Mainstreaming sustainable innovation: unlocking the potential of nature-based solutions for climate change and biodiversity

Abstract

Sustainable innovation has been widely acknowledged as the key driver for societal transitions towards sustainability. Recently, there have been widespread calls to mainstream nature-based solutions (NBS), a form of socio-ecological-technical innovation, to address urban sustainable development concerns especially for climate change and increasingly for biodiversity loss. However, what mainstreaming means and how sustainability-oriented innovations like NBS can be mainstreamed to benefit multiple agendas remains underexplored. In this paper, we first critically discuss existing literature on mainstreaming and argue that the common understanding of the concept rooted in policy sciences does not fit the governance context in which urban innovations like NBS are being shaped and adopted. Drawing on sustainability transitions and urban studies literature, we then propose a new approach that promotes the use of NBS to deliver multiple sustainability goals simultaneously. We argue that mainstreaming NBS relies on identifying and acting on a certain set of key forms of interventions - stepping stones - that can facilitate the embeddedness and maintenance of NBS across urban infrastructure regimes. Based on case studies of existing European practices, we identify pivotal stepping stones and promising pathways for mainstreaming NBS for climate change and biodiversity separately and explore what this means for addressing both agendas simultaneously.

Keywords: *Mainstreaming; Sustainable innovation; Urban; Nature-based solutions; Climate change; Biodiversity*

Highlights:

- Mainstreaming innovations involves both normalization and the retention of novelty
- Stepping stones are generic forms of viable interventions proven in practice
- Pathways for mainstreaming can be created by assembling stepping stones
- Key stepping stones vary depending on goals of nature-based solutions (NBS)
- Acting on shared stepping stones can mainstream NBS for multiple goals

1. Introduction

The idea of working with nature for sustainability is not new and has historically been applied through various concepts, including ecosystem services, natural capital, green infrastructure and ecosystem-based climate adaption. Recently, this phenomenon has gained new momentum through the growing discourse and practice of nature-based solutions (NBS), defined as "actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (Cohen-Shacham et al., 2016, p. 4). NBS can be considered an umbrella term covering a range of approaches that work with nature to achieve innovative solutions to sustainability challenges. They are marked by a focus on multi-functionality through their potential to realize various socio-economic and environmental goals (Cohen-Shacham et al., 2016; Nesshöver et al., 2017).

At a global scale, growing interest in nature-based solutions is largely being driven by the climate crisis (IPCC, 2019). While concerns have been raised about the possibility that some poorly planned natural climate solutions such as monoculture plantations may undermine wider sustainability goals, especially biodiversity (Seddon et al., 2020; 2021),NBS are also increasingly prominent within the biodiversity policy arena (IPBES, 2019). For example, the first draft (called the "Zero Draft") of the post-2020 biodiversity framework published in 2020 included the target to: "By 2030, increase contributions to climate change mitigation adaptation and disaster risk reduction from nature-based solutions and ecosystems based approaches" (CBD, 2020). More recently, benefiting biodiversity has been reemphasized as a prerequisite for validating an NBS (IUCN, 2020; Seddon et al., 2021).[1] In the urban context specifically, the European Commission's programme on Sustainable Cities and Communities emphasises the multiple benefits that NBS can generate, and a whole host of transnational municipal networks and conservation organisations are also championing NBS for urban sustainable development and for cities' contribution to addressing global climate and biodiversity challenges.

While there is a wide literature on the benefits of NBS (Kabisch et al., 2016; Walmsler et al., 2017), their adoption and implementation in cities largely remains piecemeal due to various technical, cultural and institutional barriers (Sarabi et al., 2019; 2020). As a result, there are widespread calls to mainstream NBS, i.e., to increase their uptake across a variety of sectors, scales and stakeholders (Bush and Doyon, 2019; Faivre et al., 2017; Xing et al., 2017), including for climate change (Frantzeskaki et al., 2019; Kabisch et al., 2016; Wamsler et al., 2017; 2020) and biodiversity (Cohen-Shacham et al., 2019; DG for Research and Innovation, 2020). Despite the broad endorsement of the need for mainstreaming, questions remain concerning what mainstreaming means and how it can be achieved to address multiple sustainability challenges in cities. This is especially significant given that careful planning is needed to ensure that NBS can realise different sustainability goals simultaneously and that trade-offs between different outcomes are managed and mitigated where possible (Choi et al., 2021). Yet the question of what mainstreaming NBS involves is rarely subject to critical scrutiny. For the most part, mainstreaming is used interchangeably with the idea of increasing uptake across more

[1] While NBS are clearly defined as having simultaneous benefits for biodiversity and human well-being (IUCN, 2020; Seddon et al., 2021), this is not yet an approach that will work in all contexts, especially in urban settings. For example, a green roof providing cooling for a building and the wider environment, lowering carbon use and emission, and contributing health and well-being benefits, which did not directly improve biodiversity, should not be discounted as not a valuable urban NBS. Therefore, we suggest that NBS should be guided by the principle of doing 'no harm' to biodiversity rather than each individually having to contribute to its benefits. On this basis, in this paper we explore how NBS can be mainstreamed to realize their full potentials, i.e., simultaneously addressing climate and biodiversity (and other sustainability) goals in cities.

(and more diverse) actors and/or in terms of 'scaling up' NBS so that they are used more extensively (Fastenrath et al., 2020). In this paper, we suggest that engaging with how, by and for whom NBS could or should be mainstreamed requires a wider discussion on the conceptualization of mainstreaming. To this end we bring insights from the field of innovation research and sustainability transitions to the debate on mainstreaming within the field of policy science to suggest that there is a need to move beyond conventional approaches which focus on policy integration to focus on how NBS come to be normalised within urban policy and practice. Based on this approach, we review existing practice in European cities and explore the ways in which NBS can be mainstreamed to contribute to urban climate and biodiversity goals.

The remainder of this paper is structured as follows: Section 2 critically discusses existing literature on mainstreaming and argues that the common understanding of mainstreaming, which has its roots in policy sciences, has limitations that make it difficult to apply to the governance and promotion of urban sustainable innovations like NBS. Drawing on sustainability transitions and urban studies, we instead propose a new approach that can promote the use of NBS to deliver multiple sustainability goals simultaneously. Section 3 describes how we derive and test our approach using qualitative case studies and section 4 reports on the findings regarding the key forms of interventions (or what we term 'stepping stones') and promising pathways for mainstreaming NBS for climate and biodiversity separately as well as for both agendas at the same time. We conclude the paper by discussing the implications for mainstreaming NBS in section 5.

