described actions are linked as a synergy, and that by working in an integrated manner, the social dimensions of livability have benefited: resource loops were kept closed to maximize water use; as a result, resources are kept in use and actively preserve the value generated at the interface of water systems with other urban systems (i.e. public space, mobility, recreation, and health).

Designing out (waste) externalities

Analyses of designing out externality mainly focused on two actions: i) targeting the negative impact for the environmental and social dimensions, and ii) improving the efficiency of resources (value and amount) for their correct valuation. The analysis traced risk management and resource efficiency as indications of progress toward reduced levels of discharge to the environment and reduced social exposure, as well as best value for water use and amounts of (fresh) resources. Data present descriptions that distinguish the deployment of NBS and WRT, because there are no suggestions on interrelated effects for the reduction of externalities.

NBS are the wide-ranging response to flooding risks, which have been addressed by constructed wetlands and the riverside park along the Besòs River. The NBS implementation considered the torrential profile of the river and the management of flooding risk after the 1962 flood, of 2345 m^3/s, to be the last 500-year flood (Tort-Donada et al., 2020). To illustrate this point, the civic interviewee pointed out the relevance of water reuse through NBS for addressing the negative social and environmental impacts as *"… the Besòs was a rainbow-colored sewer. And they (public authorities) said: No, you can't throw it down the drain. So, what are your options? You construct a sewage treatment plant; then, do you discharge treated sewage into the river? Not at all! You reuse the water because it has already been cleaned. That is to internalize, when you practice it, the entire degradation process that results in your productive process; you save as much money as possible on clean industry systems, recycling systems, reuse systems, and purification systems…"*. Previous research has claimed that resource efficiency based on NBS should be given more emphasis; for instance, risk management costs have been avoided because of the green corridor intervention and particularly along the river banks (Barcelona, 2013).

Underground urban infrastructures, such as parking lots and subways, faced flooding risks due to rising levels of aquifer groundwater (Tubau et al., 2017). As the academic interviewee described, this was addressed as isolated actions for technologies development, in which the groundwater potentials were based on the amounts of resources used, defined as the available resources volume (water quantity): *"In the 1970s the industry left, and stopped the* (need for) *consuming water, so the water table caused flooding in the parking lots that were built, …to avoid flooding of these parking lots, years ago the UPC (academy) installed an automatic pumping system, of about 300 or 400 L/S, or 6 to 10 hm^3/year."* This is consistent with the city's overall concern about groundwater resources, as Barcelona was a pioneer in the development of a secondary distribution network for phreatic water (Tubau et al., 2017).

Besides water availability, a shift for a fit-to-purpose water is justified by the potential demand and supply coupling. The WRT emerged to achieve this purpose within the *Pect Litoral Besòs* project (2017-2021), which is based on a quadruple helix consortium of a regional innovation strategy based on smart specialization (RIS3) for urban sustainability research (https://www.besossostenible.cat/)- (Pect Litoral Besòs, 2017). In fact, the WRT has been developed for monitoring river and coastal water quality, to recycle these resources and for exploring more sustainable uses: "*Currently, less than 1% is used for irrigation and 99% goes to the sewer system… So, the initiative* *of this project* (PECT) *was to give a more sustainable use of these groundwaters*."

If supply is classified by water qualities, potential new demand can be identified based on how user consumption patterns and requirements can be coupled to specific use purposes, which reduces costs and unnecessary treatments, and thus designs out externalities. However, the academic interviewee described this process of coupling demand and supply as a challenge that depends on the economic activities settled in the area: "*There isn't much industry left here, it's bad… We are making an inventory… and then we could find users, but on a smaller scale.*" The area's de-industrialization reduced demand for water resources, raising the question of who might benefit from the use of groundwater. As the development of the fit-to-purpose strategy is justified by the merge of demand and supply, potential long-term uses could be related to the Besòs river streamflow (closing the loop as *interface between groundwater and the river*) and the urban metabolic infrastructure, as described by the industry interviewee: "*We* (urban metabolic infrastructure) *have gone from being a peripheral industrial area of extra-radius to urban fabric… we are part of a city management service… that maybe one day we will move out from 2 km from the sea, but at the moment it's not viable.*"

These findings highlight the apparent lack of an integrated methodology for (waste) externalities in the design-out process and the need for a perspective on the nexus among water systems and urban development. The actions and circularity examples for the river demonstrate how it is related to flooding risk and management, with NBS recognized for reducing externalities and avoiding costs (i.e. economic efficiency, cost-effectiveness). However, there is still a valuation gap that includes non-market methods, such as natural capital, human capital, and social capital. For the aquifer, the analysis shows isolated actions and examples of circularity in technological solutions that have improved resource efficiency in the short term. As a result, there is an opportunity to better target negative environmental and social impacts, as well as waste reduction efficiency, to support a correct valuation of designing out externalities.

5.5. Conclusions

In this study, we identified shifts toward SUWM supported by alternative practices. For this, we developed a framework of an interconnected set of analytical categories based on literature of CE principles and water systems, which was used in a case study. This research combines different information sources to provide a general representation of the Besòs river case, focusing on the role played by NBS and WRT in a two-decade process of interplay with the urban water system and its context-specific dynamics. This study contributes to the operationalization of CE by providing an integrated understanding of alternative practices, their uses, the circularity of features and actions, and their implementation and outcome for SUWM.

The results show alternative practices regenerated natural capital through NBS, thus supporting ecosystem health and preserving and enhancing biodiversity and water quality; overall, NBS and WRT aim to prevent pollution and reduce human disruption. The shifts promoted by these actions and circularity features are linked as a sequential process. NBS has been key for repurposing wastewater for streamflow augmentation, which keeps resources in use, while promoting synergies with the public space, for mobility, recreation, and improved health. The shifts promoted by these actions and circularity features work as a synergy. NBS and WRT have been integrated to allow both risk management and fit-to-purpose strategies; using WRT could help to increase the marginal potential and avoid waste of resources. However, these actions and circularity features need an integrated methodology to address the nexus between water systems and urban development, to promote designing out waste externalities.

As these analytical categories are interconnected, their contributions to SUWM reveal how actions and circularity features endorse flexibility and cross-sectoral collaborations. Specifically, flexibility and cross-sectoral collaborations are supported by: i) active monitoring that captures the sequential process of change; ii) communication about the benefits to the lay citizens that emphasizes the synergy among urban systems, and iii) improving accountancy of both the market and non-market values, as a good methodology related to reducing externalities.

These findings imply that both the socio-ecological approach of NBS and the socio-technical approach of WRT contribute to integrating and managing water systems in complementary ways. Further, incremental shifts at the micro-level contributed to a local system integration and more sustainable urban water cycle management; this is important, as alternative practices can dynamically reformulate the problem at the urban systems intersections, allowing the context-specific challenges where these practices take place to be addressed. For instance, the initial input for NBS was to avoid resource degradation in the river, and for WTR, to avoid resource waste in the aquifer; in contrast, the current challenges are related to production and consumption patterns of users, which this in turn depends on the nexus with the activities and uses of urban land, regardless of the technology.

Finally, integrating and managing water systems will require higher levels of collaboration to support a cross-sectoral strategy and flexibility; such a joint effort will be able to address this challenge of urban systems intersections not only in the short term, but also in the long term. Further research could develop a similar analysis, as these findings are limited to one local case study, and additional evidence could better demonstrate the nature of the links used for the integration and management of alternative practices, water systems, and urban development.

6. Citizens perceptions on NBS benefits

Assessing the benefits of nature-based solutions in the Barcelona metropolitan area based on citizen perceptions (Art 3).

Abstract

Nature-based solutions (NBS) address societal challenges, such as risk vulnerability and climate resilience, and provide a potential for local adaptation. Other green conceptualizations besides NBS, such as green infrastructures (GI) and ecosystem services (ES), seem to be useful for indicating the potential of nature in urban climate resilience through the provision of a multifunctional landscape, simultaneous services and benefits and stakeholder participation. The extent to which user insight into usual experiences and practices can contribute to NBS management to improve locally adapted solutions could be further explored as part of the NBS concept. Here, we aim to provide empirical evidence about the usual experiences and practices of citizens with respect to NBS. Further, we will address how this insight contributes to NBS management. This study investigated user perceptions based on a public perception survey, to gain information that can be used for (among other things) locally adapted NBS management. To collect evidence, 114 surveys were conducted with users of the Besòs riverside park, an NBS in the Barcelona metropolitan area. The results show that the NBS users are the citizens living near the area who visit the area frequently, mainly for social, cultural, recreational benefits and for health-related purposes. These findings suggest that conducting surveys at the local level is beneficial for gathering evidence on user experiences, perceptions, and practices with respect to NBS, and that this insight could contribute both to NBS monitoring as well as to increasing user awareness and knowledge about an NBS. Stakeholder participation complements the aim of officially recognizing the Besòs area as a key GI for the water cycle in the upcoming Barcelona metropolitan master plan. User insight and NBS management could thus interact to promote a more localized, decentralized, and bottom-up management strategy.

Keywords

Urban vulnerability; climate resilience; NBS monitoring; Barcelona; Besòs river area

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6.1. Introduction

Nature-based solutions (NBS) belong to an overarching green concept that refers to the innovative use of nature for addressing societal challenges (Dignum et al., 2020). A core idea behind the NBS concept is that, as a place-based intervention, NBS solve different issues through nature-based processes, thereby providing multi-solutions that require the participation of different stakeholders as well as local adaptation for a context-specific response (Dorst et al., 2019). NBS implementations address a variety of challenges, including risk vulnerability and climate resilience to events such as floods, droughts, heatwaves, and rising sea levels. In peri-urban areas, NBS are used for water challenges as a way of addressing the pressures related to climate, risks, and urbanization (Ramírez-Agudelo et al., 2020). NBS provide context-specific results in simultaneous and different dimensions, such as land use planning to support biodiversity (Balzan et al., 2019) and social benefits via positive human well-being outcomes (Beery et al., 2017).

Previous research has established NBS as a comprehensive concept, or "umbrella", for other green concepts (Albert et al., 2019; Raymond et al., 2017). In fact, a close link between NBS with the terms of green infrastructure (GI) and ecosystem services (ES) is frequently documented in the literature (Dorst et al., 2019; Escobedo et al., 2019; Hanson et al., 2019). The relationship between these "green concepts" is interpreted by the role of nature in different processes. For instance, NBS promote the use of nature as a way of providing solutions; GI is a strategically planned network for a multifunctional landscape that delivers ES; and in turn, ES refers to the simultaneous provision of benefits and services of nature for various beneficiaries, including non-human.

Previous research differentiates these concepts by promoting their distinctiveness. Dorst et al. (2019) expose how NBS is characterized by core ideas: i) nature-based; ii) solution-orientation and multifunctionality; iii) integrative implementation; and iv) adaptation to the context. Escobedo et al. (2019) describe GI as a strategically planned network that delivers a wide range of ecosystem services (ES), supported by how the European Union (EU) and the Food and Agriculture Organization (FAO) have defined GI. The authors explain that these organizations consider GI to be a strategically planned network of natural areas (as high-quality areas), as well as semi-natural and cultivated areas, with other environmental features. These features are designed and managed to deliver ES such as to protect biodiversity in urban and peri-urban settings. Belmeziti et al. (2018) refer to ES as the simultaneous benefits and services, in which nature serves to address various issues, such as those related to water, climate, urban, fauna and flora, and social well-being.

Specifically, the literature on innovation based on nature focuses on the link between the NBS concept and the green infrastructure (GI) and ecosystem services (ES) concepts (Beißler & Hack, 2019; Hanson et al., 2019; Mesimäki et al., 2019; Reynaud et al., 2017; Ronchi et al., 2020). Research presents the linkage of NBS–ES by emphasizing climate change (Calliari et al., 2019; Calvert et al., 2018; Pedersen Zari et al., 2020), while links with GI (e.g., GI–NBS and GI–ES) accentuate the spatial aspects of the "infrastructure" in its spatial context, such as land use changes and urban planning (Castelli et al., 2017; Denjean et al., 2017; Langemeyer et al., 2020; Ordóñez et al., 2019; Sallustio et al., 2019; Wild et al., 2017, 2019; Zhang et al., 2019).

Implementation performance is a central aspect of these green concepts as approaches that help to reduce context-specific vulnerability through co-benefits, multifunctionality, and stakeholder participation, which are considered as simultaneous and key features. The co-benefits, which are mainly associated with the ES term, provide services for climate, urban, social, and fauna; multifunctionality, which is derived from the GI concept, is associated with urban systems intersections; and stakeholder participation, which operates primarily through NBS, is a key feature indicating the purpose of active integration of the multiple actors.

The co-benefits term identifies the benefits and services of nature through the ecological, social, and economic dimensions of sustainability, which are usually assessed through ES. The role of nature is differentiated through ES categorization, which distinguishes the provisioning, regulating, cultural, and supporting services (TEEB– The Economics of Ecosystems and Biodiversity, 2011). For instance, co-benefits related to water issues can limit pollution, retain peak flow, recharge groundwater, reduce the volume of water exported from the space, and/or receive and manage water from another space; co-benefits for fauna include providing food and serving as a corridor, habitat, temporary refuges, and resting areas during migration (Belmeziti et al., 2018).

GI, in particular, plays an important role in maximizing the environmental, social, and economic potential of natural capital through multifunctional use, which contributes to resilience. Multifunctionality, especially through GI, is a key advantage for urban life quality (Artmann & Sartison, 2018; Dorst et al., 2021; Säumel et al., 2019). GI and its multifunctional use help to benefit from the environmental, social, and economic potential of natural capital (Belčáková et al., 2019). In addition, multifunctionality contributes to the potential of synergies and intersections of nature with urban systems in peri-urban landscapes (Ramírez-Agudelo et al., 2021). Multifunctional GI facilitates human interactions with nature and its multiple values (e.g., human well-being); for daily experiences, this supports conceptualization such as biophilic cities, for frequent and qualitative contacts with nature (Beery et al., 2017).

The multi-actor dynamics behind implementation processes, such as the participation of different stakeholders, are considered key for NBS mainstreaming and learning. Stakeholder participation relates to the high involvement in NBS of public authorities, followed by civil society, sector-related actors (such as water actors), and business and private representatives (as the least involved actors) (Ramírez-Agudelo et al., 2020). Citizen perceptions aid a wider uptake of NBS, as a transitional path towards its technological adoption (Davies & Lafortezza, 2019). Citizen involvement and stakeholder networks are significant for localized learning processes (Dignum et al., 2020). Teaching interventions can effectively promote knowledge of the territory, thereby increasing the participants' social resilience and their ability to adapt to adversity (Brunetta & Salata, 2019).

Previous research has revealed that surveys are an effective way to gather, analyze, and present the perceptions of different social actors on the use of nature, as well as specific aspects of GI, NBS, and ES. For instance, Balázsi et al. (2021) developed an expert survey to better understand cultural ES related to farmlands in Europe. Ferreira et al. (2022) implemented citizen surveys to assess the coherence of the policies emerging from stakeholder perceptions of urban climate challenges and their preferred NBS, to tackle them in two cities in Portugal.

However, how insight into the usual experiences and practices of users can contribute to NBS management for locally adapted solutions needs to be further explored. The present study uses citizen perception surveys to provide empirical evidence for potential local support, in order to answer two key questions: i) What are usual experiences and practices of citizens with NBS? and ii) How can this insight contribute to NBS management? We present a qualitative analysis of citizen perceptions at the site of the Besòs river restoration in the Barcelona metropolitan area. Through their participation in the survey, respondents have provided a descriptive input to answer the guiding questions of this study.

This intervention is examined from the standpoint of NBS; however, the Besòs restoration was a ten-year process (from 1996 to 2006), in which constructed wetlands and a riverside park were implemented to address mainly water challenges (Tort-Donada et al., 2020). As a first step, we use the survey results to describe the Barcelona case, based on the citizens' usual experiences and practices and their perceptions of NBS in terms of services and benefits, as well as on characterization of various user profiles. In a second step, we discuss the citizens' usual experiences, perceptions, and practices as contributions to NBS management, as it could complement the aim of officially recognizing the Besòs area as a key GI for the water cycle in the upcoming Barcelona metropolitan master plan (AMB, 2020). In a third step, we consider how NBS management could be beneficial for users.

This study of user perceptions is relevant for NBS management, urban planning, and local adaptation strategies, all of which contribute to climate resilience (Dorst et al., 2021). This research aims for a better understanding of user perceptions by providing evidence that validates their insight into NBS adoption as shaped by local conditions, as a transitional pathway for what has been named "community-empowered placemaking combined with 'ecosystem literacy'" (Davies & Lafortezza, 2019). Surveys, among many other tools, could facilitate the purpose of adding value to the information gathered for NBS management—for example, for facilitating citizens involvement and informed acceptance (or contestation) for wider uptake and learning.

6.2. Materials and methods

The study used surveys to better understand public perception of a specific NBS case in the Barcelona metropolitan area. User insight is key to learn about several aspects for NBS implementation, such as its acceptability, contestation, and involvement as a transformational pathway. Previous studies have shown that surveys are useful for presenting perceptions on specific nature-based aspects. Descriptions from the historical background were then used to explain the circumstances of the intervention (from 1996 to 2006) and the problem-solving feature. Surveys were used to collect the public perception of the intervention, which provides various benefits from natural solutions along the course of the Besòs river in the Barcelona metropolitan area (See Figure 12).

Case study

To avoid redundancy, the case study description has been omitted. Please see the overview of the research area (Section 3.3).

Survey content and approach

Data used in this study were collected through detailed surveys during six campaigns in June 2021. Participants were asked to complete a 15-question survey (Q1-15) divided into three sections: (I) to describe their experience and their visiting practices; (II) to examine their perception of NBS services – benefits; and (III) to characterize the user profiles.

In Section I, the questionnaire aimed to identify the types of visits, visit habits/patterns, and changes in these habits due to the COVID-19 quarantine "of each user surveyed". The general-aspects question (Q1) asked about frequency of visits, usual day(s) of visitation, usual schedules, and time spent in the area. The questions on visiting habits/patterns identified: i) how participants usually access/arrive to the area (Q2), by giving them the option to choose from four transport modes, or to add another response; ii) whether they came alone or accompanied during the visit (Q3); and iii) the date they first visited the park (Q4). Two questions addressed changes in their visits because of the COVID-19 pandemic (Q5), and their observation of changes in park visitation during 2020 (Q6).

In Section II, the questionnaire aimed to examine the users' ideas related to NBS services and benefits as ES and disservices. Participants were asked to select three reasons for their personal motivation/benefits for visiting the area, from ten options. The options given were based on the most typical activities that can take place in an urban park. However, the option of "other" was available for another type of motivation/benefit (Q7). They were then asked about their level of agreement with the ten statements framed in the sentence: *"For neighbors, an important aspect of the river park is that it improves…",* including NBS services and benefits (Q8). Users were then asked to subjectively rate how important they considered the previous ten aspects to be (Q9). The final question aimed to identify the disservices, based on a selection of three (out of five) options of the most problematic aspects for the neighbors (Q10).

