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Review

Reviewing financing barriers and strategies for urban nature-based solutions

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ABSTRACT

Obtaining public and/or private finance for upscaling urban nature-based solutions (NBS) is a key barrier for reaching urban sustainability goals, including climate mitigation and adaptation. We carry out a systematic review of the academic literature to understand the key barriers and corresponding strategies for financing urban NBS. First, we report on specific financing challenges and strategies found for NBS uptake in four urban ecological domains: buildings, facades and roofs; urban green space (parks, trees); allotment gardens (including urban agriculture); and green-blue infrastructure. Across domains, we identify two overarching barriers of NBS finance: (1) coordination between private and public financiers and (2) integration of NBS benefits into valuation and accounting methods. We discuss strategies found in the literature that address these barriers; here, two things stand out. One, there is a large variety of valuation strategies that does not yet allow for an integrated accounting and valuation framework for NBS. Two, strategies aimed at coordinating public/private finance generally look for ways to encourage specific actors (real estate developers, residents) that benefit privately from an NBS to provide co-financing. We visualize our findings into a framework for enabling (public and/or private) finance for upscaling urban NBS.

1. Introduction

Nature-based solutions (NBS) are a form of eco-innovation that specifically promote nature as a means for providing solutions to climate change (mitigation and adaptation), bad air quality, loss of biodiversity, vulnerable coastlines and other threatened ecosystems, food insecurity and health, social and economic deterioration/injustice (Kabisch et al., 2016, p. 2; Nesshöver et al., 2017, p. 1216–1217). The European Commission additionally emphasizes NBS as a way to realise socially inclusive green growth (European Commission 2015). In general, NBS are recognized for their ability to simultaneously deliver multiple benefits ('solutions') to urban sustainability goals, such as biodiversity, climate change mitigation and adaptation, as well as social wellbeing (Kabisch et al., 2016).

NBS are realised in different urban ecological domains such as green buildings, facades and roofs, green space connected to grey infrastructure (playgrounds, street trees), parks and urban forests, allotments and community gardens as well as of different types of green-blue spaces such as lakes, urban drainage systems, permeable surfaces and wetlands. Derelict and former industrial areas and brownfield sites can potentially be re-developed as urban NBS. This diversity of NBS illustrates that NBS are adapted to place-based conditions (Dorst et al., 2019); each ecological domain or context can provide a unique set of services, benefits and values for different urban stakeholders, ranging from ecological services such as climate mitigation and water management to social and economic benefits, such as social cohesion and economic development. Urban NBS often represent local public goods (Besley and Coate 2003)—benefitting primarily those citizens in the area where they are located.

The concept of NBS overlaps with other concepts, most strongly so with ecosystem-based adaptation and green infrastructure (Dorst et al., 2019) and, to some extent, with concepts such as ecological engineering, ecosystem services and natural capital (Nesshöver et al., 2017) and ecosystem-based disaster risk reduction and natural water retention measures (Kabisch et al., 2016). Although the concept of NBS has been referred to as 'still poorly defined and vague' (Nature editorial, 2017),

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several authors have attempted to carve out the key elements or criteria of what NBS comprise. One recurring element is the need for NBS to be place-based and adapted to uncertainty/complexity; another is their multifunctionality (Albert et al., 2017), requiring stakeholder involvement or integrative governance and planning (Nesshöver et al., 2017; Dorst et al., 2019). Furthermore, the innovativeness and solution-orientation of NBS (again, to specific contextual challenges) is often stressed (Kabisch et al., 2016; Dorst et al., 2019).

The multiplicity of benefits that are assigned to NBS include their ability to create green growth, reduce climate risks (heat, flooding) and enhance biodiversity (European Commission 2015; IUCN 2015; Kabisch et al., 2016). Nature-based solutions can represent innovations, such as green roofs (Herrera-Gomez et al., 2017) or sustainable urban drainage systems (Sara et al., 2016). In other cases, the type of nature may be less innovative (such as urban parks), but instead, the way in which such nature is re-oriented towards complex urban challenges is innovative (Kabisch et al., 2016).