2. Conceptualizing mainstreaming for sustainable innovation

Mainstreaming is a concept that has been used in different fields with different meanings. In a general sense, mainstream is used to signify a prevailing trend or opinion, such that to be or become mainstream is to belong to or be characteristic of an "established tradition [or] field of activity", to be conventional (Oxford English Dictionary, online). Within the field of environmental governance, with its roots in policy sciences, it is this kind of approach to mainstreaming which prevails such that mainstreaming is intended to signify processes through which new ideas, instruments, or interventions come to be *part of* or *integrated into* established traditions, fields of activity and conventions. Yet this commonsense approach neglects the ways in which mainstreaming requires a change in the rules of the game which challenges existing ideas, attitudes, or activities that are considered normal, in turn disrupting the "natural order of things" (Picciotto, 2002: 323). Literature on socio-technical innovation has pointed to the importance of disruption and reconfiguration as the way in which new entities and interventions – from solar panels to electric vehicles or, in this case, NBS – come to be established as the "new normal". Here we review each of these literatures in turn, arguing that when it comes to NBS, as a form of sustainable innovation that entails socio-material intervention in the urban fabric, mainstreaming as policy integration offers an overly narrow conceptual starting point for understanding how such interventions come to be normalized and that the literature on socio-technical transitions offers the basis for an alternative approach.

2.1 Mainstreaming in environmental policy literature

In literature on environmental governance, mainstreaming is often considered to be a specific form of Environmental Policy Integration (EPI) (Runhaar et al., 2014; Karlsson-Vinkhuyzen et al., 2018). EPI is the process of integrating one or more emerging legitimate environmental concerns into the decision-making processes of existing non-environmental sectors (Nilsson and Persson, 2003; Persson et al., 2016; Russel et al., 2018), such as integrating climate policy

into the land use sector and integrating biodiversity considerations into the agricultural sector. The rationale underlying EPI is that environmental problems are cross-cutting issues, with multi-sector causes and multi-sector effects. Mainstreaming here is seen as an effective approach to deal with the problem by increasing the cohesion between policies and the opportunity of taking advantage of synergies (Kok and De Coninck 2007; Rauken et al., 2014).

Influenced by this interpretation of mainstreaming, researchers have explored many themes, including: the factors that render mainstreaming effective in government dominated contexts (e.g., Gupta and Grijp, 2010; Kok et al., 2008; Persson and Klein, 2009); the barriers and levers for mainstreaming (e.g. Biesbroek et al., 2013; Karlsson-Vinkhuyzen et al., 2018; Runhaar et al., 2018); and different mainstreaming strategies (e.g. Uittenbroek et al., 2013; Wamsler, 2015; Wamsler and Pauleit, 2016). For example, researchers examining the mainstreaming of biodiversity have investigated how mainstreaming is taking place in various production landscapes and economic sectors (Cowling et al., 2008; Karlsson-Vinkhuyzen et al., 2017), international policy domains (Kok et al., 2010), and development planning and national policies (Huntley, 2014; Whitehorn et al., 2019). When it comes to mainstreaming NBS, research is also adopting the EPI approach to explore the mainstreaming of ecosystem-based adaption or natural climate solutions (Wamsler et al., 2014; Wamsler et al., 2020). Yet, we find there are three key shortcomings with this approach to mainstreaming.

First, the EPI approach to mainstreaming tends to assume that it has a strong element of steering, initiated and led by government(s) (Karlsson-Vinkhuyzen et al., 2017; Russel et al., 2018). This narrow interpretation pays limited attention to the broader realm of environmental governance with its multiple forms, diversity of actors and modes of steering (Rhodes, 2007). Moreover, NBS as urban sustainability experiments involve changing the established socio-material relations and assemblages that constitute the urban governance and go beyond the institutional boundaries of the local state (Bulkeley and Castán Broto, 2013). Given that urban experimentation is an increasingly crucial mode of environmental governance, we suggest that the understanding of mainstreaming needs to look beyond the EPI literature when it comes to sustainable innovations or experiments to take into account the multi-level governance of urban sustainability and the ways in which various interventions, projects and schemes led by different urban actors generate urban governance.

Second, mainstreaming as envisaged within the EPI literature tends to imply a unidirectional movement where one issue is integrated into another existing policy domain. The focus is often on garnering indirect political commitment from other actors by integrating a new topic into strategic framing for another policy area, often without changing organizational structure and routines. Consequently, institutional change has barely been acknowledged in current literature as an integral part of mainstreaming (Uittenbroek, 2015). However, sustainable innovations have the potential to transform institutions, social practices, and cultural norms. NBS, for example, can not only functionally replace grey infrastructure to deliver and manage urban services, but they can also simultaneously be designed to redress existing inequalities (Tozer et al., 2020) and improve social justice outcomes (Toxopeus et al., 2020), or to promote urban resilience and economic regeneration (Frantzeskaki, 2019). This, however, requires breaking through the incumbent systems that are bound by material, institutional and cognitive obduracy that are resistant to change (Sengers et al., 2019). For example, the prevailing institutional and cultural mindset favoring development and growth makes it difficult for policy-makers and planners to make firmer decisions around building regulations to preserve the natural environment within cities. An expanded understanding of mainstreaming is needed to capture the broader dynamics shaping the integration of sustainable innovations into urban development.

The third limitation of the EPI approach to mainstreaming is its focus on individual issues such that it overlooks the ways in which synergy between emerging environmental objectives can be generated. For example, with some exceptions (Burch et al., 2014; Kupika and Nhamo, 2016), studies on mainstreaming climate change adaptation seldom discuss how mainstreaming adaptation policy can assist the mainstreaming of biodiversity or vice versa, although they recognize biodiversity contributions and benefits (e.g. Huntley and Redford, 2014; Uittenbroek, 2015; Runhaar et al., 2018). However, sustainable innovations can impact multiple domains at once and focusing solely on one outcome makes it difficult to consciously navigate tradeoffs, let alone promote synergies. An intended feature of NBS is their multifunctionality and potential to address multiple sustainability challenges simultaneously. To unlock and maximize such potential, a reconceptualization of mainstreaming is needed.

2.2 Mainstreaming from sustainability transitions and urban governance perspectives

In contrast to the EPI approach, research on (urban) sustainability transitions draws attention to the importance of taking a broader approach that examines how novel responses to sustainability challenges are resisted or embedded (Bulkeley et al. 2015). Technologies, governance practices, behaviors, institutional structures etc. are embedded into wider systems, or 'regimes', that are historically configured and path-dependent, locked into established pathways of development that follow a logic of incremental socio-technical change (Geels, 2004; Fuenfschilling and Truffer, 2014). Stable regimes generate benefits for incumbent practices and technologies, creating norms that shape future development and often resisting disruptions or changes. Sustainable innovations like NBS are explicit interventions in urban infrastructure regimes, defined here as "the stable configurations of institutions, techniques and artefacts which determine 'normal' sociotechnical developments in a city and thus shape general urban processes and the urban metabolism" (Monstadt, 2009, p. 1937). Mainstreaming such forms of innovation thus involves disrupting and reconfiguring the regime to embed new technologies, practices, and institutions.

How urban infrastructure regimes change is a question that has occupied researchers across urban governance and transition studies. Socio-technical transition theories such as the multi-level perspective (MLP) provide insights on understanding change (and obduracy) to socio-technical systems (Geels, 2005; 2010). In this approach, shifts in technological regimes and related social practices occur in response to pressures from either experimental 'niches' or external forces ('landscape' in the transitions terminology). The MLP model elaborates the interaction among these three levels – regime, niche, and landscape, and implies that sustainability transitions occur through the emergence, alignment, and scaling up of radical socio-technical innovations (Grin et al., 2010). Literature in sustainability transitions has identified sustainable innovations as the seeds of change (Seyfang and Smith 2007; Seyfang et al., 2014) looking closely on the ways they create new practices, narratives and understandings of sustainability as well as viewing how they disrupt and transform infrastructure systems. More specifically in the urban context, transition studies point to experimentation in cities as a means through which to realise sustainability transitions and related system innovations (Bulkeley and Castán Broto, 2013; Seyfang & Smith, 2007; Smith & Raven, 2012).