Section III characterized the user profiles based on gender identity, age, birthplace, postcode, and current employment situation (Q11-15), respectively. Despite the fact that the surveys did not include open-ended questions, some participants indicated specific aspects of their visit, which were noted by the interviewers, included as field observations in the results.

Data collection and analysis

The aim of this study was to survey as many people as possible, and of any profile, in order to have a representative sample for the user perception analysis. The survey was conducted from a Thursday to a Sunday in June 2021, during both the mornings (9 AM to 11 AM) and the evenings (5 PM to 7 PM), to include groups of people who visit the park at different times during the day. Thursday and Friday were chosen to represent the group of users who visit the riverside park on weekdays, while the two weekend days, to represent users who visit it on weekends/public holidays. The survey was carried out at the end of spring/beginning of summer when the weather in Barcelona is typically pleasant and sunny, with people probably more inclined to be outdoors. It should be noted that social life had not returned to normal following the COVID-19 pandemic restrictions in the Barcelona metropolitan area; for example, there were still mobility restrictions and night-time curfews (from 10 PM to 6 AM).

Data were analyzed following the questionnaire order as empirical evidence for user perceptions of the Besòs riverside park as an NBS implementation. The first section was analyzed to identify user experiences and practices in the park; the second section, to examine the perception of the NBS services, benefits, and disservices; and the third section, to characterize the user profile based on their gender, age, birthplace, postcode, and employment situation.

All user responses were classified, and graphed using Microsoft Excel. We obtained 114 responses from users, 37 of whom identified as women, 76 as men, and 1 did not respond. Once all data had been processed, the results were represented in pie charts, as a visual tool for effective understanding of the survey responses. The surveyors (who are the co-authors NR, MB, and ER) played an active observer/listener role on-site during the survey campaigns, which aided in better understanding the citizen insights. The additional notes taken during the surveys based on the participants´ comments were used for the Results and Discussion as complementary information (presented in italicized text).

6.3. Results: User perceptions and profile

User experiences and practices

The first section of the questionnaire identified the citizens' usual experiences and practices (Figure 25). For the general aspects of the visits (Q1), most respondents were frequent users, visiting the riverside park three or more times per week (70%), and their visits were comparable on weekdays and weekends. Almost half of those surveyed (47%) reported that the best time to visit the riverside park is in the mid-afternoon (around 6 pm), with the vast majority spending 1 to 2 hours there (61%). In response to the questions about habits/patterns during their visits, most of the participants responded that they usually walk to the area (81%; Q2), and almost half of them visit the area alone (47%; Q3). Interestingly, the time since their first visit to the Besòs riverside park varied (Q4): a large proportion first visited the riverside park within the last 5 years, with 34% from 1 to 5 years ago, and 16% within the past year. However, 21% visited it for the first time nearly 20 years ago, and some even stated "*when the park opened*".

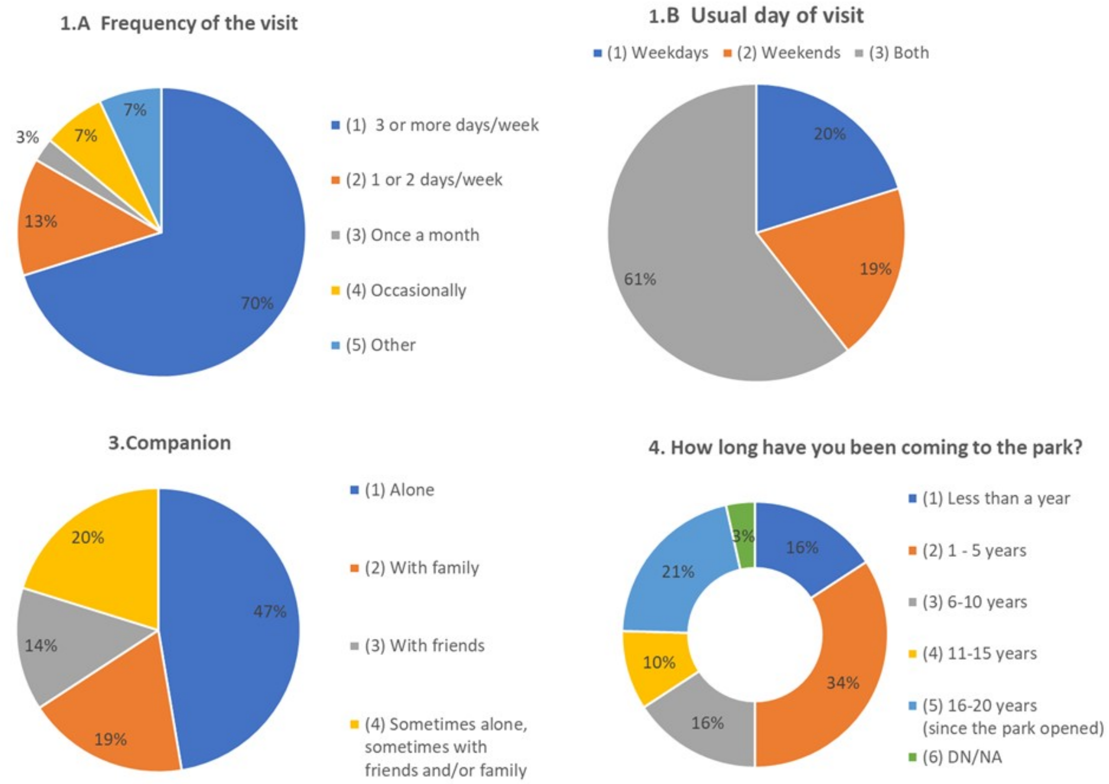

Figure 25. Responses to citizens' usual experiences and practices - section I (Q1-4)

The responses to the two questions concerning changes in their visiting habits revealed that a significant majority of citizens (79%) visited the park with the same frequency (45%) or even more frequently (34%) during the COVID-19 pandemic (Q5 and Q6; Figure 26). In addition, most of them (71%) observed changes in the park's influx during the 2020 pandemic, and their perception is that *"people were drawn to the park as soon as the stay-home confinement ended"*.

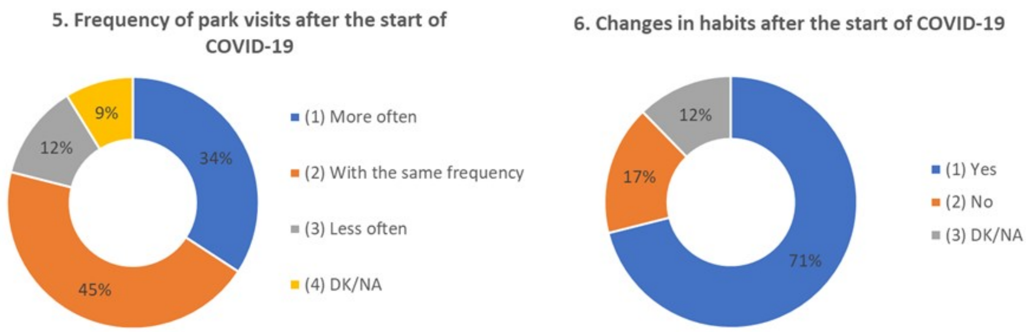

Figure 26. Responses concerning the COVID-19 pandemic - - section I (Q5 and 6)

Users insight to the NBS services, benefits, and disservices

In Section II, the questionnaire examined the user perceptions related to NBS services and benefits as ES, as well as to its disservices. When asked to select three reasons for their personal motivation/benefits for visiting the area (Q7), the participants' most common responses were: to go for a walk; for health-related reasons; to be in a wide, open space; and to relax and reduce stress. The survey question about NBS services and benefits was problematic for respondents. When asked about their agreement with statements framed under the sentence: *"For neighbors, an important aspect of the river park is that it improves…"*, their responses seem to express that all the output measures of the river park were equally important to them (Q8; Figure 27).

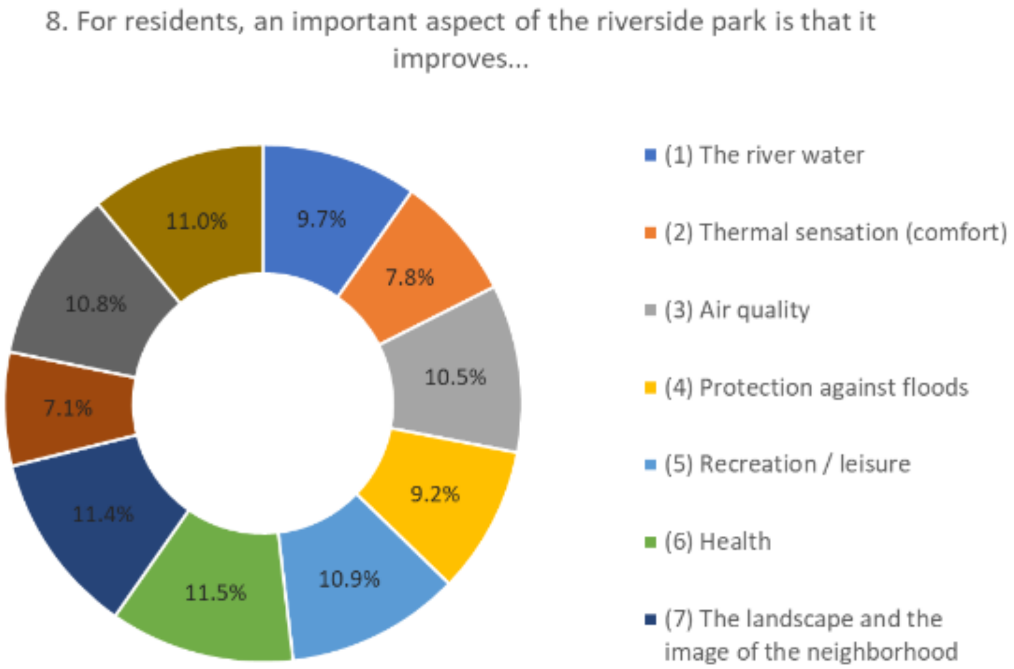

Figure 27. Responses to question 8 - services and benefits

Thus, responses about the importance of the services and benefits (Q9) were difficult to assess. Also, as the park is mostly visited by neighbors, especially older people commented on how it used to be: *"the park is much better than before—they take care of the green area and the smells"*, revealing their knowledge and interest in the presence of biodiversity. The question about disservices was quickly answered (Q10): more than half of the respondents considered that none of the aspects asked were problematic for the riverside park; in contrast, they indicated that mosquitoes, rodents, trash, dog excrement, and too few services in the park (e.g., toilets, beach bar, equipment) were considered to be the most problematic. For the latter, the neighbors surveyed frequently expressed that the need for bins, benches, water fountains, and toilets was *"urgent!"*

User profiles

In Section III, the analysis of the profile of those surveyed showed that the park is mostly used by neighbors, who according to their postcode are residents of Sant Adrià del Besòs, Santa Coloma de Gramenet, Badalona, and Barcelona. They represent various ages, but mainly older than 30 years (74%) (Q12; Figure 28). The survey was completed by both men and women, but as a result of a random sampling strategy, these results show a gender disparity (with more men participants than women).

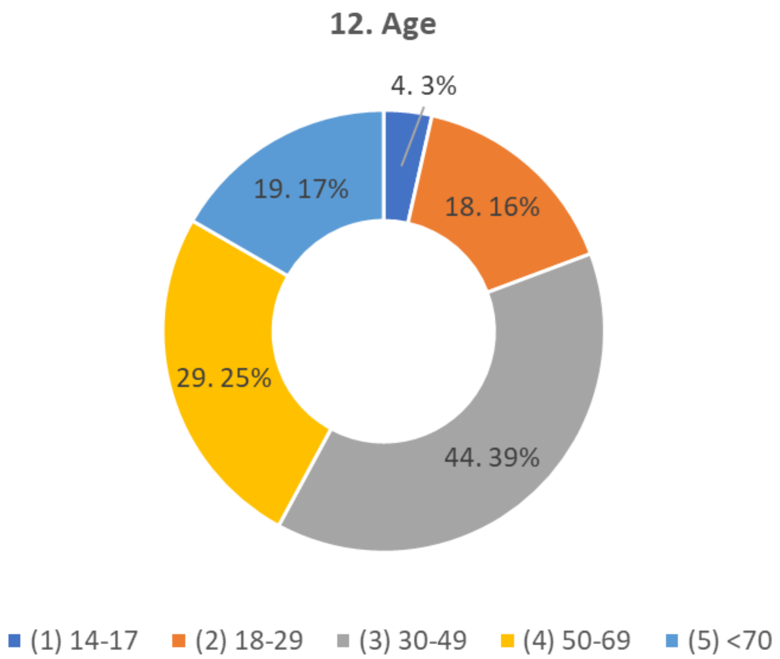

Figure 28. Responses to section III (Q12) –Users age

Two-thirds of users were born in Spain, and the remaining one-third were born in Bangladesh, Bolivia, Chile, Colombia, Ecuador, France, Italy, Morocco, Pakistan, Paraguay, Peru, Dominican Republic, United States, or Venezuela (Q13; Figure 29). The sample of the 114 respondents was significantly heterogeneous in terms of origin-of-birth and age.

Figure 29. Responses to question 13 - 15, about countries of citizen's birthplaces

6.4. Discussion: Citizen insight and NBS management

These findings indicate that the use of citizen perception surveys is useful for two central purposes: first, it gathers evidence about how users perceive the NBS, and second, it identifies how this citizen insight could contribute to NBS management, which is the focus of this discussion.

Citizen insight as contributions to NBS management

The frequent use of the area by citizens is driven by various uses and motives to visit the riverside park, highlighting the importance of the NBS in its context—here, as a multifunctional green infrastructure that has the form and the (spatial) conditions for recreational, social, and cultural purposes. In addition, users seemed to be informed about the risk vulnerabilities of the area, especially the ones who were long-term users, as they could provide a 'before-and-after' perspective. However, users seemed mostly unaware of the operationalization conditions established in NBS management to reconcile the area as an urban park, in particular as the precaution and adaptation measures follow (non-human) priorities, i.e. access restrictions, lack of furniture, lack of shade (from trees), etc. Awareness and knowledge about the delivery of co-benefits seem to depend on the users' recognition of how the NBS addresses risk vulnerabilities, which will probably be a central feature for using the citizen insight to support NBS monitoring. This identification of awareness and knowledge is considered a reference of the experiential learning on the problem and solution orientation of NBS (Dorst et al., 2019).

During the survey's campaigns, we observed that riverside park use is concentrated on one bank at a given time—for instance, by people seeking sunlight exposure in the mornings (right side bank–BCN) and protective shade in the afternoons (left side bank–MiR/SC/SAB). Also, respondents commented that the right bank (BCN side) is affected by the proximity to the highway B-10 (*Ronda litoral*), and that the left bank of the river (MiR/SC/SAB) was preferable: *"it's better in terms of the infrastructure"*. The left bank has a pathway that is divided into a bike lane, as a fast-moving corridor between the municipalities, and a pedestrian lane. However, conflict can emerge in this open and wide space, because bikes cross or turn faster than they should; several respondents commented that the bike lane should be better marked with signposts, as "*many cyclists do not respect the lanes*".

The spaces beneath the bridges crossing the river serve as climate refuges in this search for thermal comfort. In particular, the interaction of thermal sensation with spatial conditions, such as a shadow from sunlight or exposure to it, enhances the experience of users and creates routines in the use of the riverside park as GI. These spaces, for example, provide shade for a variety of activities, such as salsa dancing classes, teaching children to ride a bike, and social gatherings. This finding shows that the riverside park provides thermal comfort through its multifunctionality and infrastructure hybridization, as the delivery of ES through GI. This recognition reinforces the argument of a previous study about green roofs as urban GI, in which thermal regulation was highlighted as a main ES for Barcelona city (Langemeyer et al., 2020).

One of these climate protected spaces, in particular, is used for extended meetings of a specific social group. Interestingly, when surveyed, some participants of this specific group responded that they were visiting the park for the first time; for this reason; their responses could be the most indicative of a lack of awareness of the intervention. Consequently, a participatory approach for increasing awareness of NBS to its users may be an advantage, because in contrast to its multifunctionality, the problem-solving feature behind the NBS is not implicit knowledge gained via experience.

Users are aware of the influence of the user behavior and park use, as well as the differences that are likely to cause conflict among different user groups. For instance, participants described conflict related to other's behavior and the use of the park, such as alcohol bottles and similar acts of incivility, and the lack of police action. It could seem contradictory that many neighbors are aware of the flood risk, control access, and warning alarm system, yet respond to the disservice question by stating that "*the park's timetable is inconvenient*," and that the lack of urban furniture is unjustified (Figure 30). Users also seem unaware of the river bank management and differential lawn treatments, for which citizens have expressed how its "*lack of maintenance*" interferes with their occupation of the space, or how it could be improved because *"the irrigation schedule is out of control… and they should water the lawn when the park is closed to avoid puddles"*.

Figure 30. Besòs riverside park in Barcelona metropolitan area.
(A) Access control and the alarm system; (B) the right river bank, which corresponds to Barcelona (BCN); and (C) the left river bank as a continuum (MiR/SC/SAB).

The river's intervention has advanced in the recognition of the multiple actors involved and in specific efforts for integrating various stakeholders, which are central for an NBS standpoint. In particular, stakeholder participation, and especially that of citizens, could be beneficial for a more coherent development of NBS, as citizen participation was not considered an input during the river restoration design (Tort-Donada et al., 2020). The Besòs Consortium, which is the organization in charge of the NBS management at the local level (https://consorcibesos.cat/), has implemented different actions that have enhanced the NBS in terms of its management and its innovation development. These actions have benefitted from the multi-actor dynamics supporting NBS, and in particular, from surveys that highlight user perceptions, communication campaigns for knowledge and learning, and plans for coordinated action and stakeholder networks.

In 2015, surveys were carried out at the riverside park to determine public perception on management conditions, which gathered evidence to confirm maintenance acceptability as well as inputs for its enhancement. Because it is a canalized river, different expositions, such as knowledge- and innovation-related activities, have been implemented along the riverside 'walls' in order to enhance the user experiences and recreational needs with knowledge and learning. For instance, in 2018, the 'The Besòs 2017: a photographic uprising' presented a photography exposition on the river's transformation, while the 2019 exhibit on 'Biodiversity of the Besòs: birds of the river' was seen as an effort to raise awareness about the process of change and the co-benefits of biodiversity (e.g., as bird watching activities) that highlight the benefits of teaching and learning activities in-place (Brunetta & Salata, 2019).

In 2021, an innovation advance was developed through a pilot for other NBS types, such as the construction of a green-wall pilot along the riverside, implying the resolution of several challenges for further NBS adoption. Because the area is prone to flash flooding, the green-wall elements were designed as fixed to ensure a risk-free implementation, and the use of nature called for the need to be creative about watering a wall, as well as the users' acceptance of the species used expressed in their willingness and behaviors for conserving it. In the same year, the promotion of the Besòs peri-urban experiences was implemented, as an action in the '48 hours of agriculture and urban greenery' as part of Barcelona's activities as the World Capital of Sustainable Food 2021, which may benefit the area from the (future) support of different stakeholder networks (Dignum et al., 2020).