Although the potential of nature-based solutions as a cost-effective enabler of urban sustainability has been recognized, the implementation, management and upscaling of NBS face numerous barriers and challenges (European Commission 2015; Kabisch et al., 2016; Nesshöver et al., 2017; Davies and Lafortezza 2019). A recurring key barrier is obtaining finance, public and/or private (Specht et al., 2014; Huston et al., 2015; Droste et al., 2017; Nesshöver et al., 2017; Frantzeskaki et al., 2019). Public finance seems the logical route for NBS due to the public good character of many urban NBS interventions; however, public finance for NBS is not self-evident. Sustainable urban infrastructure investment suffers from a focus by municipalities and project developers on investments that realise economic growth, favouring real estate development (Koppenjan and Enserink 2009). According to many authors, reduced public funds for urban nature cannot be seen as separate from the current politics of urban environmental management, criticized to be part of a neoliberal 'green growth' discourse (McCarthy and Prudham 2004; Brand 2007; Wanner 2015).

At a more practical level, municipalities often suffer from short-term decision-making cycles and decreasing staff as well as expertise for environmental management, whereas NBS investments require long-term strategies and dedicated maintenance budgets (Kabisch et al., 2016). Also, since the benefits of NBS cut across different municipal departments—with each their own budgets and objectives—NBS investment creates the challenge of coordinating these budgets for joint investments (Kabisch 2015; Droste et al., 2017). Following recession and austerity, public finance for NBS is challenged, as well (Konstantinidis and Vlachou 2018).

Much is expected from (collaboration with) private actors such as real estate firms, businesses and citizens with respect to NBS delivery and financing (European Commission 2015; Kabisch et al., 2016). However, considering the innovative character of many urban NBS, access to private finance faces crucial challenges due to well-documented market failures in the innovation finance literature (e.g. Demirel and Parris 2015; Demirel and Danisman 2019; Toxopeus 2019). Finance for innovative, sustainable activities face market failures due to two positive externalities that are produced, also referred to as the double externality problem (Rennings 2000; Faber and Frenken 2009). The first externality relates to knowledge spill-overs of the innovation to other firms, making it uncertain whether investors will reap private payoffs. The second externality relates to the ecological public good that is delivered in the process of sustainable innovation (Polzin 2017; Toxopeus 2019). Also, NBS are infrastructural investments with a long-term, illiquid character. Long-term, infrastructural investments are traditionally seen as the domain of public policy into which private investors do not enter naturally (Campiglio 2016).

The innovation finance literature addresses the public-private finance relationship in sharing risks and gains of innovation (Mazzucato 2013; Polzin et al., 2016; Polzin 2017; Geddes et al., 2018), which can be applied to many types of NBS. Public actors (such as state investment banks) often take on large high risk portfolios in innovative sectors, influencing not only the uptake of sustainable innovations but also their direction (Mazzucato and Semieniuk 2018). In general, sustainable innovation trajectories involve a strategized interplay of public and private actors, where public players help lower risk for private investors through environmental policy, co-investment into R&D, increasing investment transparency (through i.e. demonstration projects), and internalization of externalities by enabling trading mechanisms (Polzin 2017; Mazzucato and Semieniuk 2018; Geddes et al., 2018).

The topic of mobilizing finance for urban NBS also raises social justice concerns. Strategies for accessing (public-private) finance for NBS will inevitably affect decision-making on where and how to develop urban NBS, which in turn will influence how 'socially just' this green urban development is. Market-driven greening strategies involving private capital aimed at regeneration and economic development usually target middle- and high-income citizens, increasing concerns about the green gentrification of neighbourhoods (Haase et al., 2017; Anguelovski et al., 2018). Thus, while additional financing can 'increase the pie' of urban NBS, how the 'pie is sliced' will define its justice-outcomes, and therefore requires careful governance decisions (Toxopeus et al., 2020).

Although finance for urban NBS has been identified as a challenge and recommendable work has been done to address this from a public finance perspective (Droste et al., 2017), to our knowledge, there exists no structured review of academic literature that articulates and addresses the urban NBS financing challenge. Such an overview would provide an effective starting point for both academics and practitioners to understand and strategize for realizing finance for urban NBS. In line with the urgency of implementing urban NBS, this paper fills that gap by providing a systematic review of the academic literature relevant to improving the financing of nature-based solutions, drawing on related themes such as urban regeneration and green infrastructure. Because little has been written on finance for urban NBS and to make the review more granular, we take a deep dive into the literature on ecological domains in which urban NBS are situated: (1) green buildings (roofs, facades and agriculture), (2) urban green spaces; (3) community gardens and urban agriculture and (4) integrated green-blue spaces. We review the literature in each ecological domain to understand the financing barriers that are identified and the strategies that are taken to alleviate financing constraints for (different types of) NBS, and we look for overarching barriers and strategies.