Through experimentation, local governments, private sector, and civil society actors seek to demonstrate, experience, learn and challenge what it might mean to respond to urban sustainability problems (Bulkeley et al., 2015). Out of a multiplicity of interventions, emerging and fluid ideas, practices, expectations, technologies, and new social relations can be

developed and aligned into a new, potentially more sustainable socio-technical configuration (Pereira et al. 2018). One line of thinking suggests that such experiments come to be mainstreamed primarily through the process of 'scaling-up', defined by Rotmans and Loorbach (2008, p. 27) as applying 'a successful experiment at a higher scale level'. For many sustainability transitions scholars, scaling up implies that sustainable innovations that are initially unusual have become the dominant or mainstream practices (Grin et al. 2010; Loorbach and Rotmans 2006; Augenstein et al., 2020), which subsequently alter the governance structure (Bos and Brown, 2012).

Scholars from disparate fields have developed a range of frameworks to model upscaling and its processes (Lam et al., 2020). For example, by applying a transition management and multi-level perspective, van den Bosch and Rotmans (2008) considers the process of *deepening, broadening*, and *scaling up* to increase the impact of transition experiments, while adopting an acceleration mechanisms perspective, Gorissen et al. (2018) propose five processes to speed up sustainability transitions, namely *upscaling, replicating, partnering, instrumentalizing and embedding.* Despite the diverse ways to describe different sets of dynamics, the understanding of upscaling is generally limited to the extension and/or dissemination of new products, services, and models within different types of scales (e.g., spatial, temporal, jurisdictional, institutional, etc.) (see, for example, van Winden and van den Buuse, 2017; Fastenrath et al., 2020).

More recently, the prevailing idea of 'scaling' has been expanded, and to some extent, challenged. As upscaling is deemed necessary for sustainable innovations to increase their positive societal impacts, Lam et al. (2020, p. 3) argue that the achievement of significant implications does not 'exclusively involves levels or scales (e.g., of governance or quantity)' but can also involve changing values and mind-sets. Further, Augensteign et al. (2020, p. 143, emphasis in original) insightfully point out that 'scaling up from an experiment or a niche means that new ways of "doing, thinking, organizing" emerge in a given system as the new normal, rather than scaling or spreading one specific *element* within given and unchanged institutional structures'. In this sense, upscaling indicates 'a qualitative shift towards a structural transformation of a societal (sub) system' (Augenstein et al., 2020, p. 143).

More bluntly, as argued by Bulkeley et al. (2015), the issue is not the scaling of experiments, but instead the manner in which they come to be integrated into and reconfigure urban circulations, namely the flows of materials, capital, and organizing principles, etc. within a city system and beyond. Dynamic urban circulations reinforce existing economic and political structures, so "the insertion of experiments in particular urban milieu constitute attempts to reconfigure existing forms of circulations" (Bulkeley et al., 2015, p. 46). Therefore, if we are concerned with making experimentation matter as effective responses to climate change, then it is "a question of ensuring that they come to disrupt, reconfigure, and circulate through the more-or-less spatially extensive or socially-politically 'dense' networks of which they are already part, opening up cracks in the urban milieu that allow for other forms of possible urban futures to take hold" (Bulkeley, 2021, p. 10). The processes of embedding an experiment, redirecting and reconfiguring urban material and non-material flows, enable new assembling of ideas, people, power and resources and create the capacity to intervene in different urban contexts (Goh, 2019), which are what makes climate change experiments viable and vital (Hughes and Besco, 2018). Through such process, experiments can be embedded in urban systems and sustain themselves, while also maintaining their novelty as innovations (Castán Broto and Bulkeley, 2013). New rationales of nature and space production come to the fore and certain forms of metabolic circulation become viewed as normal (Castán Broto and Bulkeley, 2013). Experimentation can thus be sustained and gain 'momentum' in the city,

enabling urban sustainability transitions (Graham and Thrift, 2007). Therefore, we argue that mainstreaming sustainable innovation like NBS is best understood as a process through which these experiments and innovations are embedded into urban systems such that they reconfigure the flow of power, resources and materials and gain momentum to transform mainstream institutions, infrastructures, and social norms.

Disrupting regimes to enable mainstreaming is no easy task. Incumbent regimes are pointedly obdurate (Sydow et al., 2009; Uittenbroek, 2015). They are comprised of different domains which are interdependent and interrelated, and each of which also comprises a unique set of rules, norms, traditions and rationales that shape how people think and act (Fuenfschilling and Truffer, 2014; Holtz et al., 2008). Interventions in these domains that challenge established ways of thinking, doing, and organizing urbanism hold the potential to catalyze wider changes and further mainstream new sustainable innovations. Mainstreaming therefore relies on identifying key interventions or leverage points that can offer opportunities to catalyze the uptake and support the maintenance of sustainable innovations across the functional domains of urban infrastructure regimes.

In the rest of this paper, we apply this approach to mainstreaming to analyze how mainstreaming NBS involves the reconfiguration of the urban infrastructure regime to culturally, socially, politically, and economically normalize NBS. This approach allows us to examine how NBS can come to be regarded as both as a 'normal' part of urban development while still retaining 'novelty' by genuinely introducing new ways of thinking, doing and organizing and retaining space for experimentation and learning. We focus on how NBS can be mainstreamed to contribute to both climate change and biodiversity solutions in order to illustrate how this understanding of mainstreaming can be applied in order to reveal and further leverage synergies and tackle trade-offs between various sustainability outcomes.

3. Methodology

Our exploration of the mainstreaming of NBS builds on practices-based evidence that comes from comparative case-study analysis. Within the EU Horizon 2020 NATURVATION project,[2] a part of work is devoted to generating internationally comparative insights into the ways in which incumbent urban infrastructure regimes shape critical pathways for mainstreaming NBS innovations and how the conditions that limit their use can be overcome. We examine three empirical domains within urban infrastructure regimes that are key for the development and management of urban infrastructures, green spaces and the built environment: 1) *the regulatory domain*, which involves the governance, regulatory and legal frameworks that determine urban planning and infrastructure decision-making; 2) *the financial domain*, which relates to the availability of capital funding and willingness in the financial sector to invest in NBS as well as the capacity of the insurance industry to include such interventions in their calculations; and 3) *the urban development domain*, which is about the interests, practices, technologies of the urban development industry involved in the provision of infrastructures and housing in cities (Dorst et al., 2018). Each of these three domains has a different set of associated stakeholders and actor groups, providing different lenses through which to look at infrastructure regimes (see Table 1). It is noteworthy that there are some overlaps in the types of stakeholders included across the three domains. For instance, some nature conservation NGOs were interviewed as part of the urban development domain if they actively engaged with design and construction activities. The analysis was done individually concerning the regulatory, financial and urban development domains of six countries – United Kingdom (UK),

[2] See acknowledgement.