For this purpose, increased commitment to citizen participation could stem from urban experimentation and/or social innovation practices, in which active users and beneficiaries promote "the right to shape the city using human initiative" (Hollands, 2015). Similar innovative experiences in other contexts have shown the development of tools to help cities and their urban residents meet their recreational needs through better-informed decision-making, such as Bremen's *meingrün* application (https://app.meingruen.org/). The Web app was developed to provide citizens with solid information regarding the location of green areas within the city, their quality and amenities, as well as their reachability, within the 'meinGrün project' (Leibniz-Institut für ökologische Raumentwicklung (IÖER), 2020).

Management for increasing user awareness and knowledge about NBS

The findings show that, in the Besòs, the NBS endorses the availability of a multifunctional landscape that supports concurrent activities (planned or informal) carried out regularly during the late spring-early summer (June as the period surveyed). This multifunctional landscape corresponds to the users' interest in active mobility (co-benefit) as one of their primary motivations is walking, emphasizing their motivation to visit the area for physical and mental health benefits (Vert et al., 2019). Because access to use the riverside park is restricted at night, in order to control flooding risks and security issues, the citizens' daily use of NBS add to the 'multifunctional landscape by operating on a timetable' as a feature that could be monitored for its management. The findings suggest that, at the local level, the interaction between users and NBS could be considered as an information-supported routine, allowing for a closer interaction, as a two-way information exchange, between users' insight and the NBS management.

This interaction is useful for facilitating NBS management with input by citizens, as it can support the efforts for precaution and adaptation to a changing environment. In addition, a multidisciplinary integration at a local level could further consider citizens as part of the expert users. User insight could contribute to NBS monitoring, for example, with key information on daily maintenance needs, which could be used for informing about risk vulnerability and/or for contrasting user experiences, perceptions, and practices, with the priorities established for precaution and adaptation. Alternatively, NBS monitoring could provide useful information to different stakeholders, including citizens, about the biotic conditions shaping NBS conservation and maintenance. This interaction could be facilitated by a variety of on-ground tools, such as urban experimentation and/or social innovation, which will most likely transform the existing and dominant practices of NBS (Loorbach et al., 2017).

An approach to NBS management that interacts with user perceptions about the waterfront renaturalization could lead towards its recognition as an actor playing a role for a more local, decentralized, and bottom-up implementation. Thus, urban experimentation and/or social innovation can be used as means of recognizing how this interaction may have significant implications for a just and a hybrid NBS governance (Toxopeus et al., 2020).

In the Besòs case, an increased participation is required to ensure its acceptability, as citizen insight has disclosed concerns along NBS implementations related to management activities. For instance, monitoring user perceptions can facilitate collaborations, and avoid contestations, about priorities in daily practices, e.g., bike mobility vs. walking for health and recreation, and/or wetlands management for biodiversity conservation and water quality. Also, the Besòs riverside park receives nearly a million visits per year (Vert et al., 2019); here, the citizen insight that we obtained may be representative of these visitors and provide information that reveals gained knowledge, which gradually enhances the role of citizens as expert users of the intervention.

This promotion is likely to raise public awareness and knowledge that support nature in urban planning, such as the integration of NBS management (including ecosystem services) as the non-human priorities and disservices. Awareness about this prioritization could reconcile the ecological purposes and social expectations for a coherent management and services delivery. Overall, this will aid to scale up GI and to broaden NBS adoption, as a transitional pathway in which its capacity is community-supported, to 'rival, replace or combine' gray infrastructure (Davies & Lafortezza, 2019). Accordingly, stakeholder participation should be further endorsed in light of an upcoming update of the Barcelona metropolitan master plan, which aims to officially recognize the Besòs area as a key GI at the metropolitan level, primarily for the water cycle (AMB, 2020).

Further research is needed to determine whether the information used for decision-making in NBS management is consistent with the information available to users, as well as the various stakeholders. This could validate, for example, how specific informative actions aimed to increase their awareness and knowledge on NBS benefit user perceptions. For this purpose, studies could make use of various methods to gather evidence on users' perception, including traditional survey campaigns with qualitative or quantitative orientations (Ferreira et al., 2022), or more sophisticated approaches for real-time evidence, such as citizen science, serious games, or experimentation for education and training through urban living labs (von Wirth et al., 2019). Evidence for tools that facilitate the resolution of climate adaptation concerns is relevant and urgent for the local level, particularly for the information exchange on experiences, perceptions, and practices, especially in light of controversies and uncertainties, such as the mediation of 'sustainability accounts' for urban reconfigurations (Hodson et al., 2017).

6.5. Conclusions

This analysis characterized the case of the Besòs river in the Barcelona metropolitan area based on citizen perception surveys to identify the citizen experiences and practices, their user profiles, the user perceptions of the NBS, as well as how this information could contribute to NBS management. The survey results show that the area is mainly used by citizens living near the area, who visit the area frequently, mainly for social, cultural, and recreational benefits related to health-related purposes—thus profiting from the simultaneous benefits and services provided by the multifunctional landscape and infrastructure hybridization. However, increased interactions based on user insight can facilitate awareness of the NBS features and biotic management. Further endorsement of stakeholder participation could better highlight to the general public how an NBS can help to ease ecological, social, climate risks, and urban-related vulnerabilities.

This analysis underscored the idea of interactions, as user insight is important not only for identifying the experiences, perceptions, and practices of beneficiaries, but also for NBS management. As a transformative governance approach, tools and practices can support a more participatory structure to integrate NBS into urban planning, and collectively shape a more resilient city. Limitations of this study include only taking surveys during June, which corresponds to the late spring/early summer, which is arguably the nicest season in the region and could introduce a bias into respondents' opinions. Therefore, additional campaigns during other months/other seasons could be conducted to determine whether there is seasonal variability in responses. In addition, follow-up studies could make use of an improved version of the survey or another method of gathering citizen insights, with qualitative orientations for including non-categorical questions, or quantitative to measure the users' impact.

Tools that enable citizen participation by integrating citizen insight into urban planning are important, and are urgently needed, considering the changes in climate and the net-zero strategies for local adaptation deployments. However, monitoring citizen perception remains an open topic for urban climate challenges, as both short- and long-term processes can facilitate NBS management. Urban experimentation and/or social innovation approaches could also be used in implementing NBS to establish greater commitment and trust, to determine who should be involved, when, and in which positions, and to create a more local, decentralized, and bottom-up management strategy.

7. Citizens participation in urban reconfiguration

Brownfield redevelopment in the Barcelona metropolitan area: Implications of a non-binding participatory practice for sustainability transitions (Art 4).

Abstract

Brownfields redevelopment is an alternative for a sustainable built environment because it addresses concerns on derelict, contamination, and vacant land occupation. Accordingly, different 'urban sustainability accounts' as understandings endorsed by multiple actors interpret, negotiate, and coordinate the vision of a sustainable built environment. A better understanding of the process via which urban sustainability accounts shape and inform urban reconfiguration through a non-binding practice in urban planning could be further explored. For this purpose, this study provides empirical evidence of a brownfield redevelopment in the Barcelona metropolitan area, during the formulation phase of a littoral master plan. The analysis described its public engagement as: i) model, as a non-binding participatory practice within the 'The Three Chimneys' process; ii) subjects, as the participants involved; iii) objects, as the urban sustainability accounts and its mediation, to inform and shape the metropolitan littoral. Participatory practices on derelict and contaminated industrial areas along waterfronts appear to be useful for (re)defining urbanization as an option for a sustainable built environment, rather than a predetermined goal of participatory processes to address climate-related pressures. More reflexive participatory practices are means for broader understandings of sustainability and for co-creating open-ended processes of urban experimentation for urban sustainability transitions.

Keywords

Transitions; Gentrification; Nature-based solutions; Competitiveness; *Litoral Besòs*

Manuscript under review in the Journal of Environmental Science and Policy (submitted on the 2022/01)

7.1. Introduction

Brownfield redevelopment has been long considered as an alternative to avoid vacant land occupation, while addressing concerns of derelict and contamination of a sustainable built environment (Wright, 1997). Cities, as socio-technical systems, entail an interdependent interplay of infrastructures, people, and rules (Geels, 2004). Addressing societal challenges such as climate change, urbanization, and social cohesion calls for integrating existing solutions into systemic responses, in which urban areas are relevant arenas for transforming current urban systems towards sustainability (Hölscher, Frantzeskaki, & Loorbach, 2019).

Research on urban transition shows that the vision of a sustainable built environment is established through the mediation of the different understandings of 'urban sustainability accounts' endorsed by multiple actors (Hodson et al., 2017). Urban transitions research has identified innovation in urban systems as the endorsements of alternative practices to shifts in environmental, technical, and social dimensions, as presented for example in water systems as shifts towards a more sustainable urban water management (Ramírez-Agudelo et al., 2021). These shifts are delivered through different interventions in physical infrastructures and institutional responses, linked to concrete efforts for innovation, which deliver outputs and outcomes for experimentation, learning, and scaling (Luederitz et al., 2017). In fact, cities play a fundamental role in fostering experimentation by providing a supportive context or the emergence and take-up of (disruptive) innovation as potential transformative change agents (Fuenfschilling et al., 2019).

However, in the transition towards a more sustainable urban living, the tensions (and/or endorsements) of new practices call for exploration on the contextual issues of sustainable development (Martin et al., 2018). These issues could be exemplified, for example, by how urban planning defines the (new) spatial and temporal rules governing the interaction of physical infrastructures and citizens' concerns about their territory's future (Fainstein, 2010). By using empirical evidence from a non-binding participatory process during the formulation phase of a brownfield redevelopment master plan (PDU Front Litoral), which aims to consolidate the Barcelona metropolitan area littoral (Generalitat de Catalunya, 2018). In this sense, the models of participation in urban planning and the implications that these practices have in the urban reconfigurations could be further explored.

This analysis contributes empirical evidence on how a non-binding participatory process influences urban sustainability accounts, with implications as an overall process that supports or restrains an urban reconfiguration, as the urban experimentation required to form the systemic solution and 'disruptive' innovation (Loorbach et al., 2017; Luederitz et al., 2017; Wolfram, 2016). Empirically, this study examines a non-binding participatory process held in the Besòs Sea Front (Barcelona Metropolitan Area), for its better understanding as objects of learning by asking which urban sustainability accounts shape and inform the urban reconfiguration?

Methodologically, this analysis uses a conceptual framework as a tool developed within the research field of urban sustainability transitions. To inform the conceptual framework, the analysis describes the non-binding practice as the public engagement through the characterization of the subjects as participants, the objects as the issues exposed as urban sustainability accounts, and the participatory practice models and experiments as the normativities of democratic engagement. Then, the analysis serves to discuss how these accounts inform and shape urban reconfigurations by i) competing; ii) co-existing; and iii) complementing mechanisms (Chilvers & Kearnes, 2019; Hodson et al., 2017).

7.2. Conceptual framework

Research on urban sustainability transitions could be carried out for a better understanding of the process of change, from various and complementary perspectives. Previous studies have explored the multiple actors' dynamics and the relationship between participatory practices in sustainability transitions, highlighting the concepts of public engagement and forms of reconfiguration (Chilvers & Kearnes, 2019; Hodson et al., 2017). This conceptual framework for the analysis of non-binding participatory practices aims to be as an opportunity to identify the socio-technical elements involved in achieving the desired effects of addressing societal challenges (Luederitz et al., 2017).

Public engagement for sustainability transitions

Research on reflexive participatory practices in sustainability transitions proposes the notion that public engagement is co-produced, relational, and emergent; as models and normativities of participation could be distinguished as experimental, co-produced, and in the making; or in contrast, as fixed, pre-given, and have ready-made perspectives (Chilvers & Kearnes, 2019; Chilvers & Longhurst, 2016). This research has advanced by 'opening up and comparing' the diverse and interconnected forms of participation that represent wider socio-technical systems to be 'purposefully reflexive' about the potential to expose reflexivity, humility, diversity, responsibility, responsiveness, and experimental virtues and qualities. In this sense, it has been considered that the analysis of the procedural formats of public engagement is key to identify the objects as the issues, the subjects as the participants, and the participatory practice models and experiments as the normativities of democratic engagement. Considering the objects as the issues under discussion as the multiple understandings of sustainability could aid in a better understanding of the forms of reconfiguration (Hodson et al., 2017).

Forms of reconfiguration: Urban sustainability accounts

As an analytical focus within urban transitions research, forms of reconfiguration are likely to be based on three dimensions: socio-technical arrangements, forms of urban governance, and urban sustainability accounts (Hodson et al., 2017). For the latter, the key research issue is to understand how multiple accounts of sustainability are interpreted, negotiated and coordinated (or not), and to determine what accounts of sustainability become dominant in shaping experimental processes (objects) and who is promoting them (subjects)? Hence, in any city, multiple actors (subjects as participants), through their different understandings or 'urban sustainability' (objects as issues), endorse the accounts to become dominant in informing and shaping urban reconfigurations, through specific practices (models as the normativities of democratic engagement).

These accounts basically expose the concerns with 'urban sustainability' (the objects of public engagement), which are likely to be built on multiple, often competing, co-existing and complimentary negotiations and fusions. 'Competing' recognizes struggles between new vs. new or new vs. old socio-technical arrangements in which the actor's concerns are opposing. 'Co-existing' exposes parallel and independent socio-technical arrangements with non-conflictual concerns. 'Complementing' shows the link between new and old socio-technical arrangements that have been beneficially merged, with mutually reinforcing concerns.

A vision of a sustainable built environment is promoted by multiple actors (participants), by accounts (issues) mediated through competing, co-existing, or complementing mechanisms (dominance). To interpret, negotiate, and coordinate these urban sustainability accounts, a better understanding of their implications is required, in addition to a comparative understanding of these issues across cities (Hodson et al., 2017). These concepts are integrated as a conceptual framework for guiding the analysis of the participatory practice for urban transitions (Table 16 and Figure 31).

Table 16. Framework for non-binding participatory practices

	Element and description	**Function**	**Descriptors**
Model	Models and normative of the participatory practices in urban planning	Process characterization	Model of participation (non-binding) as practices and formats that can be 'fixed, pre-given, and ready-made' or more 'experimental, co-produced, and in the making'.
Subjects	Participants' identification based on the quadruple helix model and the different stakeholders' roles in the promotion of the urban sustainability accounts	Identification (QH)	The public authorities (GOV); the civil society or citizens (CIV); the academia or research representatives (UNI), and the industry or private actors (IND).
		Roles	Leading the process (formulators, leaders, co-creators, deliberators); Involved (active attendants, passive attendants, and absents); and who benefits from its results (beneficiaries).
Objects	Analyzing reconfiguration as the dynamics of the multiple understandings of urban sustainability.	Opposing	Competing understandings and orientations for sustainability goals
		Non-conflictual	Parallel and non-conflictual understandings and orientations
		Reinforcing	Mutually reinforcing or comprised through issue linkage between alternative sustainability understandings and orientations

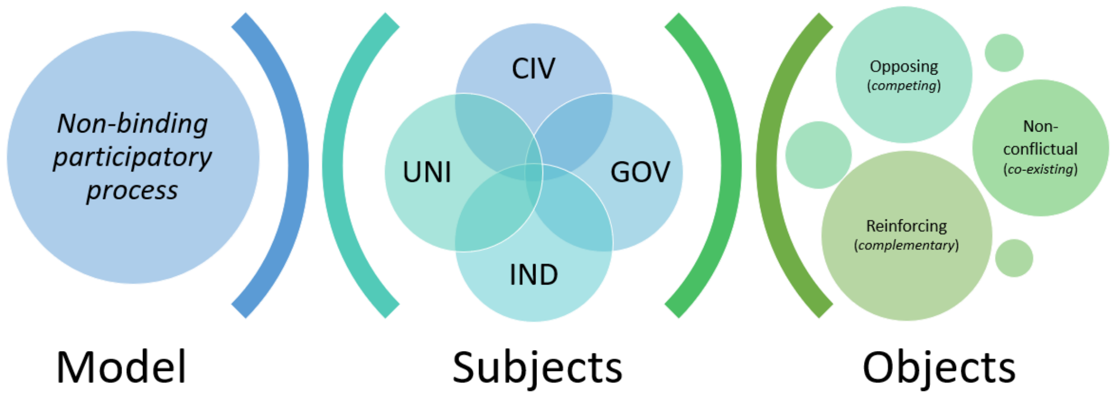

Figure 31. Representation of the conceptual framework

7.3. Materials and methods

This research is based on a case study of participatory practices in urban planning to further explore its implications in urban sustainability transitions research. Empirical evidence is used from a non-binding participatory process during the formulation phase of a brownfield redevelopment master plan of the *Tres Xemeneies* (*PDU Front Litoral*) in the Barcelona metropolitan area (Generalitat de Catalunya, 2018) (Figure 32).

Figure 32. Location of 'The Three Chimneys' brownfield

(A) Location of the Seafront with respect to the Besòs riverfront. Source: Google; and (B) Photograph of the Three Chimneys' brownfield area from the river Besòs; (C) Photograph of the river final section; (4) Photograph of the current façade of the Littoral Besòs. Source: Author.

The master plan aims to consolidate the Barcelona metropolitan area littoral, as the redevelopment corresponds to 32 hectares of industrial land in the Mediterranean Sea waterfront. In particular, the area was the location of three

Chimneys, a coal-energy plant which is considered a XX century heritage and icon of the area, representing the link between energy production and the industrialization process of Catalonia (

Figure 33).

Figure 33. Images for the brownfield area. Source: Consortium Besòs.
Images of the Tres Xemeneies participatory process's dedicated website (http://frontlitoral.cat/)

During the non-binding participatory process, data was collected to gather the stakeholders' arguments within the master plan formulation (September 2018 - January 2019) and analyzed regarding the conceptual framework presented in section 7.2. Participant observation was conducted to follow and analyze the participation that was encouraged in the process through six (6) encounters, in the formats of seminars and sessions, which offered specific information related to the master plan formulation. Also, the use of content-analysis on the documents disseminated helped to identify the key actors involved, their roles, and to gather their specific perspectives not only on the master plan formulation process, but on the area and the initiatives for development. An important aspect to highlight is that all the information of process is available as a complete report on the participants deliberation (Consorci Besòs, 2018).

The data of the participatory process was analyzed to answer to the guiding question of which accounts of urban sustainability inform and shape urban reconfigurations. This purpose is achieved by the use of the conceptual framework in the analysis of the non-binding participatory practice in the Barcelona case in terms of the subjects, objects, and models. These procedural formats of public engagement for 'reflexive participatory practices' proposed by Chilvers & Kearnes (2019), helped to recognize the urban sustainability accounts as the multiple understandings and the mechanisms of: competing

by opposing concerns, co-existing by non-conflictual concerns, and complementing by reinforcing concerns developed by Hodson et al. (2017).
The models of participatory practices and experiments refer to the characterization of the non-binding participatory process as an open phase for stakeholder's engagement within the urban master plan formulation. The subjects were identified as the multiple stakeholders involved in the process and their role(s) along the participatory practice based on the quadruple helix concept. The objects of public engagement, as the main findings, were acknowledged as the issues mentioned related to the research focus on brownfield redevelopment: land occupation, contamination, and derelict in the brownfield transformation, to identify the dominant accounts of urban sustainability. As a result, the discussion focused on the implications of this participatory practice for a more sustainable built environment, and the analysis concludes with a reflection on the overall process's implications for urban reconfigurations and transformative urban planning practices.