This review is structured as follows. We explain how the relevant literature is assembled in the methods section and present our findings in three steps. First, we report on specific financing barriers and strategies for NBS uptake in four urban ecological domains. Next, we identify two overarching barriers of NBS finance across domains: coordination and governance across public/private financiers and adjustment of valuation and accounting methods to include the multiple benefits provided by NBS. We visualize these in a framework for understanding and enabling finance for urban NBS. The findings section forms the basis for discussion and conclusion.

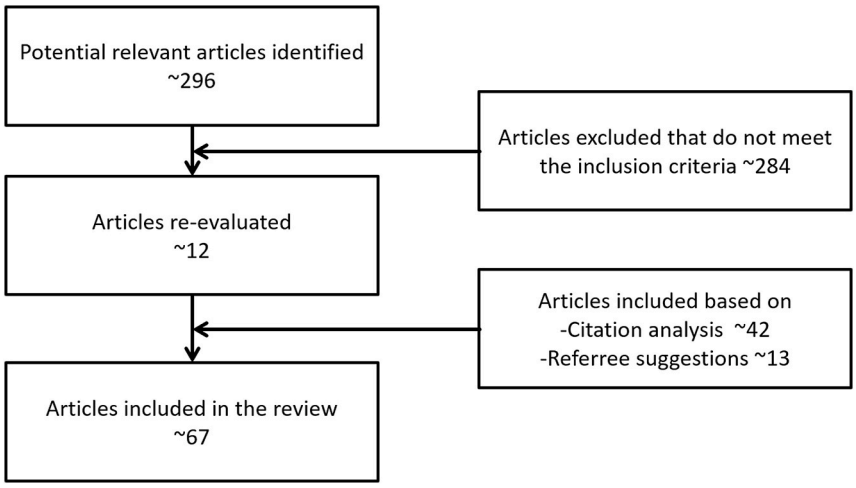

Fig. 1. Process of article selection.

Theme	Longlist	Shortlist
Urban NBS	Urban, nature-based solutions, innovation, socio-technological change, urban sustainability transition, socio-technical, resilient cities, infrastructure, nature, innovation, urban infrastructural regimes, sustainable cities	Urban OR City Innovation
Finance	Financial structure, financing, public-private finance, investment, funding	financ* OR invest* OR fund*
Ecological domains	Urban forests, green roofs, green-blue infrastructure, urban water systems, urban agriculture	nature OR forest OR green OR water

Fig. 2. Themes, longlist and shortlist for systematic literature search terms.

2. Methodology

2.1. Protocol

To limit selection bias and create a transparent, replicable, up-to-date and comprehensive literature review that sought to collate all relevant peer-reviewed evidence,[1] we used systematic methods[2] such as eligibility and exclusion criteria and a literature database as well as a protocol. This approach is increasingly used in medical, environmental (Cochrane Collaboration 2011) and social sciences (Pittaway et al., 2004; Reim et al., 2015) and allows us to differentiate the broad topic of financing questions into ecological domains, while allowing for criterial topics to emerge from the literature to form our final theoretical framework (assessment of the literature, see section 5). In this respect, we sought to analyse 'socio-economic outcomes' and optimal management options, which necessitated a systematic review (CEE 2019).

After an initial selection of literature through a keyword search (title, abstract and keywords) in the comprehensive literature database SCOPUS – https://www.scopus.com, we systematically excluded articles based on exclusion criteria. The narrower article base was screened for relevance to the research topic, based on which we decided whether to add the article to the final list. We then performed a citation analysis within this selection and looked for additional literature from specific NBS domains (e.g. urban forests, green roofs) to enhance our review with more specific papers and examples of NBS finance. This leaves us with a final selection of 67 articles that we included in the review. All three steps (see Fig. 1) are in line with Key CEE Standards for Conduct and Reporting (CEE 2019, sec. 5).

2.2. Conducting the systematic review

To set up the systematic review, we first created a longlist of main keywords per theme. During our scan of the primary literature, we added keywords as we became more familiar with the relevant literature for the final longlist (see also Reim et al., 2015 for a similar approach).

From this longlist of keywords on the topics of urban NBS, innovation and finance, we selected our main combination of search terms in titles, abstracts and keywords of published literature (shortlist) (see Fig. 2). The final search terms that we used in SCOPUS were combined as follows: TITLE-ABS-KEY ((urban OR city) AND (financ* OR invest* OR fund*) AND innovation AND (nature OR forest OR green OR water)).