Germany, Hungary, Spain, Sweden and the Netherlands – as well as that of the EU. Each of these qualifies as one case. Drawing upon a desk study of grey literature and policy documents, interviews, and a participant observation placement for each case, detailed findings for each domain in each of the seven cases were documented in 21 working papers.

Table 1. The stakeholder groups making up each of the functional domains (Source: adapted from van der Jagt et al. (2020))

Regulatory domain	Financial domain	Urban development domain
• Supra-national government • National government • Sub-national government (regional, urban) • Government agencies (e.g. water dept.) • Lobby groups/Trusts/Charities • Politicians • Policy advisory organizations (e.g. knowledge institutes)	• Development companies • Architects and landscape designers • Utilities • Transport infrastructure providers • Housing providers (e.g. housing corporations) • Urban development consultancies • Large landowners	• Banks • (Re-)Insurance companies • Institutional and other investors • Financial consultants • Foundations • Networks of financial actors • Rating agencies

The project team then identified the key barriers and opportunities for mainstreaming NBS in the different domains (i.e., regulatory, finance, and urban development) based on the evidence collected from the comparative case-study analysis. This analysis led to the identification of key interventions that are promising in their potential to promote the wider uptake of NBS. As many of the identified interventions overlapped across the regulatory, urban development, and finance domains, the project team further synthesized these actions into a generic category of interventions, or what we termed 'stepping stones' (process overview provided in van der Jagt et al. (2020)). This process involved iterative analysis and discussions. In total, 20 stepping stones were identified as pivotal for advancing the uptake of NBS.[3]

These stepping stones cut across different functional domains of urban infrastructure regimes and different urban contexts, and can be activated by a range of urban actors, including policymakers, professionals, communities, businesses, and others. When translated into detailed, context-specific interventions, they can open up the possibilities for alternatives to current rules, norms, traditions and rationales to promote the embeddedness and maintenance, namely the mainstreaming, of NBS. Individually, each of the stepping stones can catalyze change towards the uptake of NBS, but when they are aligned to reinforce each other – when they create a pathway – they can generate greater momentum for mainstreaming NBS than individual actions would be able to achieve. Given that stepping stones can be aligned in different ways, there can be multiple pathways available for mainstreaming NBS.

Different combinations of stepping stones will be relevant for NBS mainstreaming depending on the urban context and the sustainability challenges that actors are seeking to address. For this paper, we analyzed which of these 20 stepping stones are promising in their potential to mainstream NBS specifically as a solution to a) climate change challenges, b) biodiversity challenges, and c) both climate change and biodiversity challenges simultaneously. We analyzed the 21 working papers on the comparative case-study analysis to identify

[3] See Table 1 in the Supplementary Material.

interventions that were effective in enabling the uptake of NBS geared towards different urban sustainability challenges (including climate and biodiversity - our focus in this paper). For climate change, we focused on the effects of NBS on climate change mitigation and adaption. For biodiversity, besides conservation and restoration that are fundamental elements to the CBD, we also focused on the contributions of NBS to create a thriving city, i.e., ensuring that nature's contribution to people is also preserved and enhanced, as highlighted by the Zero Draft of the Post-2020 Global Biodiversity Framework (Xie and Bulkeley, 2020). We analyzed this data to determine which of the general 20 stepping stones are likely to be particularly important in order to mainstream NBS to address climate change and biodiversity challenges specifically.

It is important to note that focusing on stepping stones that are specific for one agenda could end up marginalizing the mainstreaming potential of NBS for the other. Moreover, it could lead to missed opportunities for creating synergies and result in conflicts or redundancy. Since it is widely advocated that climate change and biodiversity should be addressed together, the efforts to mainstream urban NBS towards these two goals should be united. Therefore, we identified the common stepping stones that work for both climate and biodiversity governance and proposed potential pathways that can mainstream NBS for both climate and biodiversity goals. Figure 1 below summarizes the analytical process of this research.

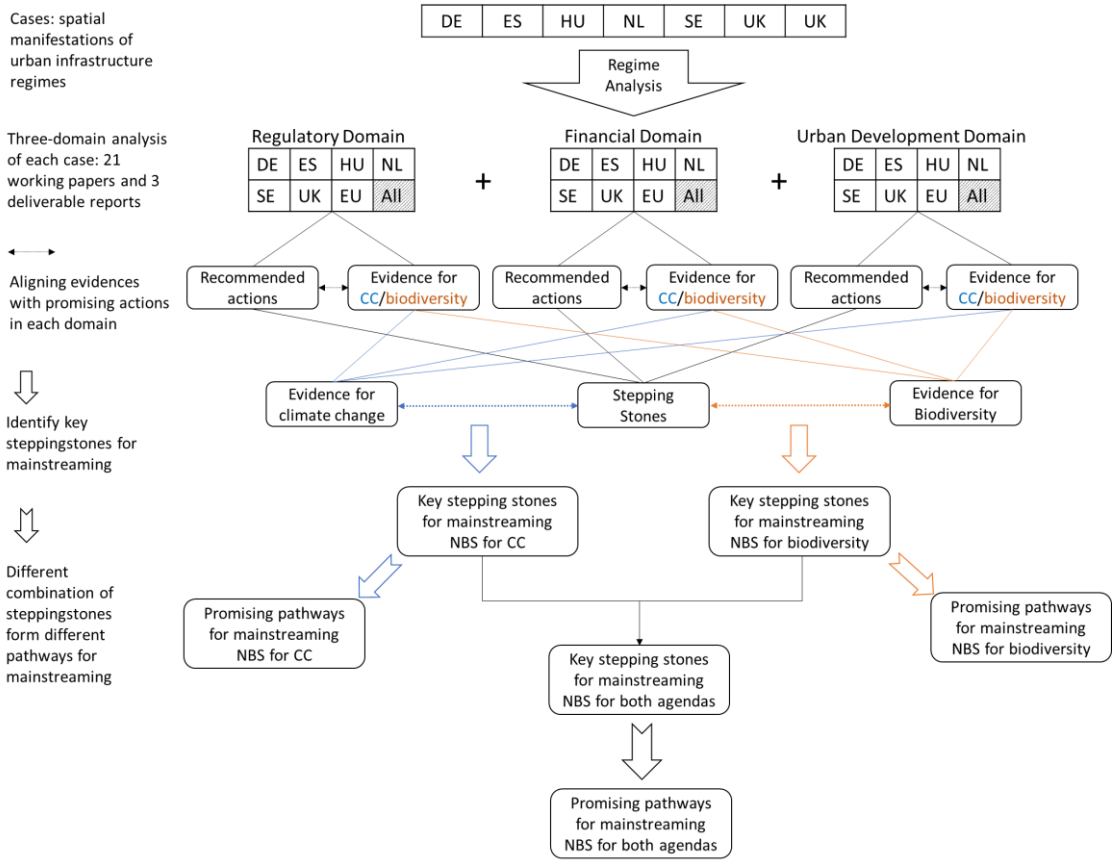

Figure 1. Analytical process

4. Mainstreaming NBS for climate change and biodiversity

The primary challenges for and the main actors involved in governance vary for different urban sustainability agendas, so there is variation in the key stepping stones that can disrupt

established domains of the incumbent urban infrastructure regimes to mainstream NBS. In this section, we demonstrate the pivotal stepping stones and emergent mainstreaming pathways for NBS that can address 1) climate change, 2) biodiversity and 3) both at once.