7.4. Results

Which urban sustainability accounts inform and shape urban reconfigurations? To answer this question, the analysis followed the conceptual framework, to identify, in Three Chimneys' brownfield redevelopment in the Barcelona metropolitan area, the public engagement as the procedural formats of models, subjects, and objects.

Model: The non-binding participatory process as a phase of the brownfield master plan

The model of participatory practice is a non-binding participatory process within the formulation phase of an urban master plan, which included an informative session, a main stage of deliberation, and feedback, as part of the "how will we do it" (http://frontlitoral.cat/). Specifically, the deliberation stage included six (6) participation encounters, during 2018 and 2019. In particular, the seminars were addressing aspects such as 'The future of the 3 Chimneys' (October 8th 2018); 'Characterization of the park and the public space' (October 15th 2018); 'Connectivity and accessibility' - (October 22nd 2018); 'The built front: Arrangement model' - (October 29th 2018). These seminars were followed by a 'Cross-sectional session' - (November 12th 2018), and a wrap-up as 'Conclusions session'- (January 21st 2019).

This deliberation followed the format of seminars and sessions with the aim to present, co-create, and validate the planned aspects, including deliberative workshops, feedback as returns on agreements and exposition of specific concerns. The overall deliberation was based on an initial selection on the occupation model, which was discussed as in terms of three options ranging from: first, a complete built space as the cost of having a high density and scarce public open space, thus, neglecting nature; second, strips as sensible built space merged with a waterfront as open space; and third, as a vacant area or non-built space (

Figure 34). The first session confirmed the second option for an 'occupied but sensible' built-up space, which was assumed as a fixed category of the participation process, and as a precondition for the intervention economic feasibility.

Figure 34. The three options for the occupation model. Source: Consortium Besòs

Images of the participatory process exposed in the documentation of the participatory process by the consortium Besòs. Information available at the dedicated website http://frontlitoral.cat/wp-content/uploads/2019/01/Resum-executiu.pdf.

Implementing an open space as a new maritime park exposes different conclusions of the deliberation maritime park, as the arguments that confirm the assumption of urbanization, as well as the feedback of the 'return' session (Table 17).

Table 17. New maritime park deliberation and feedback.

Deliberation on the new maritime park's characteristics (Seminar 2)	**Feedback on the new maritime park's characteristics and equipment**
The majority opinion is in favor of a large metropolitan reference park, which makes renaturalization compatible and attention to climate change with responsible use by citizens.	The opinion is shared that it is necessary to toward obtaining a space that respects nature, which encourages the development of appropriate flora and fauna, but maintains the possibility of leisure.
A significant sector of participants expressed concern about the size of the park due to the occupation of the new buildability.	The metropolitan importance of the park, as the last piece of coast to rethink, is fundamental.
The facilities suggested as necessary and compatible with this park are sports (existing), educational and research centers, care centers for the elderly and health centers.	
Everyone is in favor of maintaining the sports pavilion, although there is no problem in moving the outdoor tracks, if required by future planning. Concern is expressed about the relocation of the football field existing, betting mostly for it to stay where it is.	Regarding existing facilities, there is a firm commitment to maintaining the sports center building, although the relocation of outdoor facilities may be considered. As for the football field, it has to study whether it will stay where it is now or whether a better location can be found in the same area or in a nearby one. This decision must be made with the agreement of its users.

Source: Participatory process's dedicated website (http://frontlitoral.cat/)

Later on, the definition of land uses presented different alternatives and arguments concerned with the economic activities to develop in the area (Figure 35).

Economic activity with a predominance of **workshops and small business**	Economic activity with a predominance of **leisure and hotels**	Economic activity with a predominance of **offices**

- ❑ "compatible with research, investigation, historical memory and possible public management of infrastructures."
- ❑ "so that it creates entrepreneurial jobs rather than turning the area into a dormitory city"
- ❑ Diversity - small scale

- ❑ "As a citizen, I want to enjoy the environment."
- ❑ "Hotels anticipate that the sale value of the PDU will be maximized, and thus the park area will be maximized."
- ❑ "It must have movement and life in order to begin; otherwise, it will be a dead zone."

- ❑ "for employment in the Besòs area"
- ❑ "Offices will add value through innovative and environmentally friendly business activities"

Figure 35. Inputs on the land uses as economic activities from the sessions.

This motivated the possibility to present potential new uses in the set of the heritage buildings of the three Chimneys and the turbine room. For this purpose, the Consortium Besòs established an 'Office receiving and evaluating projects and proposals for use for the '*Tres Xemeneies*'. Eleven proposals were submitted, nine specific projects and two overall proposals, including an International Knowledge Hub for Sustainable Development and Peace and a co-created *'Besòs para Besòs'*, shifting the role of the participants to formulators and opening the deliberation towards a more open-ended process (Table 18).

Table 18. Proposals for the Three Chimneys. Source: Consortium Besòs

Related themes	**#**	**Projects and Proposals**
Research and innovation related activities	*1*	Cultural center with a part dedicated to the Energy Museum and the rest to commercial and hotel uses
	4	Micro-gravity research center and laboratory related to the University and the business sector
	5	Center for research, development and the city of the maritime and fluvial energies of the future
	7	Clean Energy Experimentation Center
	8	Installation of an energy deposit store
	11	International Knowledge Hub for Sustainable Development and Peace.
Tourism related activities	*2*	Convention and congress center with accompanying surfaces for hotel use
	3	Amusement park-theme park related to maritime activities and complementary hotel uses
	6	Body Therapy Center
Social related activities	*9*	Conclusions of the seminar conducted by *'Besòs para Besòs'* with the collaboration of Kaospilot
	10	3rd age community neighborhood

Proposals for the Three Chimneys and the turbine room buildings presented at the Consortium Besòs. Based on the information available at the Consortium website (http://consorcibesos.cat/oficina-receptora-i-avaluadora-de-projectes-i-propostes-dus-per-a-les-tres-xemeneies/). Source: Consortium Besòs

In particular, the Hub (proposal 11) is shown as an extension of the 22@ Barcelona Innovation District when branding the overall master plan operation as 22@Besòs highlight the urban transformation as part of Barcelona's tactic of 'smart' and successful urban interventions. The '*Besòs para Besòs' (*proposal 9) was developed in a parallel participatory process for co-creation of the brownfield redevelopment, facilitated by the Kaospilot innovative approach (https://www.kaospilot.dk/) - (Kaospilot, 2018). The participants (mostly citizens of the area) of this "Social Laboratory" strategy co-created a document titled "Proposals instead of Protests," which seems to reinforce the notion of purposeful participation and citizen empowerment (Arnstein, 1969).

An aspect to highlight is that this information is available as a dedicated section in the consortium website (http://consorcibesos.cat)- (Consorci Besòs, 2021), but not as part of the dedicated documents on the process website (http://frontlitoral.cat/documentacio-general/) (Consorci del Besòs, 2018; Generalitat de Catalunya, 2018). In addition, following this presentation and along the participatory process in January 2019, the consortium opened a 'technical table group' in which some participants of these proposals were invited, this initiative was validated by Bit habitat (https://bithabitat.barcelona/) (Bithabitat, 2019) after an official agreement to support the development of the area (https://consorcibesos.cat/) . In fact, BIT Habitat is a key new participant as a Barcelona (municipal) foundation that promotes urban innovation in Barcelona, as the organization dynamizing urban innovation at the 22@ innovation district.

Subjects: Stakeholders' participation and roles promoting the accounts of urban sustainability

The identification of which stakeholders were involved in the participatory process was based on a 4-helix model as the public authorities (GOV); the civil society or citizens (CIV); the academia or research representatives (UNI), and the industry or private actors (IND). In addition, different stakeholders' roles were recognized as leading the process (formulators, leaders, co-creators, deliberators); who is involved (active attendants, passive attendants, and absents); and recognized as who benefits from its results (beneficiaries).

The main actors involved in the non-binding participatory process were the public authorities (GOV) and the citizens of the area (CIV), business and industry representatives (IND) as passively present, however, no academic representatives (UNI) were officially involved. The public authorities (GOV) led the process through different organizations and hierarchy levels. Initially, a local consortium *(Consorci Besòs)* played the leadership role as the organization in charge of the technical support for this participatory practice. Two municipal administrations are involved at the local level as the territorial authorities of the master plan *(Ajuntament de Sant Adrià del Besòs* and *Ajuntament de Badalona).* A public authority at the regional level (Catalonia) is officially in charge of the planning process and its execution, the Territory and Sustainability Department of the (*Generalitat de Catalunya - Departament de Territori I sostenibilitat de la Generalitat de Catalunya*).

The citizens (CIV), as inhabitants of the area nearby (CIV), were active attendants of the proposal presentation. They represented mainly concerned citizens, neighbors of the brownfield, and some local associations. In their role as local beneficiaries, the citizens questioned and debated on different uncertain aspects of the redevelopment effects. Also, they were co-creators of the alternatives of certain aspects of the built-up environment, and then deliberators on its selection throughout the process. The business and industry representatives (IND) were passively present, they represented construction-related guilds, however, some of them were invited to participate in the technical table group. Similar to the citizens, they were involved as co-creators and deliberators, but instead of questioning the planned aspects, they were keen to inform themselves about the construction process, representing their interests. No academic representatives (UNI) were officially involved; however, their role was mentioned as potential beneficiaries and key partners as a university campus have recently settled in the area (UPC Campus Besòs, 2016).

Objects: Concerns on brownfield redevelopment informing urban reconfigurations

Throughout the non-binding participatory process, the brownfield redevelopment was mainly informed by the themes of the alternative urban uses for land occupation, addressing contamination, and changing the derelict waterfront. Land occupation issues were suggested as the intervention expects to transform the industrial land use for a mixed used program. Issues on contamination as, initially, the location of highly polluting industry caused it, and currently it's related to the active presence of urban metabolism infrastructure. In addition, other economic oriented activities are expected to change the derelict waterfront area.

The littoral reconfiguration is informed and shaped by the three mechanisms as competing, as the account on the social sustainability of the housing provision has opposing concerns in the debate for the beneficiaries of an affordable and high-quality urban living; coexisting, as non-conflictual concerns for renaturalization were integrated into a climate resilient littoral account for environmental sustainability; and complement the account on the intervention (economic) competitiveness by reinforcing how the former energy plant site could be revitalized through science, research, and innovation (Table 19).

Table 19. Urban sustainability accounts shaping the Littoral Besòs

(Promoters) and dominant accounts	Mechanisms	(Promoters) and secondary accounts
(GOV) The reconversion of brownfields for **housing** is an advantage maintaining the compact urban model of Barcelona. The occupation of centrally located plots with high density, as a functional land-use mix, that integrates existing urban fabric, and avoids vacant and non-urbanized land occupation.	*Opposing concerns*	(CIV) The civil society opposition to the new 'neighborhood' is based on the overall questioning of new housing for whom? Following the argument that 'new housing' is a threat to affordable housing rents for its actual inhabitants, who have the lower income in Barcelona, and are more vulnerable in case of gentrification-

(Promoters) and dominant accounts	**Mechanisms**	**(Promoters) and secondary accounts**
(GOV) Addressing pollution as a requisite of urbanization, which seems as the means for financing the pollution alleviation.		(CIV) Addressing pollution as a 'payment of the historic debt' for localizing high-impact activities (chemical industry, urban metabolic infrastructure) in the area that affects odor qualities, air, water, soil, beaches.
(GOV) The design of the implementation **to re-naturalize** the area by leaving space for a metropolitan waterfront infrastructure and to connect with a previous intervention of green-blue infrastructure (Riverside Park Besòs).	*Non-conflictual concerns*	(CIV) The area can change and be re-naturalized. Combined efforts have been made to recover, as previous experiences have shown the capacity to intervene in a highly polluted Besòs River (1996-2006).
(GOV-CIV) The idea that innovation for ecological purposes was a way to balance and 'resist' with decision-making executed at a higher level of interests (regional, national, European and global).		
(GOV) As presented initially in the plan formulation, the need for economic feasibility through the use of urban management and financing instruments is a pre-condition for the project development.	*Reinforcing concerns*	(CIV) The fear that they (CIV) can't afford to be involved (lack of skills, training and the consequences of inequalities)
(GOV) The intervention in the 3X location, arguing on the opportunity for an attractive spot available in the AMB. A protected space hosting land uses for higher competitiveness such as R&D companies and promoting the insertion of smaller entrepreneurships, and spin-off from the university (science).		(CIV) Complementary arguments are found in favor of redevelopment through land uses to decentralize economic activities (form Barcelona) and to promote new (economic) activities in the AMB. A key example is the presentation of a Hub known as the 22@besos, the energy hub for climate resilience.

Promoters, dominant accounts, and mechanisms informing and shaping urban reconfigurations.

As a result, these interconnected issues support the vision of brownfield redevelopment as a sustainable built environment for a littoral reconfiguration that appears to be guided by three assumptions:

- A sustainable built environment, by avoiding land occupation, to endorse functional mix as an urban planning factor that harmonizes land-uses to attract inhabitants, as new and affordable housing.

- A sustainable built (and/or non-built) environment, by addressing existing contamination, to promote climate resilience as an urban planning factor for flexible interventions, as nature-based solutions for renaturalization.

- A sustainable built environment that overcomes derelict waterfronts and preserves industrial heritage, to support a coordinated management as an urban planning factor that allows high-quality building mixed-uses and a functional mix of cost-benefit activities, which could be commemorative, as science, research, and innovation.

7.5. Discussion

This discussion follows the arguments from the non-binding participation process to recognize the implications of the concerns exposed for the brownfield redevelopment as the promotion of transformative changes for urban sustainability and for a transformative urban planning practice.

Competition mechanism: Opposing concerns for new and/or affordable housing

Because of *opposing concerns* about the social sustainability of the brownfield redevelopment, land occupation with 'new and/or affordable' housing is a dominant competing account**.** The spatial intervention, as an urban transformation through housing, validates the urbanization process in order to consolidate the littoral of the Barcelona metropolitan area as a built environment to meet the inhabitants' demand for housing within its metropolitan boundaries.

This validation is justified as an advantage for preserving Barcelona's compact urban model through the use of centrally located plots with high density and for its inhabitants as residents. In contrast, new housing is presented throughout the participatory process as a threat to current residents' affordable rents, and income disparities divide the community in favor and against the predictable effects of higher-quality urban settlement through the brownfield redevelopment. The deliberation between participants on the housing and neighborhood provision as a 'new vs. old approach' revealed how the challenge of dwelling is metropolitan and global, rather than local. As various citizens addressed throughout the participatory process, new housing differs from community-building strategies such as 'co-housing', which seems to the participants as oriented to the 'how' of the sustainable built environment and for whom.

The *opposing concerns* related to housing imply the use of functional mix factors and harmonization for mediating between social concerns of the brownfield redevelopment vision of multiple actors. Citizens seemed to have questioned how the formulation process purposely addresses their existing needs and expectations as inhabitants of a highly vulnerable territory. This exposes the participants' aim to prioritize the gentrification caused by high-quality urbanization which will affect them as the more vulnerable inhabitants (Fainstein, 2010). This opposition relates to similar concerns in other contexts, as the extent to which the way of delivering housing, as a key element for a sustainable urban environment, addresses structural urban inequalities, which have increased after a COVID-19 pandemic (Florida et al., 2021).

To consolidate the *Litoral Besòs* as a socially inclusive built environment calls for the deployment of capacities to enhance the social diversity (Fainstein, 2010). Tools and practices for housing innovation and social diversity emphasize on the coupling of housing needs and expectations, e.g. by proposing various dwelling solutions, management and tenancy models for a wider-range of household incomes as social integration is a critical dimension in Barcelona's interventions (Bottero et al., 2020). As a result, the master plan seem to be an opportunity for exploring what kind of brownfield redevelopment housing policy would produce spatial and whole-systems justice within this specific diverse urban context as a pathway to intra and intergenerational equity (Luederitz et al., 2017; Martiskainen et al., 2021; Preuß et al., 2021).

Co-existing mechanism: Non-conflictual intervention for waterfronts

Because of *non-conflictual concerns* about the environmental sustainability of brownfield redevelopment and renaturalization, is a dominant co-existing account. As an urban transformation through nature-based solutions, the spatial intervention addresses derelict and contamination in order to consolidate the littoral of the Barcelona metropolitan area as a continuum of renaturalization and open space.

This validation can be helpful for a coastal line redefinition to be capable of facing risks, such as rising sea levels for a climate resilient littoral. Renaturalization has proven to be an independent argument from urbanization processes, and the preference for a built environment along the littoral, whether encouraging or contrary. Despite the lack of public participation in its formulation, the Besòs river restoration is emphasized as a major intervention which addressed floods, avoided related losses, dealt with river degradation, and improved the urban image of the area, by addressing the multiple environmental, social and economic concerns of an urban context with a polluted river and its scarce streamflow (Tort-Donada et al., 2020).

The *non-conflictual concerns* related to NBS imply the use of climate resilience factors for mediating the brownfield redevelopment vision through an urban landscape fulfilling social and environmental concerns. Citizens' concerns seem to ratify the need for a multifunctional landscape and their active (public) engagement, highlighting the lessons learned through the Besòs river restoration experience. Specifically, implementing nature-based solutions (NBS) can address water-related challenges, associated also to derelict and contamination, and benefiting social aspects (Ramirez-Agudelo et al., 2020; Ramírez-Agudelo et al., 2021). In addition, the riverside park and the constructed wetlands, examined as NBS through the circular economy lenses, provide multiple services and benefits including: natural capital regeneration through biodiversity and water quality improvements; which by streamflow augmentation help to keep resources in use and promote urban systems synergies; and marginally reduce externalities by improving risk management (Ramírez-Agudelo et al., 2021).

To consolidate the *Litoral Besòs* as a renaturalized setting calls for incorporating the co-existing aims of social–ecological–technological systems (Egerer et al., 2021). Tools and practices for greater citizen involvement in the NBS implementation, or other green concepts, calls for an integrated understanding on the social effects of green interventions, including the factors that facilitate climate justice, as shown in Barcelona's recent aims after a climate emergency declaration (Amorim-Maia et al., 2022). The master plan seem to be an opportunity for exploring how the brownfield redevelopment promote climate neutrality and public engagement for NBS implementation, as a transdisciplinary knowledge co-production (in research design and application) towards socio-ecological stewardship and democratic governance (Bush & Doyon, 2021; Frantzeskaki, 2019; Luederitz et al., 2017).

Complementing mechanism: Reinforcing competitiveness through land uses

Because of *reinforcing concerns* about the economic sustainability of the brownfield redevelopment, the building used for science, innovation and research is a dominant complementing account. As an urban transformation through heritage revitalization, the urbanization is validated for the *Tres Xemeneies* conservation of industrial built heritage, to consolidate the littoral of the Barcelona metropolitan area as a built environment that commemorates the energy production identity through its occupation with activities related to the new industry.