The longlist of potentially relevant literature based on our final search terms led to 296 references. First, we excluded articles whose titles did not mention anything nature-based (topics include medical research, light pollution, electrical mobility, technological noise monitoring, social housing, urban cultural conservation, education in general, health insurance, social housing). If the title was too vague, we scanned the abstract to decide whether the topic of the paper fits our purpose. Second, we excluded articles that in their abstract used the

[1] According to Hunter and Schmidt (2004), this does not lead to an 'availability bias' for empirical studies if a sufficiently large article base is considered because the direction of the published and unpublished results tends to be the same.

[2] 'A systematic review is a review of evidence relevant to a clearly formulated question that uses systematic and explicit methods to identify, select and critically appraise relevant research, and to collect and analyse data from the studies that are included within the review (see https://environmentalevidencejournal.biomedcentral.com/submission-guidelines/preparing-your-manuscript/systematic-review).

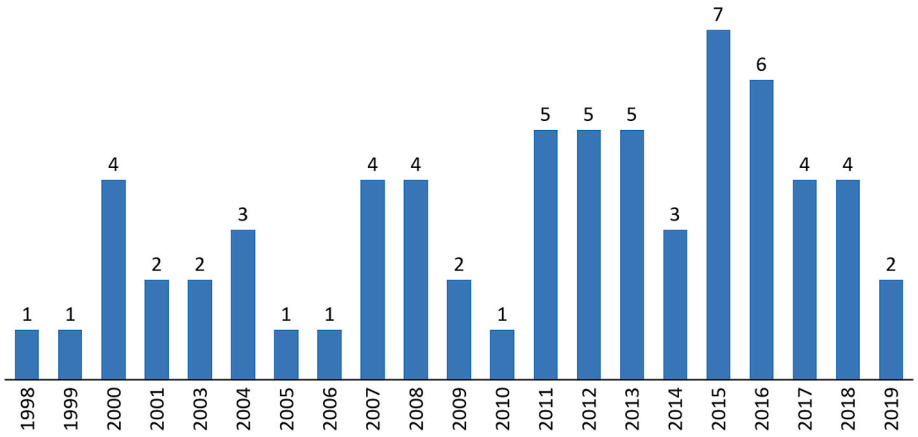

Fig. 3. Evolution of the literature base.

word 'sustainable' or 'nature' in a more business-like (i.e. sustainable cash flows) or social sense (i.e. sustainable wage rates). We also excluded articles that in their abstract did not mention anything about finance, investment or funding (which was often the case when the word 'investigation' created a hit on invest*, instead). Also, some results that appeared in Scopus were not available as full-texts, and therefore were disregarded. This procedure reduced the number of relevant articles to 12. This low number of relevant hits indicates that there is considerable room for integrating largely separated literature streams on financing NBS.

Next, we looked for additional literature based on relevant citations in the selected articles and on specific terms, such as NBS types. We scanned papers published in a special issue on urban transition in the Journal of Cleaner Production[3] as well as articles that focus directly on NBS (types) but not explicitly on finance. Furthermore, we looked specifically for articles relating to financing of specific types of urban NBS, such as urban forests, urban trees, and green roofs. We also searched for terms that deal with the valuation of nature, such as ecosystem services and natural capital. This led to the inclusion of 42 additional articles. Early reviewers of this article suggested additional literature, from which we included another 13 articles.

2.3. Synthesis

The total literature base thus amounts to 67 research articles published between 1998 and January 2019 (see Fig. 3), with the bulk of the literature published between 2011 and 2019.

A majority of papers are empirical (39), followed by conceptual pieces (22) and mixed studies (6). Fig. 4 shows the distribution across NBS types. The 'general' type includes studies across ecological domains and studies that did not directly touch upon NBS. A list of all articles is included as a supplementary file. It shows the categorization of the evidence into (ecological) economics, planning, urban- and environmental studies. Due to this categorization, we chose to conduct a qualitative synthesis (narrative) while relying on figures and tables to describe the literature (see above). We combined information on NBS ecological domains with emerging determinants for financing NBS (governance and decision making, public-private cooperation, and valuation and accounting) (CEE 2019, sec. 9).

The main literature database includes author, year, title, publication outlet (e.g. journal), NBS type (or overarching), DOI, central argument (usually from abstract), key topics, key axes derived from the key topics (that determine the final framework in section 5), type of contribution (conceptual/empirical), school of thought/stream of literature (e.g.