4.1 Mainstreaming NBS for climate change: key stepping stones and potential pathways

Tackling climate change and building resilience have become strategic priorities for many cities across the world. However, there is a long-standing preference for grey infrastructure over NBS in urban development decision-making. This status quo is reinforced by urban development practices that value, for example, engineering expertise, established quantitative data, quick results, and single-objective solutions with proven effectiveness. The adoption of urban NBS for climate change mitigation and adaptation has been limited, obstructed by a lack of data and understanding of the benefits of NBS.

Several stepping stones hold great potential for overcoming these challenges and offering opportunities to mainstream NBS. For example, **aligning NBS with urban strategic priorities** can access not only the public and institutional budget and existing capacity dedicated to urban climate agendas, but also those earmarked for other related prioritized paradigms in cities (e.g. circular economy, healthy urban living etc.). For example, the Environmental and Planning Act of the Netherlands emphasizes health promotion and protection as a key pillar of spatial planning, and aligning NBS that have climate benefits for the health goals, emphasizing their benefits through supporting recreation, social interaction, mental wellbeing, and absorbing pollutants, can promote their wider uptakes. **Generating partnerships** between public, private and third sector organizations and **creating intermediaries** that can work across sectors and address persistent institutional and knowledge silos that lead to disinterest in multi-functional NBS are also found to be influential in promoting mainstreaming. For instance, the city of Barcelona established the Urban Ecology Directorate to bring together the expertise of different departments (Environment, Planning, Mobility) for policymaking and for coordinating the development and delivery of the city's climate change plans, in which urban greening plays an important role.

A prominent barrier for mainstreaming NBS for addressing climate challenges is the high financial cost associated with urban greening measures in dense cities. Although understanding of the various benefits of NBS (e.g., health and well-being) is increasing, developers often do not consider such wider benefits since they take the form of public goods that are deemed to bring little benefits to developers. As there is a growing interest in the financial sector in dealing with urban risks associated with climate change,[4] **stimulating institutional investment for risk reduction** and **engaging the insurance sector** can not only direct both public and private investments and funds towards NBS, but also bring industry knowledge (e.g., insurers' expertise on risk evaluation) into the development of NBS. For instance, the Dutch insurance firm Achmea uses its damage cost data to inform homeowners and municipalities of the climate risk of a specific house or area through labeling (BlueLabel), which can increase the value of urban NBS and make investments more effective. The insurance sector can also act to convince other urban stakeholders (governments, financial institutions) to adopt or invest in NBS and can price climate change-related risks and reflect such risks in premiums charged to clients, which incentivizes customers to implement NBS.

In addition, **improving data and monitoring** and developing **valuation models** are both critical since they can prove the effectiveness of NBS and further support the engagement of - and

[4] For example, the Task Force on Climate-related Financial Disclosures (TCFD) continues to drive international discussion on climate risk and discourse.

collaborations between - stakeholders. The 'Green Benefit Planner' (GroeneBaten Planner) is a valuation tool developed in the Netherlands, which can provide an estimate of the monetary value associated with NBS, making it easier to include them into investment decisions. The development of evidence can be facilitated by **demonstration projects**, which can not only showcase the multiple innovative workings of NBS to build up awareness and knowledge, but also demonstrate the performance of NBS in combating climate risks and in generating benefits for urban ecology, local community and wider society. For example, in response to flooding, the UK Environment Agency invested in a large multi-year pilot project in natural flood management, complementing existing expertise in grey infrastructure engineering. Other important stepping stones that we identified include: **provide a public mandate** (e.g., tender and procurement policies, statutory plans, and mandatory measures), **provide economic incentives** (such as the Green Roof Subsidies provided in Hamburg), **build co-finance arrangements** (such as the Local Crowdfunding platform created in the Netherlands for financing local NBS), and **grow practitioner expertise** (such as the Green and White Paper on urban green spaces provided by the Federal Government of Germany).

Each of the stepping stones listed above is promising in its potential to catalyze and support NBS mainstreaming for responding to climate change. However, they also face certain constraints. One way to ensure that they can reach their full potential is to align them and implement them together. For example, **stimulating institutional investment for risks reduction** can unlock and (re)direct existing and new funding earmarked for climate adaptation measures to NBS. Nevertheless, financial institutions often rely on quantifiable data to make investment decisions. Making the case for NBS for climate adaptation to draw investments thus requires **advancing valuation models** that can specify their (monetized) benefits and costs. Whilst different urban stakeholders and financiers can each make significant contributions to fund and implement NBS, **building co-financing arrangements** within and among them can ensure that NBS that might not be cost-effective for any one actor alone are financially viable. For example, a local crowdfunding platform – Voor je Buurt (For your Neighbourhood) – in the Netherlands plays a key role in bringing together several funding streams for co-financing NBS. Co-funding NBS through new or existing financial instruments (e.g. green bonds) is much more likely to render NBS cost-effective, since it can enable all involved stakeholders to share not only the cost but also the overall risks of developing and maintaining NBS. **Engaging the insurance sector** is particularly critical in such collaborations, as insurance firms have significant expertise on damage cost reduction and their close links with other key stakeholders (e.g., government, rating agencies, firms and property owners) also make them a critical influencer and partner in developing urban NBS. These four stepping stones reinforce each other and, together, they can form a promising mainstreaming pathway – *Invest in nature-based solutions to reduce climate risk* – to stimulate the generation of new forms of investment and workable business models for NBS.

Aligning different but mutually supportive stepping stones together can form other promising pathways for mainstreaming NBS for urban climate governance. Figure 2 below presents four pathways which we have identified as having particular promise.[5]

[5] See details of these pathways in Tozer and Xie (2020).