This validation is justified as a precondition of the brownfield redevelopment by matching opinions in favor of 'innovative' uses for the 'industrial' energy plant. According to activists representing the Three Chimneys platform, the heritage building is iconic of the Catalan development of energy production, and it signifies how the Besòs area (and its working-class inhabitants) supported the Catalan industrialization. Despite the renewed emphasis on industrial commemoration as the industrial conservation is part of the redevelopment land use program, the activists argue that the pre-establishment of new uses is a precondition, and for this collective the use of the revitalized industrial heritage seems to be a baseline, rather than a goal, for validating the overall urbanization effort.

The *reinforcing concerns* demand to shape the existing built capacities for cost-effectiveness, under coordinated management factors to facilitate a transformative approach through urban planning. This feasibility prerequisite of cost-effectiveness is merged to the science and research preferred uses to highlight the urban transformation as part of Barcelona's tactic of 'smart' and successful urban interventions. Despite the prerequisite to improve the intervention competitiveness has been reinforced; it's relevant how the participatory process enhanced the democratic deliberation by promoting the presentation and reception of projects and proposals for the future of the Three Chimneys heritage appears to support this social and economic aim of the master plan formulation, which aim to mobilize social changes in the area.

To consolidate the *Litoral Besòs* of the Barcelona metropolitan area as a smart and sustainable built environment calls for the deployment of transformative capacities to xx. For a more transformative approach through urban planning this implies gaining multiple actors' trust and support, as coordinated social and technical innovation, for a meaningful sequence of actions in a mix-use strategy, for improved precaution and adaptation to be used in the sustainability criterion' assessment of the intervention's effects. Tools and practices for more transformative urban planning practice could include support for integrating urban challenges as part of competitiveness interests in land and building uses, such as scientific research and innovation interests or an audiovisual hub, such as the urban systems intersections in urban metabolism under key paradigms like circular economy, smart urbanism, for an active data collection and monitoring of urban sustainability.

In this sense, the master plan seems to be an opportunity for exploring which sequence of actions could be more relevant for a smart and sustainable intervention of a brownfield redevelopment oriented to higher resource maintenance and efficiency (Bibri, 2021; Luederitz et al., 2017).

Non-binding participatory practices and urban sustainability transitions

Non-binding participation was identified as a practice that both supports and constrains the emergence, mediation, and dominance of urban sustainability accounts, with implications for urban reconfigurations. This analysis identified the emergence of awareness on the different needs and expectations of the multiple actors involved in the aspects exposed in the formulation process and their engagement to deliberate on the very specific resulting decisions on the 'what-to' include in the brownfield. In addition, the process has allowed the emergence of flexibility in its multiple actors' dynamics as the participants became formulators of alternative uses for the heritage buildings, for which collaboration among the multiple stakeholders was used to enhance their roles along the process, and to co-create projects and proposals exposing their own priorities in this transformation. Together, the analysis exposes that the commitment to public engagement has served the purpose of better informing and shaping the 'how-to' of the brownfield redevelopment. Likewise, the sustainability accounts operate as guidelines to aim for a socially cohesive, climate resilient and smart and sustainable urban littoral.

The economic feasibility of the urbanization process serves as a fixed guiding principle of urban planning; however, for the participants, the social and ecological dimensions of the brownfield redevelopment seem as preconditions for a sustainable built environment and not only as expected, but uncertain, outcomes. Because the vision for littoral consolidation is dominated by the economic feasibility of the urbanization process, the non-binding model is limiting the urban reconfiguration as the participatory process cannot contest the 'rules of the planning', based on its 'pre-given meanings, forms, and qualities of participation' (Chilvers & Kearnes, 2019). This constraint for more deliberative and dialogic models of participation can open new questions, on the non-binding nature of participatory processes to shape and inform climate change resilience processes.

In January 2022, a new institutional agreement has been established to transform the area around the Besòs river and the *Tres Xemeneies* (https://www.barcelona.cat/infobarcelona/en/institutional-agreement-to-transform-the-area-around-the-besos-river-and-the-tres-xemeneies_1137375.html) (Ajuntament de Barcelona, 2021). This agreement changes the Consortium Besòs structure, based on municipalities, to include the Catalan regional government (*Generalitat de Catalunya*) under the common goal of "creating a digital and audiovisual hub, a significant public housing development, and a large urban park, as well as implementing all the measures required to turn the river into one of the strategic areas of the Barcelona metropolitan region".

Waterfronts, in particular, may seek future consensus on non-built alternatives to be included in deliberations for alternative waterfronts management, which could be a desirable option to deliberate through local non-binding participatory process, for example through land conservation, coastal retrofitting, or dunes restorations. This opportunity of socio-ecological-technical systems ratifies collaboration and flexibility as critical processes for a more transformative approach to urban planning in informing and shaping urban reconfigurations. More reflexive participatory practices, in this sense, are a means of gaining a broader understanding of sustainability and co-creating open-ended processes of urban experimentation for urban sustainability transitions.

7.6. Conclusions

This study analyzed a non-binding participatory practice in urban planning as a phase in the formulation of a brownfield redevelopment plan in the Barcelona metropolitan area, as an overall process that supports or restrains the emergence, mediation, and dominance of sustainable urban accounts informing and shaping transitions. Using empirical evidence, this analysis contributed to the identification of the public engagement, characterizing the model of non-binding practice, as a practice developed in different sessions and allowing feedback. The subjects influencing the process of change, by establishing who takes the leadership and promotes them, who are mainly the public authorities as promoters, and the citizens as active attendants. The objects, as the urban sustainability accounts that emerge, mediate, and dominate on the meanings of a sustainable built environment.

In a first order of learning, urban sustainability concerns such as a land occupation with new housing is a competing argument, because of its *opposing concerns* for social sustainability. Renaturalization through a public open space is an argument co-existing, because of its *non-conflictual concerns* with environmental sustainability. Land uses for innovation and research is a complementing argument, because of its *non-conflictual concerns* for the economic sustainability of the intervention. Therefore, the dominant concerns for a sustainable built environment imply gentrification, nature-based solutions and competitiveness. On a second order, the analysis shows that addressing climate-related pressures on derelict and contaminated industrial areas, calls for (re)defining urbanization as an option, rather than a predetermined goal of participatory processes. As a result, social and ecological concerns could operate similarly to the prerequisite of economic feasibility in urban planning processes.

This analysis exposes how the proposed changes and their argumentation restrains urban reconfiguration because of tensions as the collective exposed uncertainties of the intervention' effects; as well as supports and facilitates opportunities for co-creation based on its flexibility for a more transformative practice. In this brownfield redevelopment of a socially vulnerable area, a more coordinated urban management could be supported on higher flexibility and lead endorsing physical and social changes, through collaboration among multiple actors, as a transformative capacity for a more systemic response to the societal challenges of a global city's littoral. Finally, more reflexive participatory practices are means for broader understandings of sustainability and for co-creating open-ended processes of urban experimentation for urban sustainability transitions.

Summary research highlights and findings

Literature highlights (Chapter 4)

Initially, the explorative part served the purpose of having the theoretical foundation for the research. As mentioned in the background section, the conceptualization of innovation as urban experiments was studied to guide this research from the socio-technical systems and the multi-level perspective - MLP (Geels, 2004). This conceptualization is a central theoretical standpoint in transition studies, which allows to identify the elements involved in a transformative change process. For this purpose, the explorative phase presented in the chapters 1 and 2 (Introduction and background), served to introduce innovation as urban experimentation, and as a characteristic of a urban sustainable transition.

Following, the analytical phase, presented different research iterations which focused on the innovation as processes related to nature-based solutions (NBS) implementations to address water challenges. This phase started with the literature on the concept, and moved to the case study in which different analytical aims and scopes were beneficial to have a wide-ranging perspective of the *Litoral Besòs*.

Chapter 4

This chapter presented the literature review, which indicated that the dominant discourse of NBS is its endorsement as a comprehensive approach is to achieve systemic interventions, delivering multiple benefits to multi-actor in a resource-efficient manner. As an integral feature of the concept, NBS link the problem addressed to the solution, within the aim of sustainable development—in other words, facing social, environmental, economic, and institutional barriers. Thus, when referring to complex challenges, the aim for systemic interventions is to deliver results at different environmental–technical, and social levels. NBS is exposed as a comprehensive concept from two perspectives: i) The NBS problem-solving feature from the technical and spatial aspects, responding to the ecological dimension of the concept. And, ii) The NBS governance and management to identify the socio-economic aspects that support NBS implementation. The findings as lessons learned (Table 20) and barriers (Table 21), as well as their implications as the ways in which NBS as innovations (urban experiments) enable transformative shifts are presented in the right column as highlights.

Table 20. Lessons learned on NBS implementation and highlights

Lessons learned	Chapter 4 Highlights
Water challenges expose pressures due to climate, risks, and urbanization. Water challenges are interdependent, dynamic, and linked to the quality and quantity of the resource, revealing the complexity of water management in peri-urban areas.	Societal challenges of climate, risks, and urbanization need to be considered as active pressures shaping peri-urban areas and its water systems. Urban sustainability is addressing water quality and quantity concerns, which are linked issues for water and urban management.

Lessons learned	Chapter 4 Highlights
The NBS approach as various green concepts are used to refer to the innovative use of nature. For example, when referring to implementation experiences the cases reviewed use NBS, as well as other green concepts such as GI, ES, Eb. Thus, NBS is a conceptual approach open to contextualization.	The use of nature requires contextualization, as several concepts could be in place, framing the implementation under different approaches. For instance, NBS is an umbrella concept that serves to integrate ES and GI, as well as to reframe other approaches, for instance, river restoration initiatives of previous decades.
A common aspect for nature-based interventions addressing water challenges is to implement approaches that mix green/blue, green/gray, and green/blue/gray infrastructures	Innovation with nature are technical solutions in water systems that are functional for water management and of other urban systems. NBS are implemented as hybridization approaches for multifunctionality.
NBS in the peri-urban area ranges from macroscales, such as river basins and agroforestry, to buildings as a microscale. Moreover, there is not a fixed spatial scale in NBS implementation, although, in peri-urban areas it could tend to municipal levels for their planning competencies or bigger scales for implementations linking rural and urban systems.	NBS are implemented at various scales, in which its integration can allow bigger benefits and services. Because NBS in peri-urban areas can connect local interventions(municipal) to larger scales (urban and rural), coordination is an important factor for its multi-level implementation.
The multiple benefits and services delivered are interrelated, influencing different fields as landscape management; risks and climate regulation; recreation, physical and mental health, and well-being.	Because of the delivery of interrelated benefits and services, NBS are better considered under a comprehensive and cross-sectoral perspective.

Table 21. Barriers identified on NBS implementation and highlights

Barriers	Chapter 4 Highlights
NBS cannot control the overall impact of water challenges, nor can it meet all needs (e.g., high runoff volumes, high contaminant loads, etc.), with the risk of high technical uncertainty. Limitations could be financial, the lack of technological capacity, deficiency in infrastructure, data; or that affect institutional capacity. NBS require considering the benefits, services, as well as the potential risks or unintended consequences of their up-take, as its systemic implications, while avoiding uncertainty. The lack of capacities also affects the NBS market uptake and the creation of alternative business models and practices that support it, and thus, limiting partnerships and involvement. For instance, market uptake of NBS benefits as a field still requires legal regulations.	NBS implementation (and scale-up) could be limited by insufficient capacities in various domains, affecting the understanding of its systemic implications, in order to reduce uncertainties.
Aspects to consider in implementing NBS are displacement, gentrification, commodification, as well as social justice regarding access to nature and human well-being. Some NBS functions could lead to disservices, which can be perceived negatively or affect safety perceptions, i.e., fire risks on green spaces or drowning risks in SUDS. The lack of interactions among the different actors involved compromises the	NBS implementation has potential risks and unintended (social) consequences. Missing aspects are the social interaction and perceptions on the negative side of NBS implementations, including acceptability/resistance as the source of conflicts for justice issues and disservices.

Barriers	Chapter 4 Highlights
perception of NBS, which could be negative for aspects such as costs, benefits in the short- and long-term, and impact of the solution. This could lead to difficulties due to inhabitant resistance to changes, passive involvement, and insignificant increase of social cohesion, fear of the unknown, and uncertainty.	
Even if NBS implementation involves multi-actor participation, the promotion role is mainly done, and funded, by the public sector. However, study cases revealed that NBS increases individual and public awareness for lifestyle shifts. In addition, social dynamics influence the uptake and use of NBS, in terms of behavior and practices that are shaped through socio-cultural values, traditions, and perceptions.	In NBS implementation, the public sector has had the leading role. However, the limited multi-actor participation is affecting the NBS potential for behavioral changes, NBS use and uptake.

Lastly, the literature study revealed that the systemic implications of NBS may be recognized on several levels (micro, meso, and macro), emphasizing NBS as a comprehensive approach. This chapter concluded highlighting accountancy, monitoring, and communication as potential success factors for NBS implementation. These factors are beneficial for the integration and development of NBS while diminishing the overall barrier of complexity that leads to technical, institutional, economic, and social uncertainty (Figure 36).

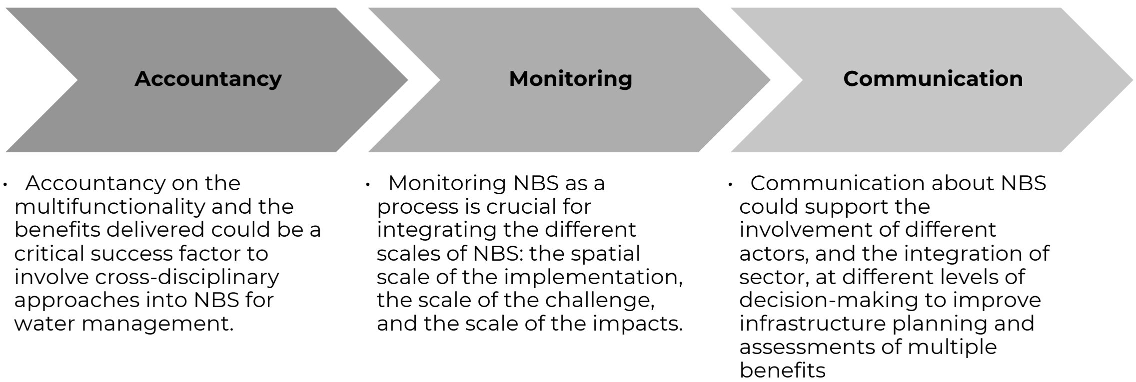

Figure 36. Concluding features for successful NBS implementations

Case study main results (Chapters 5 - 6 - 7)

This subsection will expand to the case study from the various standpoints used in the analysis of the *Litoral Besòs*, by focusing on the key findings and implications of the case study as transformative shifts.

Chapter 5

This chapter showed how the *Litoral Besòs* transformative changes promoted through urban experimentation with NBS are technological advances on the water reuse towards circularity are mainly related to:

- Water reuse for streamflow augmentation has resulted in NBS as hybrid implementations for multifunctionality, which has kept resources in use and promoted synergies that benefit social livability.

- Preventing pollution has resulted in NBS as multi-scale (and multi-level) implementations to guarantee functional environmental flows and stocks, which has regenerated natural capital and improved biodiversity and water quality.

- However, as an open system it is difficult to design-out waste externalities, as the sources are related to activities in other systems (agriculture).

This chapter concluded highlighting that the contributions to SUWM reveal how actions and circularity features endorse flexibility and cross-sectoral collaborations which are supported by improving accountancy, active monitoring, and communication (Figure 37).

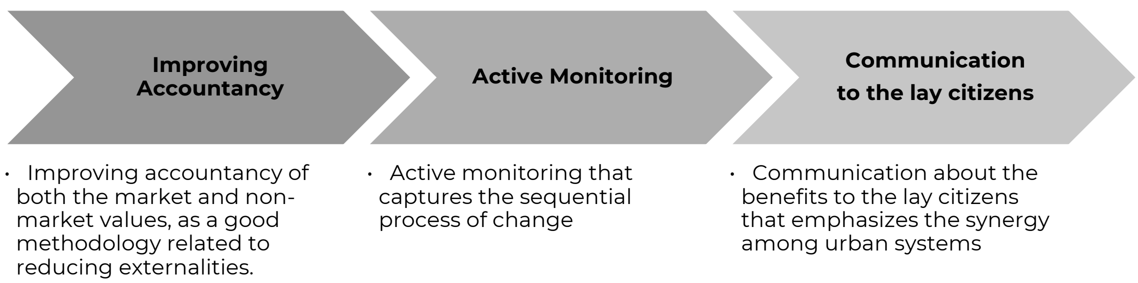

Figure 37. Key facilitators for NBS towards circularity (Chapter 5)

Following, Chapters 6 and 7 focused on the exploration on the citizens role, as the quadruple helix approach in multi-actor dynamics, which complements innovation development. These chapters included guiding questions related to the citizens perceptions in terms of their insight on NBS and their concerns on the urban reconfiguration for the seafront. These two guiding questions were used to characterize the multi-actor dynamics.

Chapter 6

This chapter presented an analysis of the *Litoral Besòs* at the Besòs river restoration (NBS), which characterized the users of the NBS, and established its potential contributions to NBS management. The qualitative analysis of 114 surveys collected during six campaigns in June 2021, served to provide empirical evidence on the NBS use by showing:

- Citizens' frequent use of the area is driven by various uses and motives. Their visit to the riverside park exposes the importance of the NBS implementation for high-socially vulnerable contexts.

- As a multifunctional green infrastructure that has the form and the (spatial) conditions, for recreational (including health), social and cultural purposes of users at the metropolitan level. It seems very convenient its official recognition as a key GI in the metropolitan masterplan update.

- Although, users seemed to be informed about the risk vulnerabilities of the area, especially the ones who were long-term users, as they could provide a 'before-and-after' perspective of the riverside park. New users seemed unaware of the precaution and adaptation measures that the NBS follows in its management.

- Awareness on the operationalization conditions established in NBS management could be used to reconcile the area as an urban park, in particular as the precaution and adaptation measures follow (non-human) priorities, i.e. access restrictions, lack of furniture, lack of (trees) shade, etc.

- Knowledge and learning on the benefits of nature could be an opportunity for monitoring, communication and the information exchange not only for identifying the experiences, perceptions, and practices of beneficiaries, but also for NBS management.

The conclusion of this analysis underscored the idea of interactions, as user insight is important and urgent, considering the changes in climate and the net-zero strategies. These tools and practices can support a more participatory structure, as a transformative governance approach, to collectively shape a more resilient city. Urban experimentation and/or social innovation approaches could also be used in implementing NBS to create a more local, decentralized, and bottom-up management strategy (Figure 38).

- (Accountancy)To establish greater commitment and trust, to determine who should be involved, when, and in which positions.
- Monitoring citizen perception remains an open topic for urban climate challenges and to facilitate NBS management.
- Tools that enable citizen participation by integrating citizen insight into urban planning are important, for local adaptation.