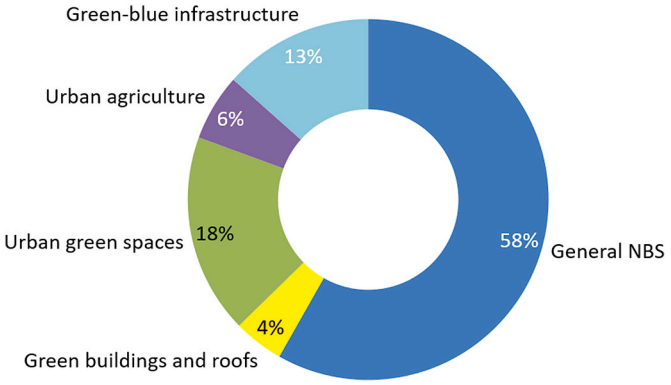

Fig. 4. Distribution of reviewed literature across ecological domains.

urban regeneration, political ecology, behavioural economics or environmental analysis) and search type. The overview can be found in Table A.1 in the online appendix (Excel format). The data compiled in this list was cross-checked by two independent reviewers (CEE 2019, sec. 7).

Based on this literature database, we present our findings in two ways. First, we reviewed the literature per ecological domain to find domain-specific barriers and strategies. Next, we reviewed all literature, including the articles that inform NBS finance at a more general level (General NBS) and identified key topics for each paper (see also Table A.1 in the supplementary file): First, we set up a coherent spreadsheet and identified key topics per paper by reading all the papers. Examples of key topics identified included natural capital accounting, tree valuation, cost benefit analysis, and economic benefits of rainwater runoff reduction. Upon studying the key topics once identified for all the papers, we clustered these key topics into three key barriers (governance and decision-making, coordination between public-private financiers and adjustment of accounting and valuation methods). For example, all examples mentioned above were clustered into 'adjustment of accounting and valuation methods'. In a second round of the analysis, we merged the first two topics 'governance and decision-making' and 'coordination between public-private financiers' because of the considerable overlap between governance, finance and decision-making issues raised in the papers.

3. Barriers and strategies for NBS finance in different ecological domains

We summarize the evidence of different financing barriers and strategies for four key ecological domains in which urban NBS are realised: building-related green, urban green space, urban agriculture

[3] http://www.sciencedirect.com/science/journal/09596526/50/supp/C.

and green-blue infrastructure. Financing strategies and barriers between ecological domains seem to vary with the extent to which private value can be captured from the particular types of NBS (i.e. produce from urban agriculture, aesthetic value of the view of residential trees) and the scale of the investment (investment size and payback period). We first discuss financing barriers and strategies that we have identified in the literature for each of the four ecological domains before addressing the whole literature base (including articles on general NBS).

3.1. Green buildings and roofs

When NBS are connected to a building (e.g. green roofs, facades building-integrated agriculture), the investment decision lies primarily at a decentralized level with the building owner or with the entrepreneur carrying out building-integrated agriculture. Some studies calculated the expected cash flows (net present value) from investing into a green roof, and concluded that the net return is negative (Carter and Keeler 2008; Khare et al., 2011). Therefore, if government finances allow for it, incentives such as municipal subsidies can potentially be very effective in attracting private green roof investments, realizing positive returns for building owners (Carter and Keeler 2008; Claus and Rousseau 2012).

The upfront investment at a consumer level can be stimulated by a tripartite model in which costs and benefits are shared equally between citizens, government and for-profit actors, such as businesses and real estate developers. This means, for example, that the government quantifies and provides information on savings at the household level, and retailers are stimulated by the government to sell low carbon products (Khare et al., 2011). Clear communication of the benefits to both society and the individual customer may drive adoption of NBS, such as green roof systems, but will also require governmental subsidies (Carter and Keeler 2008). They also find that the increased longevity of the roofing system due to a green roof (doubling of the lifetime) is the main benefit to the private building owner from investing in a green roof, but because this benefit materializes only after twenty years, building owners require a long-term vision (Carter and Keeler 2008). Since private benefits do not by themselves make a green roof an attractive investment with a positive net present value, not only subsidies but also storm water tax cuts, exemplified by some regions in Germany, can stimulate private investment into green roofs (Claus and Rousseau 2012). Standardization of amount and procedures for green roof subsidies/tax breaks is recommended to make it easier for real estate owners and investors to make use of these public incentives for their investment decisions (Claus and Rousseau 2012).