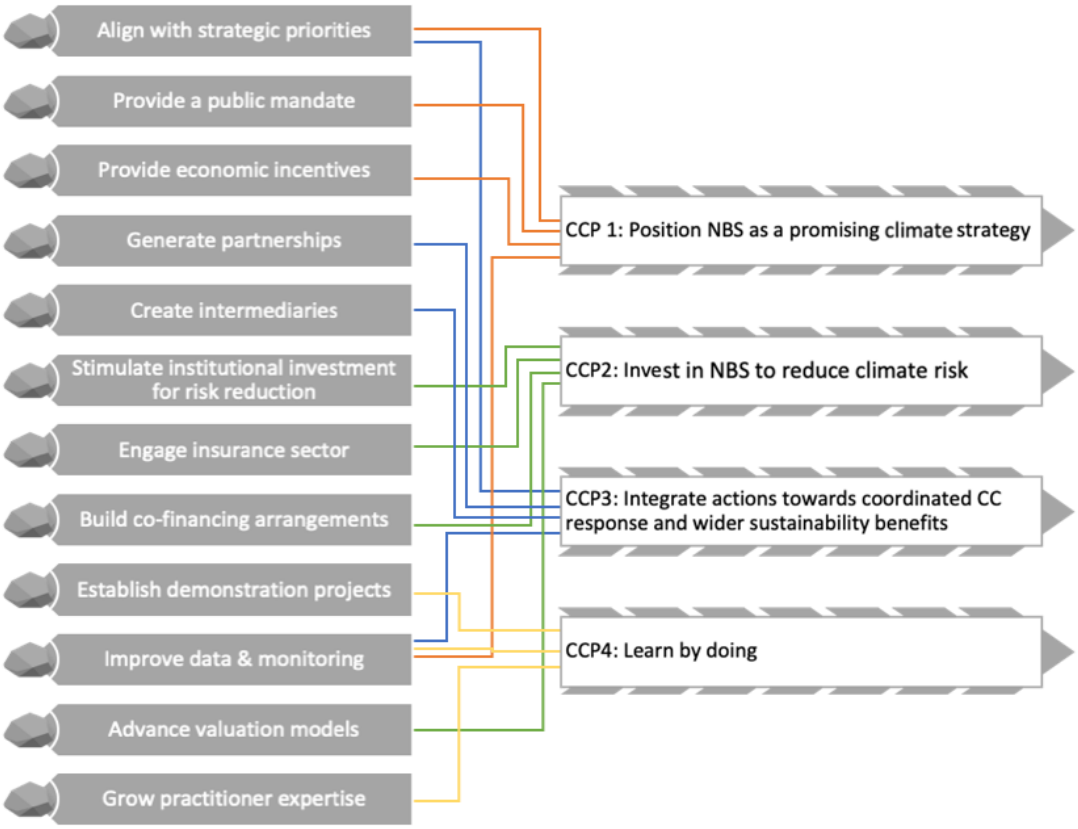

Figure 2. Key stepping stones and promising pathways for mainstreaming NBS for climate change mitigation and adaptation

4.2 Mainstreaming NBS for biodiversity: key stepping stones and potential pathways

Compared with climate change, biodiversity has been relatively marginalized in urban policymaking and planning process (Veríssimo et al., 2014; Legagneux et al., 2018). For a long history of urban development, cities were regarded as separated from nature, and such dualistic thinking resulted in the persistent neglect of biodiversity in urban governance as well as of cities in biodiversity governance. Despite local and subnational governments increasingly being recognized for their critical roles in global biodiversity governance (Bulkeley et al., 2021) and the fact that NBS have come to be seen as a key approach through which effective urban biodiversity governance can be achieved (Díaz et al. 2019; CBD 2020), research that examined NBS projects in European cities found that only a little over a third (351 out of 976) NBS have explicit biodiversity goals and actions (Xie and Bulkeley, 2020). Mainstreaming urban NBS to address biodiversity concerns requires shifting existing thinking and practice, and this can be achieved through a set of key stepping stones.

Regulate for No Net Loss is one of those critical stepping stones. In the UK, the proposed Biodiversity Net Gain policy require developers to achieve 10% net biodiversity gain through impact mitigation first and then on-site enhancement or offsetting elsewhere. Such regulation can incentivize greater investment in NBS initiatives that can conserve biodiversity or compensate its loss in one area with gain elsewhere. Another key intervention is to align biodiversity goals as well as NBS with other **strategic priorities** in cities to piggyback on existing prioritized agendas (such as climate adaptation and health enhancement). Here, highlighting the integrated benefits of nature for environment and society is the key. For example, in the Netherlands, healthy urbanization is considered a very important theme, and urban nature/biodiversity is regularly highlighted as an effective approach conducive to health

promotion, offering a route to mainstreaming NBS that can bring biodiversity gains. **Building co-financing arrangements** between public and private sectors can again enable co-funding and joint responsibility for developing and maintaining NBS that can benefit urban biodiversity. One example is habitat banking (or biodiversity banking), which brokers between developers, landowners and planning authorities to fund conservation actions intended to compensate for and mitigate unavoidable environmental impact caused by development projects.

Boosting the adoption of NBS in urban development can be driven by **providing a public mandate** to integrate NBS in governmental tender and procurement policies and other policy instruments like land use planning guidance (e.g., Stockholm's Green Space Factor stipulates a certain proportion of green space in new development projects) and by **including NBS in contractual agreements** to encourage or demand utilities (e.g. water, waste, energy) and network service providers (e.g. road, rail, and waterway authorities) to work with nature in their infrastructure development. For example, in Sweden the national transport agency – Trafikverket – developed green infrastructure guidelines articulating the company's priorities for ecosystem services alongside transport needs. Integrating NBS into **green certification schemes** (e.g. LEED, BREEAM and German DGNB) can also incentivize their adoption by developers in designing and managing buildings. In the UK, a new certification program 'Building with Nature' was developed, using green infrastructure standards to limit or offset the environmental impacts of new homes development while also promoting healthy communities that are closer to nature. Other key stepping stones for mainstreaming NBS for biodiversity in cities include: **create intermediaries**, **generate partnerships**, **provide economic incentives**, **develop market demands, improve data and monitoring**, **advance valuation models**, **establish demonstration projects**, and **grow practitioner expertise**.

While each of the stepping stones holds great potential for disrupting incumbent regimes and creating rooms for NBS to flourish to protect and enhance biodiversity in cities, such impacts can be significantly boosted when synergistic stepping stones were enacted together. For example, by **aligning with strategic priorities**, NBS that aim for biodiversity gains can make use of resources and capacity dedicated to existing prioritized agendas in cities. However, urban governance is highly departmentalized – issues of different sustainability agendas (e.g., energy, transportation, health, water, etc.) are often dispersed across different authorities. Similarly, the benefits and responsibilities for NBS are also split across different sectors (both public and private). To unite actions towards different sustainability goals and, more specifically, to promote multifunctional NBS, thus requires collective and coordinated actions. This can be achieved by **creating intermediaries** that work within and across public and private bodies and across different governmental levels. For instance, the "unburdening arrangement" established by the Building Agenda policy programme in the Netherlands incentivizes individual actions towards urban sustainability by organizing single contact points that coordinate the implementations of sustainability solutions (Xie et al., 2020a). Coordinated actions can also be supported by **generating partnerships** among different stakeholders, who might have diverse interests but can join expertise and forces to design, implement and maintain NBS. To convince different urban actors of the multi-functionality and cost-effectiveness of NBS, it is essential to **improve data and monitoring** that can demonstrate the advantages and co-benefits of NBS. Therefore, these four stepping stones together can form a promising pathway for mainstreaming NBS for biodiversity. This pathway – *Biodiversity as co-benefit of urban sustainability* – highlights that policies do not have to be specifically focused on biodiversity in order to present opportunities for mainstreaming NBS for biodiversity.