Figure 38. Key facilitators for involving citizens with NBS (Chapter 6)

Chapter 7 presented analysis of a non-binding participatory practice in urban planning, as a phase in the formulation of a brownfield redevelopment plan. This participatory process was identified as informing and shaping an urban sustainability transition for the Mediterranean seafront of the *Litoral Besòs*. The findings exposed how the process could either support or restrain the emergence, mediation, and dominance of sustainable urban accounts, which are informing and shaping transitions based on the three elements of public engagement: the model, the subjects, and the objects. The qualitative analysis of the process developed during 2018-2019 served to provide empirical evidence on the role of citizens for transformative change by showing:

- The dominant concerns for a sustainable built environment, because of its *opposing, non-conflictual and complementing concerns* of urban sustainability, imply gentrification, renaturalization (as nature-based solutions), as well as (economic) competitiveness.

- The proposed changes for the brownfield seem to restrain urban reconfiguration because of the uncertainties of the intervention' effects. Therefore, addressing climate-related pressures on derelict and contaminated industrial areas, calls for (re)defining urbanization as an option, rather than a predetermined goal of participatory processes.

- As a non-binding process, it can facilitate co-creation based on its flexibility for a more transformative practice. Accordingly, social and ecological concerns could operate similarly to the prerequisite of economic feasibility in urban planning processes.

Finally, the analysis concluded highlighting how a more coordinated urban management endorsing physical and social changes, could be supported on higher flexibility and lead through collaboration among multiple actors. Also, a more reflexive participatory practices as urban experimentation could support urban sustainability transitions (Figure 39).

Figure 39.Key facilitators for citizens participation (Chapter 7)

Following, the third part of this thesis presents the discussion and the conclusions of this research, corresponding to the explanatory part of the research.

Third part – Explanation

8. Discussion

This discussion explains how the *Litoral Besòs* case study and its interrelated processes of change can be considered transformative shifts informing an urban sustainability transition. This chapter is divided into two sections: first, considering the *Litoral Besòs* an urban sustainability transition (section 8.1); and second, explaining the research significance (8.2).

8.1. *Litoral Besòs*, an urban sustainability transition

This research has focused on a specific geographical scope in the Barcelona metropolitan area, the *Litoral Besòs*. This context-specific scope allowed to gather evidence and analyze the case from different standpoints. Together, the findings make an overall perspective of the Littoral Besòs as a social-ecological-technical system and its transformative shifts.

The Littoral Besòs is a territory in which the physical and social dynamics have changed through the innovative use of nature, which has supported a hybrid implementation of grey and green infrastructures and its aimed to support a coastal reconfiguration for a **place-based- transition**.

- The Besòs riverfront hybridization has been a sequential process of coordinated actions, which has resulted in simultaneous and synergetic benefits related to the functionality of the place and the scale of the intervention as two central features of physical and social change.
    - The multifunctionality as a space that integrates the physical changes, as well as the use of this place to promote new social practices as social changes.
    - The multi-scale as an open green space and place, in which different municipalities are connected, as well as the multi-level condition of NBS governance, in which its consideration as key green infrastructure at the metropolitan level is central.
- The Mediterranean seafront shows advances for the reconfiguration of the area, in particular, as part of the citizens **problem reframing** and **visioning importance** of the formulation plan in its participatory stage, which aims for:
    - The multifunctionality as a space to integrate a natural coastal line, which could be a renaturalized open space and the overlapping of mobility systems and land-uses to respond to the metropolitan needs of an articulated littoral and dwelling availability.
    - The multi-scale and multi-level conditioning are implicit in the Barcelona seafront reconfiguration, because of the economic, regulatory and technical support needed for this purpose.

These factors of change toward a sustainable transition expose how the Littoral Besòs has been a real-life use context, aiming for innovation through NBS and WRT. Therefore, its deployment as alternative practices in water systems (innovation development) show the capacities built through **urban experimentation** (Luederitz et al., 2017).

- In particular, in the riverfront the implementation of nature-based solutions (NBS) has endorsed changes, which have facilitated the emergence of water reuse technologies (WRT).

- These alternative practices have been useful for addressing the micro-level challenges of the linear-model issues of urban water systems, as technological niche developments (Geels, 2004).

- NBS implementation have been central for promoting physical and social changes aimed (principally) for water reuse; while both NBS and WRT serve for endorsing new paradigms such as the circular economy principles in water systems (Hoffmann et al., 2020; Nika, Vasilaki, et al., 2020).

- Together, the transformative shifts endorsed by the innovations in water systems have been contributing to a more Sustainable Urban Water Management (SUWM) (Ramírez-Agudelo et al., 2021).

Therefore, the *Litoral Besòs* has shown how the innovation developed has led to the multifunctionality and further synergies among urban systems, which have been key elements of the overall process of change 'in, of, and by' the *Litoral Besòs* (Hölscher & Frantzeskaki, 2021). This urban experimentation is a successful factor of change, supporting the reconfiguration of the *Litoral Besòs*. This directionality of change has been promoted as the interaction among different actors for social and technical innovation development related to climate resilience as open-ended explorations.

However, the analysis has identified that for an urban sustainability transition, there are various **limitations** related mainly to the *Litoral Besòs* institutional and governance capacities. The process of change has been driven as a top-down process, which has ensured rapid advances and transformative shifts:

- Physical changes are limited by the needs of biotic management for NBS and the need to have a fit-to-purpose strategy for WRT. In particular, the findings demonstrate a limited capacity to design out waste externalities, because the alternative practices can provide only local shifts, as incremental changes at the micro-level (Hoffmann et al., 2020).

- Because these practices can promote decentralized or modular changes, the shifts through NBS and WRT are different from those enabled by disruptive innovations (Hoffmann et al., 2020).

- Consequently, the practices in the Littoral Besòs seem to be constrained by its development as isolated interventions at the local scale, pending of the aim to support systemic changes in water and/or urban systems.

Moreover, these limitations relate to social and governance aspects, affecting specifically the **multi-actor dynamics**:

- In the Besòs riverfront, a top-down design and implementation of a river restoration and a riverside park has shown to be useful for coordinated action and intersectoral benefits.
    - In particular, citizen participation and engagement were identified to be an opportunity for increasing awareness and knowledge on NBS maintenance as a biotic infrastructure (Marcus et al., 2019).
    - In addition, to avoid negative perceptions and conflictual concerns, citizens involvement as users can contribute to NBS management (Raymond et al., 2017).
- In the Mediterranean seafront, a non-binding design for the formulation of the urban reconfiguration exposed how citizen engagement can endorse higher awareness and precaution on unintended consequences, such as gentrification.
    - Social concerns exposed how the governance complexity seem to constrain the potential of the physical changes of the area.
    - The urban reconfiguration depends on higher levels of decision-makers and vertical coordination (Turnheim et al., 2020), as the urban systems belong to the metropolitan, regional, and national levels of importance.

Thus, management and uptake of NBS can benefit from multi-actor dynamics, in which the role of citizens is a key local capacity. The role of the public sector, in particular of the *Consorci Besòs* has been identified as key for its leadership.

- Another limitation identified is the horizontal integration. In particular, these shifts, and their constraints, are not considered as a ´learning-by-doing' experience (Loorbach et al., 2017).
    - Thus, the effort for a renaturalized seafront is not explicitly considering the users insight as a replicable process of awareness and knowledge, in which 'hybridization' promotes NBS scalability (Hoffmann et al., 2020).

Additional factors facilitating change in water and other urban systems are required to overcome these limitations and support the goal of systemic changes. For example, these alternative practices can be embedded into grid-dominated infrastructure, promoting the 'hybridization of water systems' (Hoffmann et al., 2020). A common aspect identified with other NBS experiences is addressing water challenges through hybrid approaches that mix green/blue, green/gray, and green/blue/gray infrastructures. Because these endorsements depend on higher-levels of decision-making, the transformative shifts expose how this territory seems to have an asymmetrical correspondence of its local capacity compared to its relevance for the functionality in the metropolitan area. However, the pathway for a metropolitan sustainability transition is opened by the official recognition of the area as key metropolitan GI (AMB, 2020).

To overcome these limitations and further endorse urban experimentation and NBS potential for transformative shifts, additional activities facilitating participation and public engagement are needed. For example, these additional activities could be part of specific governance approaches promoting collaboration and co-creation activities. Consequently, as urban experimentation, open-ended purposes in urban planning are an opportunity identified in this process for the *Litoral Besòs*. The aim to build capacities for the participation of the local actors, mainly citizens, in the design, implementation, and monitoring of the transformation process. for this purpose, approaches could be supported in approaches such as urban living labs (ULL)(Steen & van Bueren, 2017).

Therefore, urban experimentation as a means of governance of sustainability challenges at the local-level can be critical, particularly with regard to the climate-change pressures and its long-term systemic issues (Castán Broto & Bulkeley, 2013). As a result, additional efforts could be made to strengthen the experimentation as an active value of the area, and identity of its inhabitants, for addressing its societal challenges. In this sense, accountability on the territorial initiatives and the actors involved is a critical feature for the comprehensive understanding of urban transformations, as the aim to 'find new ways to mediate between projects, experiments and permanent organizations' (Torrens & von Wirth, 2021).

Finally, the sum of the parts is what gives value to this research, exposing how the accountability is a key feature for an overall understanding of urban transformations by explaining the coherence of the territorial initiatives, the monitored indicators, the citizen perception, etc. This effort for accountability can be supported by communication and monitoring related tools and practices among information of projects, experiments and permanent organizations (Torrens & von Wirth, 2021).

- Accountability supported in communication and monitoring can open dialogues for reflexive mediation mechanisms of urban sustainability accounts, in actions such as platforms, public hearings, participatory public policies, etc.

- Monitoring and evaluation of local sustainability actions has been identified as critical to leverage and strengthen the role of cities in sustainability transitions (EEA, 2019).

    - Learning opportunities can be supported on monitoring and evaluation, by adhering to the indicators and procedural formats of the international, regional, and national agendas, such as the SDGs, Green Deal, Urban Agenda.

- As a result, accountancy and communication emphasize the opportunity for more sustainable modes of production and consumption, as well as fundamental transitions in socio-technical systems (Markard et al., 2020).

8.2. Significance of the *Litoral Besòs*

The aim of this research was to better understand, by the use of a case study of waterfront reconfigurations, the *Littoral Besòs,* how does the NBS implementation enable transformative shifts toward an urban sustainability transition. For this aim, the consideration of urban change as an overall process implied that transformative shifts can be analyzed as an iterative process to better inform about the lessons learnt, barriers, and the directionality of change at the local level.

Initially, a literature review on NBS for water challenges for peri-urban areas, which focused mainly on implementation experiences supported the identification of lessons learnt and barriers for change. Accordingly, the highlights extracted support how the transformative shifts expected through NBS implementations correspond to the five factors of urban sustainability transitions. Then, the analysis of the case study *Litoral Besòs* used different standpoints on NBS for waterfronts reconfigurations, which have been beneficial for detailed findings.

The urban experimentation through alternative practices, such as NBS and WRT, exposed technological advances on the water reuse towards circularity (Chapter 5). The central role of citizens, in terms of their perceptions on the NBS benefits (Chapter 6), as well as their participation and sustainability accounts in the process of urban reconfiguration for the seafront (Chapter 7).

The highlights extracted from these findings can help in the understanding on the transformative shifts expected through NBS implementations in the five factors of urban sustainability transitions (Figure 40).

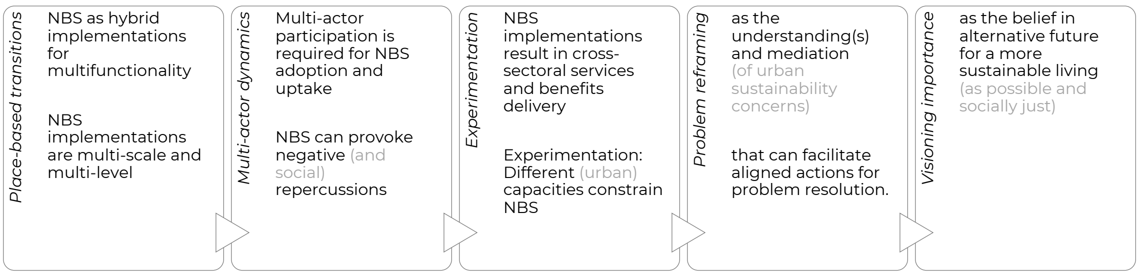

Figure 40. NBS highlights and the factors of urban sustainability transitions

For the riverfront reconfiguration, transformative shifts have been identified as the benefits of water reuse towards circularity for a more sustainable urban water management, in addition to recognizing how citizens perceptions on NBS benefits as a contribution for NBS management. For the seafront reconfiguration, the visioning process analyzed showed the benefits of citizens participation for the problem reframing of urban reconfigurations. Specifically, awareness and precaution were exposed throughout the recognition of different sustainability accounts, and the advocacy for more socially just outcomes.

As a methodological reflection, a central aspect in these explorations has been the use of secondary information sources. This information and data have been identified and collected, by following (previous and ongoing) research and urban systems monitoring in the area. The data availability of the *Litoral*

Besòs such as indicators for the territorial and socioeconomic aspects, biodiversity, water quality, as well as participatory processes for urban development has supported the advancement of this research, and its openness to different viewpoints. Therefore, a comprehensive perspective of the *Litoral Besòs* change process has been a process developed by joining different knowledge areas.

In this sense, a key facilitator for transformative change -and its research- is to facilitate information, monitoring, and communication as an interphase for knowledge exchange and networks formations for localized learning processes (Dignum et al., 2020). This data is a facilitator, and the aim, of smart-related processes of change, for competitiveness and, for the integration of urban areas throughout observation (Bixler et al., 2019). Therefore, from an economic perspective, accountancy on the added value promoted by the NBS, the costs avoided or the carbon capture potential to mainstream the intervention, and to overcome the challenges in the acceleration of innovations such as NBS for a net-zero city strategy (Markard et al., 2020).

Furthermore, this key facilitator endorses accountability, such as the delegated roles to citizens, and environment, supporting the transition from information to knowledge and towards sustainability (Carayannis & Rakhmatullin, 2014). In fact, the role played by the environment as the quintuple helix (see figure 2) is reintroduced under the social-ecological-technological' system framework -SET- to support NBS, and cities, contemporary conceptualizations (McPhearson et al., 2022).

As a chronological course of change, the *Litoral Besòs* is a context in which overcoming the environmental degradation has been a key driver for its reconfiguration. The environmental concerns were caused by the negative impacts of the industrial activities located in the area. The analysis developed focused on the NBS implementation for addressing these concerns, shown to be a useful innovation deployment, by integrating the SET's systems. The Litoral Besòs analysis showed how the concerns that initially motivated the intervention have been addressed through transformative shifts. NBS implementation has provided multiple and simultaneous benefits in the urban systems of water, public space, mobility, and social well-being. Thus, the outputs and outputs of NBS as a sustainability transition experiment (Luederitz et al., 2017).

However, under the circularity paradigm, the environmental degradation challenge, which affects the urbanization, climate, and risks management, is still an open issue. For instance, the presence of the nutrients (nitrogen and phosphorus) are still a challenge in water quality, however, for the *Litoral Besòs* as a peri-urban area this is caused by external inputs, which could be due to diffuse pollution from agriculture. The aim to design-out of waste externalities exemplified with the water quality and the high presence of nutrients has been useful to expose the need to integrate the external inputs of other peri-urban and rural systems such as agriculture and food production. According to the European Environment Agency (2022) agriculture has been causing poor chemical status in groundwater bodies.

The *Litoral Besòs* is an ongoing process that is still facing urbanization, climate and risks pressures, which are shaping the Mediterranean seafront. The findings are evidence on the systems integration by the local practices and social learnings of doing, using and interacting with NBS (Geels, 2004). The riverfront reconfiguration is gained knowledge that imply an opportunity for its use as local capacities of the area (Wolfram, 2016). Moreover, the water challenges can be better addressed by its recognition and integration on the metropolitan GI perspective. Furthermore, as a call for action an approach to reframe the problem and vision towards a regenerative Besòs can promote the circularity aim, such as the implementation of the circular economy principles, which can also be integrated towards more ambitious future as 'regenerative actions' (Jazbec et al., 2020).

This opportunity of supporting the area as key metropolitan GI entails the potential continuity of urban experimentation. For this purpose, SET conceptualizations are relevant, not only through NBS for waterfronts reconfigurations, but also as social innovations, in which multi-actor dynamics can be facilitated through an innovative governance approach for new mindsets. This process for the Littoral Besòs can aim to build capacities for the governance of experimentation, especially to face the changes in climate. The participation of the local actors, mainly citizens can be an opportunity to enhance the design, implementation, and monitoring of the services delivered through the hybrid infrastructure in waterfronts reconfigurations.

Strategic actions for climate resilience through the urban transformation processes could be supported in approaches for open ended explorations and higher flexibility such as ULL (Steen & van Bueren, 2017). When viewed as open-ended processes, these governance approaches and its experimental practices can be learning experiments for higher reflexivity on the problem-solving features of urban innovation development (Luederitz et al., 2017). The long-term processes of change may involve these features as part of the means supporting the iteration among the 'problem reformulation' and the knowledge gained throughout the 'vision' mediation (Hodson et al., 2017), and as sites of contested implementation (Chilvers & Kearnes, 2019).

The focus on the geographical area served the purpose to further explore the innovation in water systems and the multi-actor dynamics through the incorporation of nature-based solutions as a socio-ecological-technical innovation. Specifically, by considering the river restoration as an NBS has been useful for a long-term analysis of the spatial changes in the area, as addressing the environmental degradation has been a sustained process that started a couple of decades ago. The changes promoted in the area through the implementation of NBS has shown that urban experimentation is prone to intersections and interrelations with other urban systems such as public space and mobility. These systems affect the social well-being of the users and their perceptions of the area.

This analysis is considered an advancement, but not an exhaustive analysis of the littoral Besòs transformations, as these advancements correspond to a specific process in the area's change. Despite this study provided a wide-range analysis of the case study; the findings are focused on understanding

NBS as an alternative practice used to address water challenges. In this order, it is possible that these findings may undervalue the role of actors, and other groups involved in pushing other processes of urban system's reconfigurations. These results call for caution against broad generalizations, because it's a single-case study limited by different aspects that restrain its potential for comparability and generalization.

Further research, however, on the case study or similar can continue using the urban sustainability transition concept to better identify the implications of NBS for addressing these societal challenges. Moreover, this exploration in other geographical scopes can continue with the development of conceptual tools to enhance the local governance. Finally, NBS, as providers of adaptive capacities, must still overcome some constraints, which makes necessary to favor institutional shifts, more open-ended urban planning practices, and bottom-up management strategies.

9. Conclusions

This research has focused on a specific geographical scope, the littoral Besòs in the Barcelona metropolitan area. This context-specific scope allowed to gather evidence and analyze the case from different standpoints. Together, the findings make an overall perspective of the Littoral Besòs as a social-ecological-technical system and its transformative shifts. The aim of the present research was to analyze a process of change endorsed by NBS for waterfronts reconfigurations toward urban sustainability at the local level. This examination of the overall process of change at the *Litoral Besòs* has been characterized as an urban sustainability transition, which serves to recognize its directionality, identifying how NBS implementations are ongoing and broad change processes at the local level.