Three other promising pathways were identified for mainstreaming NBS for urban biodiversity. As shown in Figure 3, each of the pathways consist of a set of key stepping stones.[6]

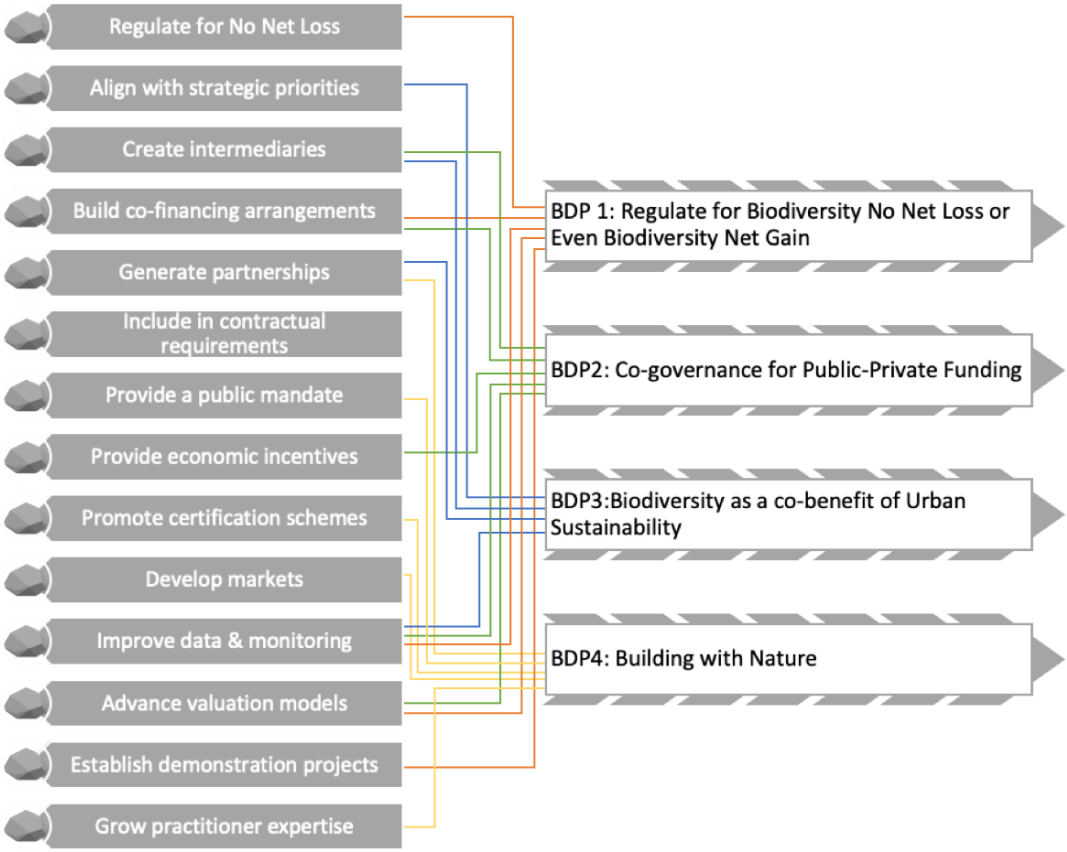

Figure 3. Key stepping stones and promising pathways for mainstreaming NBS for biodiversity

4.3 Mainstreaming NBS for both climate change and biodiversity: building on the synergies

A number of stepping stones are pivotal for both mainstreaming NBS for climate and for mainstreaming NBS for biodiversity. However, there are some stepping stones that are particularly important for one agenda but not so for the other. For example, **stimulating institutional investment for risk reduction** and **engaging insurance sector** are significant for mainstreaming NBS for climate change, but they are often not related to urban biodiversity goals. In turn, stepping stones such as **regulating for No Net Loss** and **promoting certification schemes** that are crucial for mainstreaming NBS for biodiversity are not so relevant for addressing climate risks and impacts in cities. Focusing on stepping stones that are specifically important for one sustainability goal could result in NBS that marginalize or even undermine efforts to reach other goals. For example, a narrow focus on implementing biodiversity No Net Loss regulation without concern for the other benefits of NBS could result in interventions that either take place in parallel or opposition to efforts to work with NBS for climate change mitigation or adaption. This could lead to counter-productive outcomes, sending confusing signals to actors who are responsible for implementing NBS about their purpose and value, and missing important opportunities to reach both goals simultaneously.

Mainstreaming NBS that can deliver co-benefits for climate change and biodiversity in cities thus requires a focus on stepping stones that are pivotal to realizing both agendas. These

[6] See detailed discussion of these pathways in Xie (2020).

include: (1) Align with strategic priorities, (2) provide a public mandate, (3) provide economic incentives, (4) generate partnerships, (5) create intermediaries, (6) build co-financing arrangements, (7) establish demonstration projects, (8) improve data & monitoring, (9) advance valuation models, and (10) grow practitioner expertise (see Fig. 4). Here again, whilst stepping stones like *provide a public mandate* and *create intermediaries* often emphasize the role of governmental sectors, the majority of them can be activated by different urban actors (public, private and civil society). For example, establishing a demonstration projects such as a community garden can be initiated by local communities; generating partnerships among public and private sectors can be facilitated by non-governmental organizations; and improving data and monitoring can be led by banks (such as the Triodos Bank and ASN Bank in the Netherlands), insurance firms (such as the Dutch insurance firm Achmea) and other businesses.

Different configurations of these common stepping stones can again form multiple pathways for mainstreaming NBS that can deliver synergistic benefits for climate and biodiversity. For example, **establishing demonstration projects** can not only experiment with place-specific NBS that work for both climate and biodiversity, but also demonstrate the multiple benefits of NBS as well as further increase awareness and build knowledge. This, however, requires **improving data and monitoring**, which can allow performance assessment and timely adjustment of the projects. In addition, developing **practitioner expertise** on designing, implementing and maintaining NBS is also key since the multifunctional characteristics of NBS often do not neatly match the expertise in established professional disciplines or policy areas and tend to require customization for place-specific conditions. Experimentation with NBS on the ground can enable further development of this context-specific knowledge. Therefore, these mutually reinforcing stepping stones can together form a promising pathway – *Experiment, evaluate and demonstrate* – for mainstreaming NBS for both climate and biodiversity.

Figure 4 demonstrates the other two configurations of stepping stones to form mainstreaming pathways for NBS that can bring co-benefits for climate and biodiversity. One integrated pathway (IP 1) – *Position NBS as a win-win strategy for both climate change and biodiversity* – highlights the multifunctionality of NBS and emphasizes the creation of incentives, opportunities and favorable conditions for multifunctional measures in addressing urban sustainability challenges. The other pathway (IP2) – *Develop integrated financing for actions that can deliver co-benefits* – focuses on partnership buildings as well as the advancement of valuation mechanism to pool funding resources dedicated for climate and biodiversity actions in cities and to synthesize knowledge and techniques possessed by different urban actors to co-fund and co-develop NBS.

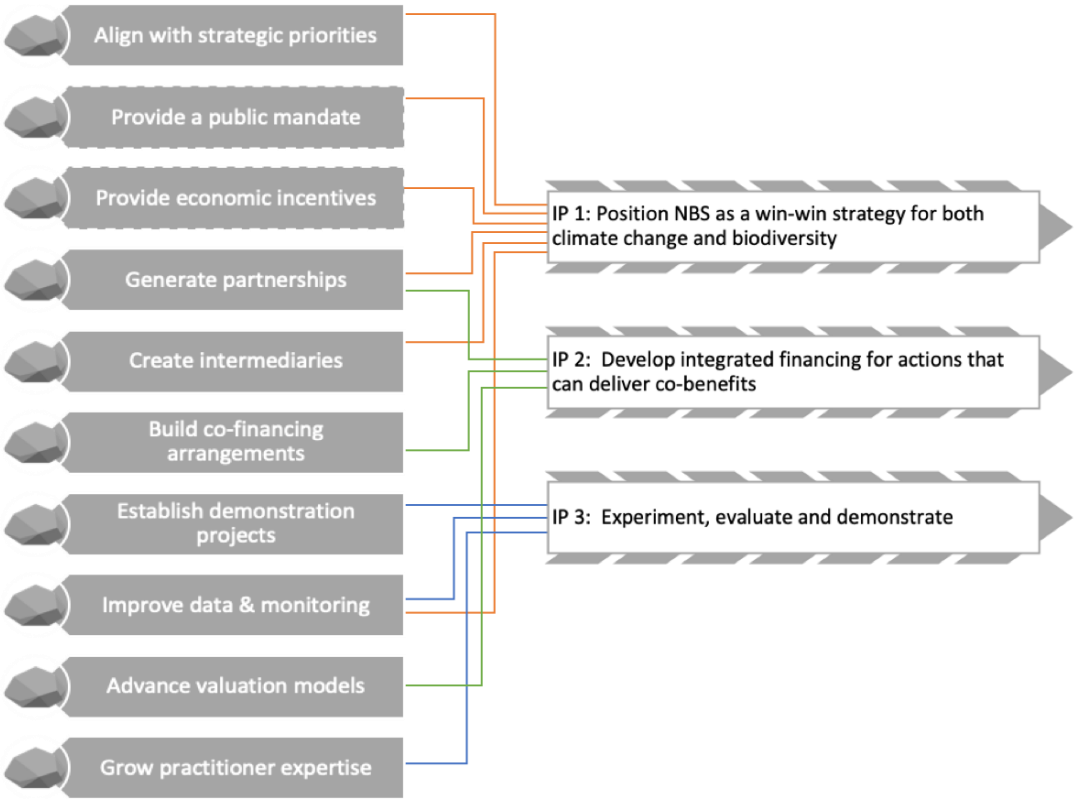

Figure 4. Key stepping stones and promising pathways for mainstreaming NBS for both climate change and biodiversity

5. Discussion and Conclusion

We have explored how the mainstreaming of urban sustainable innovations like NBS can be achieved, especially in order to realize multiple goals simultaneously. We have argued that the common understanding of mainstreaming in environmental governance, rooted in policy sciences and focused on policy integration at the governmental level, does not fit the multi-actor character and multi-level nature of sustainable innovations and the growth of governance through experimentation. Here mainstreaming is more than scaling up specific interventions and involves a process of creating a 'new normal' by disrupting and reconfiguring urban circulations that shape the urban infrastructure regimes while maintaining the novelty of sustainable innovation. Rather than focusing on the steering of government actors or the linear trajectories of upscaling innovations, such an approach recognizes the importance of diverse interventions across different sectors led by a multiplicity of actors (public, private or civil society) that can incentivize and facilitate the systemic shifts in thinking, doing and organizing, allowing a 'new normal' to be established.

As our analysis shows, to promote NBS in urban responses that can address the climate and biodiversity crisis together, a number of stepping stones across the regulatory domain, financial domain and urban development domain of urban infrastructure regimes and across different contexts and levels are promising. These stepping stones hold the potential to tackle existing structural barriers that constrain the wider uptake of NBS. They could adjust the current flows of power, resources and materials to enable the embeddedness of NBS in urban systems. Assembling stepping stones that are mutually supportive and translating them into detailed interventions that are adapted to local contexts can promote NBS mainstreaming.

In some cases, the activation of stepping stones relies on the private sector that often stays out of the policy-making process (e.g., insurance sector); and many of the stepping stones emphasize joint efforts by public and private sectors, as well as the civil society (e.g., generate partnerships and build co-financing arrangements). Intermediary actors who operate between sites/organizations thus could be critical in drawing attention to the catalytic potential of stepping stones and engaging with other actors to build on what already exists. Understanding mainstreaming as normalizing innovation in everyday decision-making and practices, which can take different approaches and take place in different parts of the governance system, endows the concept of mainstreaming with considerable flexibility to recognize the multiple capacities brought by different actors that hold great potential for catalyzing or facilitating the establishment of new forms of urban metabolic circulations.

Besides the process of 'normalization', we argue mainstreaming also involves sustaining the novelty of experiments and innovations. Mainstreaming NBS should not mean that their distinction and novel qualities disappear from view. The novel qualities of sustainable innovations point to the aspects of the incumbent regime that interventions are disrupting, which makes it essential that these qualities be asserted and reproduced. For example, *advance valuation models* and *improve data and monitoring* were two of the stepping stones we identified as pivotal for mainstreaming NBS for climate and biodiversity. Focusing on normalization alone might lead a narrow activation of these stepping stones to develop quantitative data on NBS performance that can integrate into existing calculations of urban infrastructure service provision and risk tolerance that guide grey infrastructure investment. As a result, some grey infrastructure is swapped for some green infrastructure, but systemically little else has changed and NBS have become normal but not novel. However, developing new practices of valuation and monitoring that are capable of embracing the uncertainty and fluidity of nature and valuing a range of benefits has the potential to embed a wider range of NBS with broader implications for reconfiguration. Striking a balance between being normal (acceptable) and being novel (providing added value) is then at the heart of successful mainstreaming efforts (Castán Broto and Bulkeley, 2013). Furthermore, the importance of learning has been highlighted in mainstreaming NBS – one of the four pathways we identified for mainstreaming NBS for climate is focused on learning by doing so as to develop context-specific knowledge. Maintaining the experimental feature of NBS enables continuous learning of the design, implementation and upkeep, and thus can provide crucial knowledge for the wider adoption of NBS. Therefore, mainstreaming involves the dual and interrelated process of normalizing and maintaining novelty.

In addition to conceptualizing mainstreaming for NBS, our analysis has also demonstrated how to apply this approach in order to identify the pivotal stepping stones and to assemble flexible but promising pathways to mainstream NBS into urban development to realize urban sustainability goals. Based on case studies of existing experimentation in European cities, we have identified different set of stepping stones and distinct pathways for mainstreaming NBS for climate benefits and for biodiversity benefits, but the dual-track approach for mainstreaming impedes any possible synergies between climate and biodiversity actions. Trade-offs can arise if urban climate responses 'encourage NBS with low biodiversity value, such as afforestation with non-native monocultures' (Seddon et al., 2020, p.1; Xie et al., 2020b). To synergistically pursue climate and biodiversity benefits and to minimize trade-offs, we have argued that mainstreaming NBS should be based on common stepping stones that are significant for both climate and biodiversity. These stepping stones can form multiple pathways through which NBS can be mainstreamed for climate and biodiversity gains. Our analysis here is far from exhaustive, and different stepping stones and pathways are likely to hold more or less potential in particular circumstances. Policymakers and others interested in pursuing NBS for addressing urban sustainability challenges should identify the most pivotal

stepping stones that align with their particular contexts and build pathways towards the goals that are most significant in generating a transformative approach to sustainability.

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