This urban reconfiguration has resulted in transformative shifts in various urban sectors, with different users benefiting from the outputs and outcomes. For example, NBS for waterfront reconfigurations are used as alternative practices to address different challenges, including water quality and quantity issues, while providing ecosystem services, and green infrastructure. Taken together, these implications suggest that a strategic integration of NBS management into urban planning can enable NBS operationalization for a coherent and just transformation. Therefore, the seafront reconfiguration can be the arena to reframe the mechanisms that are used to mediate in the social, economic, and environmental aims of the urban sustainability.

The insights gained from this study may be if assistance for research, and to decision-makers, interesting in strengthening the role that citizens can play in urban reconfigurations. Citizens, are users and beneficiaries, shaping the responses to urbanization, climate change and risks through their cultural practices and social learnings. As a result, the riverfront Besòs has proven to be the result of public sector commitment and leadership, more than the design of a process for active citizen participation or collaboration. Consequently, urban chance in waterfronts reconfigurations has shown to be the interrelated processes, outputs and outcomes. Innovation developments such as NBS implementation can bring together different actors, to facilitate precaution and awareness, on the accounts for higher aims for addressing the sustainability concerns.

Finally, the findings imply that NBS must be considered in a territorial context to better understand their potential to endorse the fundamental, structural, and multi-dimensional change for an urban sustainability transition. The use of the urban sustainability transitions as a general concept highlights the significance of this conceptual lenses in facilitating the understanding of "how" the process of change -as fundamental, systemic, and long-term- are deployed by cities and with citizens at the local level. Moreover, the use of the NBS comprehensive concept in a specific case study serve to reframe urban problems, in which the vision of future alternatives, and from different perspectives, can benefit from advocating for climate and social justice to guide more resilient and inclusive urban reconfigurations.

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Appendix

Chapter 4 - Appendix A

Table A1. List of included references with case location and reference code.

Code	Country	Location	Title	Authors	Year
1	Denmark	Aarhus	Making the ecosystem services approach operational: A case study application to the Aarhus River, Denmark.	Riegels, N.; Lynggaard-Jensen, A.; Krogsgaard Jensen, J.; Gerner, N.V.; Anzaldua, G.; Mark, O.; Butts, M.; Birk, S.	2020
2	Denmark Sweden	Copenhagen Kristianstad	Fostering incidental experiences of nature through green infrastructure planning.	Beery, T.H.; Raymond, C.M.; Kyttä, M.; Olafsson, A.S.; Plieninger, T.; Sandberg, M.; Stenseke, M.; Tengö, M.; Jönsson, K.I.	2017
3	France	Villeurbanne	Improving the multifunctionality of urban green spaces: Relations between components of green spaces and urban services.	Belmeziti, A.; Cherqui, F.; Kaufmann, B.	2018
4	Greece	Athens	Resilient landscapes in Mediterranean urban areas: Understanding factors influencing forest trends.	Tomao, A.; Quatrini, V.; Corona, P.; Ferrara, A.; Lafortezza, R.; Salvati, L.	2017
5	Italy	Trento	Assessing nature-based recreation to support urban green infrastructure planning in Trento (Italy).	Cortinovis, C.; Zulian, G.; Geneletti, D.	2018
6	Italy	Rome	Regulating Ecosystem Services and Green Infrastructure: assessment of Urban Heat Island effect mitigation in the Municipality of Rome, Italy.	Marando, F.; Salvatori, E.; Sebastiani, A.; Fusaro, L.; Manes, F.	2019
7	Italy	Rome	Local scale prioritisation of green infrastructure for enhancing biodiversity in Peri-Urban agroecosystems: A multi-step process applied in the Metropolitan City of Rome (Italy).	Capotorti, G.; De Lazzari, V.; Ortí, M.A.	2019
8	Italy	Rescaldina	Integrating green infrastructure into spatial planning regulations to improve the performance of urban ecosystems. Insights from an Italian case study.	Ronchi, S.; Arcidiacono, A.; Pogliani, L.	2020
9	Italy	Moncalieri	Mapping urban resilience for spatial planning-A first attempt to measure the vulnerability of the system.	Brunetta, G.; Salata, S.	2019
10	Italy	Gorla Maggiore	Going green? Ex-post valuation of a multipurpose water infrastructure in Northern Italy.	Reynaud, A.; Lanzanova, D.; Liquete, C.; Grizzetti, B.	2017
11	Italy	Gorla Maggiore	Integrated valuation of a nature-based solution for water pollution control. Highlighting hidden benefits.	Liquete, C.; Udias, A.; Conte, G.; Grizzetti, B.; Masi, F.	2016
12	Italy	Avola	Planning for spatial equity - A performance-based approach for sustainable urban drainage systems.	La Rosa, D.; Pappalardo, V.	2020
13	Poland Slovakia	Wroclaw Bratislava	The green infrastructure in cities as a tool for climate change	Belčáková, I.; Świader, M.; Bartyna-Zielińska, M.	2019

Code	Country	Location	Title	Authors	Year
			adaptation and mitigation: Slovakian and polish experiences.		
14	Slovenia	Ljubljana	Engaging stakeholders in the assessment of NBS effectiveness in flood risk reduction: A participatory System Dynamics Model for benefits and co-benefits evaluation.	Pagano, A.; Pluchinotta, I.; Pengal, P.; Cokan, B.; Giordano, R.	2019
15	Spain	Barcelona	Creating urban green infrastructure where it is needed – A spatial ecosystem service-based decision analysis of green roofs in Barcelona.	Langemeyer, J.; Wedgwood, D.; McPhearson, T.; Baró, F.; Madsen, A.L.; Barton, D.N.	2020
16	United Kingdom	London	Accounting for groundwater in future city visions.	Bricker, S.H.; Banks, V.J.; Galik, G.; Tapete, D.; Jones, R.	2017
17	United Kingdom	Liverpool	Re-defining the characteristics of environmental volunteering: Creating a typology of community-scale green infrastructure.	Jerome, G.; Mell, I.; Shaw, D.	2017
18	Germany Germany Netherlands Norway Cuba	Andernach Heidelberg Rotterdam Oslo Havana	Edible city solutions-one step further to foster social resilience through enhanced socio-cultural ecosystem services in cities.	Säumel, I.; Reddy, S.E.; Wachtel, T.	2019
19	Spain China	Barcelona Shanghai	Nature-based solutions for urban landscapes under post-industrialization and globalization: Barcelona versus Shanghai.	Fan, P.; Ouyang, Z.; Basnou, C.; Pino, J.; Park, H.; Chen, J.	2017
20	Portugal United Kingdom Iran	Xarrama Foyle Shazand	Health comparative comprehensive assessment of watersheds with different climates.	Hazbavi, Z.; Keesstra, S.D.; Nunes, J.P.; Baartman, J.E.M.; Gholamalifard, M.; Sadeghi, S.H.	2018
21	United Kingdom Colombia Ecuador India	London Bogotá Guayaquil Chennai	Evaluating natural infrastructure for flood management within the watersheds of selected global cities.	Gunnell, K.; Mulligan, M.; Francis, R.A.; Hole, D.G.	2019
22	India	Nagpur City	Ecosystem based Disaster Risk Reduction approaches (EbDRR) as a prerequisite for inclusive urban transformation of Nagpur City, India.	Dhyani, S.; Lahoti, S.; Khare, S.; Pujari, P.; Verma, P.	2018
23	Iran		A comparison of statistical methods and multi-criteria decision making to map flood hazard susceptibility in Northern Iran.	Arabameri, A.; Rezaei, K.; Cerdà, A.; Conoscenti, C.; Kalantari, Z.	2019
24	China	Shanghai	Influence of blue infrastructure on lawn thermal microclimate in a subtropical green space.	Fung, C.K.W.; Jim, C.Y.	2020
25	China	Jiangsu	Embedded reservoir and constructed wetland for drinking water source protection: Effects on nutrient removal and phytoplankton succession.	Yang, C.; Nan, J.; Yu, H.; Li, J.	2020
26	China	-	Groundwater depletion and contamination: Spatial distribution of groundwater resources sustainability in China.	Jia, X.; O'Connor, D.; Hou, D.; Jin, Y.; Li, G.; Zheng, C.; Ok, Y.S.; Tsang, D.C.W.; Luo, J.	2019
27	Cambodia Indonesia Lao PDR Myanmar Timor Leste Vietnam	-	Groundwater as a source of drinking water in southeast Asia and the Pacific: A multi-country review of current reliance and resource concerns.	Carrard, N.; Foster, T.; Willetts, J.	2019

Code	Country	Location	Title	Authors	Year
28	Bolivia	Santa Cruz de la Sierra	Planting waterscapes: Green infrastructures, landscape and hydrological modeling for the future of Santa Cruz de la Sierra, Bolivia.	Castelli, G.; Foderi, C.; Guzman, B.H.; Ossoli, L.; Kempff, Y.; Bresci, E.; Salbitano, F.	2017
29	Canada	-	The use of ecosystem services concepts in Canadian municipal plans.	Thompson, K.; Sherren, K.; Duinker, P.N.	2019
30	United States	Texas	Subdivision design and landscape structure: Case study of The Woodlands, Texas, US.	Kim, J.	2019
31	United States Ethiopia	Detroit Addis Ababa	Guide for using green infrastructure in urban environments for stormwater management.	McFarland, A.R.; Larsen, L.; Yeshitela, K.; Engida, A.N.; Love, N.G.	2019
32	Ethiopia Tanzania	Addis Ababa Dar es Salaam	Examining urban water management practices – Challenges and possibilities for transitions to sustainable urban water management in Sub-Saharan cities.	Herslund, L.; Mguni, P.	2019
33	Kenia	Nairobi	Hybrid infrastructures, hybrid governance: New evidence from Nairobi (Kenya) on green-blue-grey infrastructure in informal settlements: "Urban hydroclimatic risks in the 21st century: Integrating engineering, natural, physical and social sciences to build.	Mulligan, J.; Bukachi, V.; Clause, J.C.; Jewell, R.; Kirimi, F.; Odbert, C.	2020
34	Australia	Melbourne	The role of water utilities in urban greening: A case study of Melbourne, Australia.	Furlong, C.; Phelan, K.; Dodson, J.	2018
35	Vanuatu	Port Vila	Devising urban ecosystem-based adaptation (EbA) projects with developing nations: A case study of Port Vila, Vanuatu.	Pedersen Zari, M.; Blaschke, P.M.; Jackson, B.; Komugabe-Dixson, A.; Livesey, C.; Loubser, D.I.; Martinez-Almoyna Gual, C.; Maxwell, D.; Rastandeh, A.; Renwick, J.; et al.	2020

Table A2. List of cases with challenges and descriptions.

Code	Challenges	Description
1	Effective-incorporation of socio-cultural services	River restoration (to improve recreation and aesthetic aspects)
2	Effective-incorporation of socio-cultural services	Incidental experience of nature
3	Stormwater management	Stormwater management
4	Flood risks Freshwater withdrawals Climate regulation	Regulating impacts on water through forests
5	Effective-incorporation of socio-cultural services	Nature-based recreational systems
6	Climate regulation	(Not specific for water NBS) Climate regulation
7	Urban water systems management Freshwater withdrawals	Preservation and improvement of ES and landscape (water included)
8	Flood risks Climate regulation	Flooding, urban heat island effect
9	Freshwater withdrawals	Identification of vulnerability
10	Water pollution purification / filtration	Flood risk and water pollution

Code	Challenges	Description
	Flood risks	
11	Water pollution purification / filtration	Water pollution control
12	Climate change mitigation and/or adaptation Flood risks	Flood risk due to climate change and urbanization processes
13	Climate change mitigation and/or adaptation Climate regulation	Blue-green infrastructure
14	Flood risks Effective-incorporation of socio-cultural services	Capability of NBS to produce co-benefits (nature conservation, community well-being, etc.) besides supporting risk reduction (flood risk reduction)
15	Stormwater management	Stormwater runoff control
16	Water pollution purification / filtration	Groundwater Management
17	Effective-incorporation of socio-cultural services	Not related to water (but interesting for community-scale engagement)
18	Climate change mitigation and/or adaptation Socio-cultural services Climate regulation	Edible Cities
19	(not specific for water NBS)	Urban environmental challenges that arise as a city rapidly urbanizes
20	Urban water systems management Freshwater withdrawals	Watershed health assessment.
21	Flood risks	Flood risk
22	Flood risks Drought / Water scarcity Climate regulation	Ecosystem-based Disaster Risk Reduction (EbDRR): water shortage, floods and increasing temperature
23	Flood risks	Flood hazard
24	Climate regulation	Thermal microclimate regulation
25	Freshwater supply	Preservation of drinking water
26	Urban water systems management	Water Management
27	Freshwater supply	Drinking water source
28	Drought / Water scarcity Freshwater supply	decline in water supply for the city
29	Freshwater withdrawals	Application of Ecosystem Services
30	Flood risks Freshwater supply	Flood risk, water supply
31	Stormwater management	Stormwater management
32	Urban water systems management Freshwater supply	Water management and supply
33	Stormwater management Urban water systems management	stormwater management and wastewater drainage
34	Urban water systems management Freshwater withdrawals	Water utilities to ensure water security
35	Urban water systems management Freshwater withdrawals	Water security; Coastal ecosystems regeneration; Integrated urban water systems (stormwater, greywater, blackwater, drinking water)

Table A3. Structure of ES and description (TEEB) and main aspects identified.

ES	Description	Aspects identified		Codes
Provisioning Services	Food	Food production	Food supply	4
			Food production	15
			Improve (edible cities)	18
	Raw materials	Raw materials production	Wood extraction	11
	Freshwater	Rain water harvesting	Water yield	8
			Control and assure water supply	9
			Water supply	16,32

ES	Description	Aspects identified		Codes
			Water harvesting	22
			Drinking water sources	25
			Drinking water supplies	27
			Freshwater supply	28
	Medicinal Resources	Not identified		
Regulating Services	Local Climate Air Quality	Climate regulation	Mitigate urban heat island effect	3
			Climate regulation (Cooling Capacity of Green Infrastructure elements obtained from land surface temperature)	6
			Microclimate adaptation	8
			Thermal regulation	15
			Microclimate regulation (reduced UHI)	22
			Cooling capacity	24
	Carbon sequestration and storage	Carbon sequestration	Carbon sequestration	8
			Carbon sequestration (carbon sink)	22
	Moderation of extreme events	Flood protection	Water level fluctuation	2
			Reduce water volume, retain peak flow, recharge groundwater	3
			Flood protection	7, 11
			Flood prevention	10
			Flood regulation and control	21
			Flood control	23
		Stormwater runoff control	Water drainage (runoff mitigation, stormwater management)	8
			Stormwater runoff control	15
			Decelerate rainwater runoff and minimizing flood peaks	22
			Runoff mitigation	31
	Waste-water treatment	Pollution control	Bio-remediation; filtration, sequestration, storage and accumulation; dilution	1
			To trap (filter) pollution	3
			Water quality regulation	7
			Pollution control	10
			Water purification	11
			Dilute and attenuate contaminants	16
			Nutrients and phytoplankton concentration in water, in order to assure water quality.	25
			Pollutant removal	31
	Erosion prevention and maintenance of soil fertility	Erosion prevention	Erosion control; soil fertility regulation;	7
			Sediment retention; soil erosion prevention	8
	Regulation of Water Flow	Regulation of Water Flow	Hydrological cycle and water flow	1
			Forests and others regulating ES protection.	4
			Control water vulnerabilities	9
	Pollination	Pollination	Pollination support	7
	Biological control	Not identified		
Cultural Services	Recreation and, mental and physical health	Physical health	Physical and experiential interactions	1
			Pleasure and recreational activities, cultural activities, serve as pathway/ barrier, nature observation	3
			Applications, for the spatially-explicit assessment of ecosystem services, but increasingly applied to assess potential and opportunities for nature-based recreation	5
			Outdoor recreation (pedestrian and cycling paths)	8
			Recreational use	10
			Recreation	11
			Recreational opportunities	15
			Recreational prospects	22
		Mental well-being	Mental well-being Social well-being	2
			Relief from everyday stress	22

ES	Description	Aspects identified		Codes
		Physical health	Promotion of health behaviors (physical activity)	2
	Aesthetic appreciation and inspiration for culture, art and design	Aesthetics	Aesthetic and cultural values	22
			Aesthetic value	24
		Cultural and historical heritage Aesthetics	Cultural and historical heritage	8
	Spiritual experience and sense of place	Social cohesion	Form social ties	3
			Facilitation of social cohesion	15
	Tourism	Not identified		
Supporting Services	Habitat for species	Natural habitat/ shelter	Nursery populations and habitats	1
			Habitat/shelter for fauna/flora, good resources for fauna	3
			Conservation of crops and farmland.	7
			Maintenance of natural habitats	11
			Habitats for pollinators	15
	Maintenance of genetic diversity	Not identified		

Table A4. List of cases with Ecosystem services.

Code	Provisioning Services	Regulating Services	Cultural Services	Supporting Services
1		Waste-water treatment	Recreation and, mental and physical health	Habitat for species
		Regulation of Water Flow		
2		Moderation of extreme events	Recreation and, mental and physical health	
3		Local Climate Air Quality	Recreation and, mental and physical health	Habitat for species
		Moderation of extreme events	Spiritual experience and sense of place	
		Waste-water treatment		
4	Food	Regulation of Water Flow		
5			Recreation and, mental and physical health	
6		Local Climate Air Quality		
7		Moderation of extreme events		Habitat for species
		Waste-water treatment		
		Erosion prevention and maintenance of soil fertility		
		Pollination		
8	Freshwater	Local Climate Air Quality	Recreation and, mental and physical health	
		Carbon sequestration and storage		
		Moderation of extreme events	Aesthetic appreciation and inspiration for culture, art and design	
		Erosion prevention and maintenance of soil fertility		
9	Freshwater	Regulation of Water Flow		
10		Moderation of extreme events	Recreation and, mental and physical health	
		Waste-water treatment		
11	Raw materials	Moderation of extreme events	Recreation and, mental and physical health	Habitat for species
		Waste-water treatment		
15	Food	Local Climate Air Quality	Recreation and, mental and physical health	Habitat for species
		Moderation of extreme events	Spiritual experience and sense of place	
16	Freshwater	Waste-water treatment		
18	Food			

Code	Provisioning Services	Regulating Services	Cultural Services	Supporting Services
21		Moderation of extreme events		
22	Freshwater	Local Climate Air Quality	Recreation and, mental and physical health	
		Carbon sequestration and storage	Aesthetic appreciation and inspiration for culture, art and design	
		Moderation of extreme events		
23		Moderation of extreme events		
24		Local Climate Air Quality	Aesthetic appreciation and inspiration for culture, art and design	
25	Freshwater	Waste-water treatment		
27	Freshwater			
28	Freshwater			
31		Moderation of extreme events		
		Waste-water treatment		
32	Freshwater			

Table A5. Summary of NBS types, challenges and Ecosystem Services.

Code	NBS Types	Challenges	Ecosystem Services
1	Other	Effective-incorporation of socio-cultural services	Waste-water treatment Regulation of Water Flow Recreation and, mental and physical health Habitat for species
2	Wetland Other	Effective-incorporation of socio-cultural services	Moderation of extreme events Recreation and, mental and physical health
3	Green roof/wall Permeable pavement Other	Stormwater management	Local Climate Air Quality Moderation of extreme events Waste-water treatment Recreation and, mental and physical health Spiritual experience and sense of place Habitat for species
4	River park Wetland Other	Flood risks Freshwater withdrawals Climate regulation	Food Regulation of Water Flow
5	River park Agroforestry Wetland Park	Effective-incorporation of Socio-cultural services	Recreation and, mental and physical health
6	Other	Climate regulation	Local Climate Air Quality
7	SUDS Agroforestry Park Other	Urban water systems management Freshwater withdrawals	Moderation of extreme events Waste-water treatment Erosion prevention and maintenance of soil fertility Pollination Habitat for species
8	Green roof/wall Park Rain Garden Phytorid treatment Permeable pavement Other	Flood risks Climate regulation	Freshwater Local Climate Air Quality Carbon sequestration and storage Moderation of extreme events Erosion prevention and maintenance of soil fertility Recreation and, mental and physical health Aesthetic appreciation and inspiration for culture, art and design
9	SUDS Green roof/wall River park Agroforestry Park	Freshwater withdrawals	Freshwater Regulation of Water Flow

Code	NBS Types	Challenges	Ecosystem Services
	Other		
10	River park Wetland	Water pollution purification / filtration Flood risks	Moderation of extreme events Waste-water treatment Recreation and, mental and physical health
11	River park Wetland	Water pollution purification / filtration	Raw materials production Moderation of extreme events Waste-water treatment Recreation and, mental and physical health Habitat for species
12	SUDS Green roof/wall Wetland Bioswale Permeable pavement	Climate change mitigation and/or adaptation Flood risks	
13	SUDS Green roof/wall River park Agroforestry Wetland Park	Climate change mitigation and/or adaptation Climate regulation	-
14	Wetland	Flood risks Effective-incorporation of socio-cultural services	-
15	Green roof/wall	Stormwater management	Food Local Climate Air Quality Moderation of extreme events Recreation and, mental and physical health Spiritual experience and sense of place Habitat for species
16	SUDS Green roof/wall River park Agroforestry Wetland Park	Water pollution purification / filtration	Freshwater Waste-water treatment
17	Other	Effective-incorporation of socio-cultural services	-
18	SUDS Green roof/wall River park Agroforestry Wetland Park	Climate change mitigation and/or adaptation Effective-incorporation of socio-cultural services Climate regulation	Food
19	Other	(not specific for water NBS)	-
20	Other	Urban water systems management Freshwater withdrawals	-
21	Wetland Other	Flood risks	Moderation of extreme events
22	Phytorid treatment Other	Flood risks Drought / Water scarcity Climate regulation	Freshwater Local Climate Air Quality Carbon sequestration and storage Moderation of extreme events Recreation and, mental and physical health Aesthetic appreciation and inspiration for culture, art and design
23	Other	Flood risks	Moderation of extreme events
24	Other	Climate regulation	Local Climate Air Quality Aesthetic appreciation and inspiration for culture, art and design
25	Wetland Phytorid treatment Other	Freshwater supply	Freshwater Waste-water treatment
26	Other	Urban water systems management	
27	Other	Freshwater supply	Freshwater
28	SUDS Green roof/wall	Drought / Water scarcity Freshwater supply	Freshwater

Code	NBS Types	Challenges	Ecosystem Services
	Agroforestry		
29	SUDS Green roof/wall River park Agroforestry Wetland Park	Freshwater withdrawals	-
30	Agroforestry Other	Flood risks Freshwater supply	-
31	SUDS Green roof/wall Wetland Rain garden Bioswale Permeable pavement Other	Stormwater management	Moderation of extreme events Waste-water treatment
32	SUDS Other	Urban water systems management Freshwater supply	Freshwater
33	SUDS Wetland Rain garden Other	Stormwater management Urban water systems management	-
34	Other	Urban water systems management Freshwater withdrawals	-
35	Other	Urban water systems management Freshwater withdrawals	-

Table A6. Summary of NBS types and scales with descriptions.

Code	NBS Types	Elements Description	Scales	Description
1	Other	not specified	Municipality	
2	Wetland Other	1) wetland, river, wet meadows case; 2) green cycling lanes (surrounded of green and blue infrastructure)	Site Municipality	
3	Green roof/wall Permeable pavement Other	Trees (lone trees, afforestation), shrub (lone shrub, hedge, massif), herbaceous (grass, lawn, meadow), mineral (permeable/impermeable surface), temporary water body, green roof...	Site	University campus
4	River park Wetland Other	Forests	Neighborhood Municipality Metropolitan Area	
5	River park Agroforestry Wetland Park		Neighborhood Municipality	
6	Other	Green infrastructure (GI): street trees, urban forest, peri-urban forest, water bodies...	Metropolitan Area	
7	SUDS Agroforestry Park Other	Agroecosystems and agriculture as GI.	Metropolitan Area	
8	Green roof/wall Park Rain Garden Phytorid treatment Permeable pavement	Other not specified (e.g., green permeable pavement, rain gardens, parks, green roofs, wildlife crossings, Phyto-remediation/ Phyto-depuration, acoustic green barrier, etc.)	Municipality	

Code	NBS Types	Elements Description	Scales	Description
	Other			
9	SUDS Green roof/wall River park Agroforestry Park Other	Underground storages, floodable parks, natural wastewater treatment, increase biodiversity, landscape connections, education in schools, promote education in vulnerability of a system.	Metropolitan Area Regional (Basin level) Other	Applicable at all scales
10	River park Wetland		Municipality	
11	River park Wetland		Municipality	
12	SUDS Green roof/wall Wetland Bioswale Permeable pavement		Municipality	
13	SUDS Green roof/wall River park Agroforestry Wetland Park		Municipality	
14	Wetland	River restauration; Retention area effectiveness; Wetlands restauration; Watershed renaturation; Opening floodplains; River meandering	Municipality Regional (Basin level)	Municipality: Ljubljana, Slovenia Basin level: Glinščica river
15	Green roof/wall		Municipality	
16	SUDS Green roof/wall River park Agroforestry Wetland Park		Metropolitan Area	
17	Other		Site Neighborhood	Community scale GI
18	SUDS Green roof/wall River park Agroforestry Wetland Park		Municipality	
19	Other		Municipality	
20	Other		Municipality Regional (Basin level)	
21	Wetland Other	Floodplains, waterbodies, canopy, wetlands, soil	Regional (Basin level)	
22	Phytorid treatment Other	Phytorid waste-water treatment technology (plants with filtration and treatment capability in constructed wetlands)	Municipality	
23	Other	Terrain analysis to help planners and stakeholders to control flood hazard.	Regional (Basin level)	
24	Other	Pond	Site Other	Patch scale (lawn in an urban park)
25	Wetland Phytorid treatment Other	Conservation and control of Phytoplankton's nutrients absorption and how it affects to the quality of water	Regional (Basin level) Other	Lake

Code	NBS Types	Elements Description	Scales	Description
26	Other		Regional (Basin level) National	
27	Other		Metropolitan Area	
28	SUDS Green roof/wall Agroforestry		Municipality Regional (Basin level)	
29	SUDS Green roof/wall River park Agroforestry Wetland Park		Municipality Metropolitan Area	
30	Agroforestry Other	Soil	Municipality	
31	SUDS Green roof/wall Wetland Rain garden Bioswale Permeable pavement Other	Retention basins; rainwater harvesting; constructed wetlands; detention basins; bioswales; rain gardens; green roofs; permeable pavements	Site Municipality Regional (Basin level)	
32	SUDS Other	Water harvesting, stormwater drainage, building gabions, planting next to the river	Neighborhood Municipality	
33	SUDS Wetland Rain garden Other	bio-filtration	Site Neighborhood	local community scale
34	Other	1) Transformation of concrete drainage channel into semi-natural waterway; 2) Planting trees along waterways, drainage corridors and parks; 3) Transformation of Sewer reserve into linear park and bike track	Neighborhood	
35	Other	Riparian corridor regeneration; Restauration and protection of coastal vegetation; Intensification of peri-urban home garden; Urban trees and vegetation	Regional (Basin level)	

Table A7. Summary of cases reviewed

Code	Country	Location	Spatial	Policy Instruments	Actors
1	Denmark	Aarhus	Municipality	Regional	Public authorities Academic and research bodies
2	Denmark Sweden	Copenhagen Kristianstad	Site Municipality	Global Municipal	
3	France	Villeurbanne	Site		Academic and research bodies Water-related actors
4	Greece	Athens	Neighborhood Municipality Metropolitan Area		Academic and research bodies
5	Italy	Trento	Neighborhood Municipality		Water-related actors Industry, business and private sector
6	Italy	Rome	Metropolitan Area		Academic and research bodies
7	Italy	Rome	Metropolitan Area	Regional	Public authorities Civil society

Code	Country	Location	Spatial	Policy Instruments	Actors
					Academic and research bodies
8	Italy	Rescaldina	Municipality	Sub-national Municipal	Public authorities Academic and research bodies
9	Italy	Moncalieri	Metropolitan Area Regional (Basin level) Other	National	Public authorities Academic and research bodies
10	Italy	Gorla Maggiore	Municipality	Regional Sub-national	Public authorities Civil society Academic and research bodies Water-related actors
11	Italy	Gorla Maggiore	Municipality	Regional Sub-national	Public authorities Civil society Academic and research bodies Water-related actors
12	Italy	Avola	Municipality		Academic and research bodies
13	Poland Slovakia	Wroclaw Bratislava	Municipality	Global Regional National Municipal	Public authorities Civil society Academic and research bodies
14	Slovenia	Ljubljana	Municipality Regional (Basin level)	Regional	Public authorities Civil society
15	Spain	Barcelona	Municipality		Public authorities Civil society Academic and research bodies Industry, business and private sector
16	United Kingdom	London	Metropolitan Area	Sub-national National	Public authorities Civil society Industry, business and private sector
17	United Kingdom	Liverpool	Site Neighborhood	Local	Civil society
18	Germany Germany Netherlands Norway Cuba	Andernach Heidelberg Rotterdam Oslo Havana	Municipality	Municipal	Public authorities Civil society Academic and research bodies
19	Spain China	Barcelona Shanghai	Municipality	Municipal	Public authorities
20	Portugal United Kingdom Iran	Xarrama Foyle Shazand	Municipality Regional (Basin level)	Global	Academic and research bodies
21	United Kingdom Colombia Ecuador India	London Bogotá Guayaquil Chennai	Regional (Basin level)	Global	Academic and research bodies
22	India	Nagpur City	Municipality	Global National	Public authorities Civil society Academic and research bodies Water-related actors Industry, business and private sector
23	Iran		Regional (Basin level)		Academic and research bodies
24	China	Shanghai	Site Other		

Code	Country	Location	Spatial	Policy Instruments	Actors
25	China	Jiangsu	Regional (Basin level) Other	National	Public authorities Academic and research bodies Water-related actors
26	China	-	Regional (Basin level) National	Global	Academic and research bodies Water-related actors Industry, business and private sector
27	Cambodia Indonesia Lao PDR Myanmar Timor Leste Vietnam	-	Metropolitan Area	Global	Academic and research bodies Water-related actors
28	Bolivia	Santa Cruz de la Sierra	Municipality Regional (Basin level)	Municipal	Public authorities Civil society Academic and research bodies
29	Canada	-	Municipality Metropolitan Area	Municipal	Public authorities Civil society
30	United States	Texas	Municipality	Regional Municipal Local	
31	United States Ethiopia	Detroit Addis Ababa	Site Municipality Regional (Basin level)		Academic and research bodies
32	Ethiopia Tanzania	Addis Ababa Dar es Salaam	Neighborhood Municipality		Public authorities Civil society Water-related actors
33	Kenia	Nairobi	Site Neighborhood		Public authorities Civil society
34	Australia	Melbourne		Municipal	Public authorities Civil society Water-related actors
35	Vanuatu	Port Vila	Neighborhood Regional (Basin level)	Regional	Public authorities Civil society

Chapter 5 - Appendix A

CE principle: Regenerating natural capital - Water quality data

Data related to water quality as evidence on the performance on preventing pollution published by three secondary sources: the Catalan Water Agency (ACA, *Agència Catalana de l'Aigua*), Barcelonarius, and a scientific publication (Table A8). The analysis uses the parameters established in three regulatory instruments for water use as currently, these are the regulations establishing the limits for reuse purposes (Table A9).

Water quality includes a variety of parameters and systems; however, this study provides a general picture of the river and aquifer water qualities since 1996. Thus, it focuses on the presence of specific nutrients, nitrates (mg NO_3/L), phosphorus (mg PO_4/L), and ammonium (mg NH_4/L), which are incorporated into various water regulations, and as the nutrients with more data available for the period analyzed. Under the regulatory instruments for water use, the existing limits of these nutrient parameters determine the roles of NBS and WRT for dealing with the presence of excessive nutrients, and calls for additional actions for reuse and recovery of resources. The figures derived from this search distinguish the data sources, the years, and the accepted regulatory limits for water use as horizontal lines. Data on concentration ranges in the Besòs River for nitrates, ammonium, and phosphates are included, corresponding to NBS data, as the constructed wetlands. Similarly, nitrate and ammonium concentration ranges are included in the aquifer and the WRT data, but no data on phosphates were identified.

As presented in Table A8, the ACA (2021) published data for the river from 1996 to the present (2021), and for the aquifer from 2007 to 2019. Also, the data published by Barcelonarius (Universitat de Barcelona, 2021), an academic observatory for river quality that has collected data from 1998 to 2020 (Fortuño et al., 2018, 2019, 2020; Prat, Fortuño, Rieradevall, Acosta, Bonada, Pace, et al., 2015; Prat et al., 2009, 2010, 2011, 2013, 2014, 2017; Prat, Fortuño, Rieradevall, Acosta, Bonada, Castro, et al., 2015). Conversion factors were applied to integrate the data from the Barcelonarius project, which were presented as nitrates (N-NO_3^-), phosphates (P-PO_4^{3-}), and ammonium (N-NH_4^+) and converted to 4.43 * mg NO_3/L; 3 * mg PO_4/L; and 1.3 * mg NH_4/L, respectively.

Finally, the scientific publication on the potential uses of groundwater in the area contains data from the Besòs river and aquifer from 2007 to 2014 (Jurado et al., 2017). Quantitative data come from the desk review to analyze the technical response to water quality. The descriptive analysis is supported by qualitative data gathered from the literature, observations, and interviews. The river data is associated with the NBS performance, as no specific data or monitoring are available (to the best of our knowledge). The WRT is associated with data on the aquifer's water quality, as it establishes an input parameter; its output is provided by performance data from (Scattareggia, 2020).

Table A8. Details on the data sources for water quality

SOURCES	POINTS	ELEMENT	1996-2000	2001-2005	2006-2010	2011-2015	2016-2021
(*Agència Catalana de l'Aigua* - ACA, 2021)	River ACA 1100300	River	1996/07 1996/12 1997/07 1998/04 1998/09 1999/01 1999/05 2000/07 2000/09	2001/10 2002/01 2002/07 2003/01 2003/07 2004/02 2004/05 2005/07 2005/10	2006/07 2006/10 2007/06 2007/07 2008/02 2008/05 2008/06 2008/10 2009/06 2009/07 2009/09 2010/05 2010/06 2010/09	2011/05 2011/09 2012/07 2013/06 2013/10 2013/12 2014/05 2014/07 2014/11 2015/05 2015/06 2015/09 2015/11	2016/07 2016/11 2017/07 2017/11 2018/04 2018/05 2018/07 2018/11 2019/03 2019/05 2019/06 2019/12 2020/12 2021/01
	Aquifer AQ08015-0016 AQ08194-0001	Aquifer			2007/07 2008/05 2009/06 2010/05	2011/05 2013/10 2015/09	2018/04 2019/03
Barcelonarius Project (Fortuño et al., 2018, 2019, 2020; Prat, Fortuño, Rieradevall, Acosta, Bonada, Pace, et al., 2015; Prat et al., 2009, 2010, 2011, 2013, 2014, 2017; Prat, Fortuño, Rieradevall, Acosta, Bonada, Castro, et al., 2015)	B1 (41.455044, 2.194919)	River	1998/04	2004/05	2008/06 2009/04 2010/06	2011/06 2012/04 2015/06	2016/04 2017/05 2018/06 2019/05 2020/06
(Jurado et al., 2017)	16 observation points Location not available, but shown in figure	River and Aquifer			2007/07 2008/02 2008/10 2010/05	2013/12 2014/07	
(Scattareggia, 2020)	*Pect Besòs* 1 observation point at a pilot plant	Aquifer					2020/02

The analysis uses the parameters established in three regulatory instruments for water use as currently, these are the regulations establishing the limits for reuse purposes: the Spanish royal decrees regulate the parameters for the maintenance of the river ecological flow (RD 849/1986) (*Real Decreto 849/1986, de 11 de Abril, Por El Que Se Aprueba El Reglamento Del Dominio Público Hidráulico, Que Desarrolla Los Títulos Preliminar I, IV, V, VI y VII de La Ley 29/1985, de 2 de Agosto, de Aguas.*, 1986); the drinking water regulation, which establishes the sanitary criteria for the quality of water for human consumption (RD 140/2003) (*Real Decreto 140/2003, de 7 de Febrero, Por El Que Se Establecen Los Criterios Sanitarios de La Calidad Del Agua de Consumo Humano*, 2003); and the River Quality Directive (RD 817/2015) *(Real Decreto 817/2015, de 11 de Septiembre, Por El Que Se Establecen Los Criterios de Seguimiento y Evaluación Del Estado de Las Aguas Superficiales y Las Normas de Calidad Ambiental*, 2015). There is a local regulation for Barcelona irrigation and water quality parameters (BCN/2020) (Ajuntament de Barcelona, 2020), which proposes some parameter values, with the RD 140/2003 and its amendments by Royal Decree 902/2018 as mandatory compliance regulations (Table A9).

Table A9. Details on the data sources for water quality

Year	Water quality regulation	Nitrates (mg NO_3/L)	Phosphates (mg PO_4/L)	Ammonium (mg NH_4/L)	Observations
2020	**Barcelona irrigation water quality parameters (BCN/2020)**	0 - 10	0 - 2	0 - 5	**Accepted limits**
2015	**River Quality Directive (RD 817/2015)**	10	0.2	0.2	**Accepted limits** Very good - Good
		25	0.4	0.6	**Accepted limits** Good - Moderate
2003	**Drinking water (RD 140/2003)**	50	Not measured	0.5	**Accepted limits**
1986	**Maintenance of the ecological flow of rivers (RD 849/1986)**	50	0.7	1	**Accepted limits**

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