In the context of building-integrated agriculture, the high upfront investment cost is also mentioned as a barrier (Specht et al., 2014). Rooftop farms can be organized in a collective or private manner, as cooperatives or private businesses (Specht et al., 2016). When examining the economic dimension of a specific type of building-integrated agriculture (zero-acreage farming), the economic challenges mentioned most often were engineering and construction costs and financing the upfront investment (Specht et al., 2014). A key economic issue for building-integrated farms is how to increase the expected yield from the farm, to make the upfront investment more attractive (Specht et al., 2014). In the early stage of development of building-integrated farming, not only are investment costs high, the benefits are also difficult to quantify (Specht et al., 2014). Whereas small-scale rooftop agriculture can use proven, low-cost technologies, scaling up agriculture that is integrated with buildings will require investment into developing new lightweight materials and techniques (Specht et al., 2014). Although rooftop farms are expected to become profitable in the long term, many are in a pilot stage and lack investment funds for scale up (Specht et al., 2014). Improved understanding is needed for initial, operation and maintenance (life cycle) costs, as well as for strategies integrating social and environmental criteria into financial assessment frameworks (Nelms et al., 2005).

3.2. Urban green space (parks, trees, and urban forests)

The literature in the ecological domain of urban green space focuses on the barrier of unlocking private finance for urban greening from citizens, businesses and real estate developers, and on the challenge of valuing urban green. It estimates the value of urban trees (benefits and risks), the willingness of citizens to pay, and 'green' investment by real estate firms (in urban development projects).

Urban green space is under pressure due to land development in urban areas. Emphasizing economic valuation of urban tree and forest benefits—that is, by estimating citizen willingness to pay—can stimulate investment in urban forest construction and management, as well as prevent loss of urban trees and forests to urban development projects (Tyrväinen 2001; McPherson 2007; Zhang and Zheng 2011). The contingent valuation method is often used as an approach for assessing the total value of urban forest benefits (Tyrväinen 2001). Shadow pricing of rainwater collection (Zhang et al., 2011) or treating trees as fixed assets to calculate life cycle costs are other ways to make the added value of urban forests measurable (Funk and Domke 2008).

Fundraising amongst residents is expected to be most successful in positive economic environments and affluent residential areas, as higher household income increases willingness to pay (Zhang and Zheng 2011; Dimke et al., 2013). The hedonic price valuation has been used in many studies in the past decades to show that tree cover and parks have a positive correlation with house prices in (Luttik 2000; Schilling and Logan 2008). This data could allow municipalities to recoup some of their public investment in trees through higher levels of real estate taxation and ground sales. Also, increased house prices can motivate home owners to contribute financially to local community forest projects (Dimke et al., 2013). On the flip side, trees can also provide negative value: liability in case of tree failure can lead to costs for the (public or private) tree owner. The amount of compensation paid for property damage for residents has increased in recent years in some countries, for example, the Netherlands (van Haaften et al., 2016).

Poudyal et al. (2015) found that some carbon offset buyers are willing to pay a price premium for carbon credits sourced from urban forests due to the importance they place on additional community, economic and environmental benefits that are delivered due to their urban location. Targeting urban carbon credit sales to these specific buyers could provide additional financing for urban tree cover. Similarly, in the context of Swiss forests, consumers were found to value the local origin of non-timber forest produce (e.g. honey, berries, seeds, oils), suggesting increased willingness to pay through local labelling (Kilchling et al., 2009). Sometimes, urban green space can also be financed by marketing its multifunctionality: the transformation of a military premise into a park in Toronto was realised by leasing space within the park's premises for commercial purposes such as offices, trade shows and recreation (Genco 2007).

3.3. Community gardens and urban agriculture

The literature on urban community gardens focuses on overcoming financial barriers in a bottom-up manner. Funding is often minimal and consists of in-kind donations or grants. Using social network theory, Ghose and Pettygrove (2014) showed how urban community gardening use embeddedness in networks to organize grassroot agriculture in spite of minimal funding, an approach which is also referred to as bootstrapping in the entrepreneurial financing literature (Ebben and Johnson 2006). Opportunities to overcome a lack of funding through bottom-up community building using sustainable (urban) crowdfunding strategies are pinpointed in other contexts, as well (Hörisch 2015; Bieri 2015; Calic and Mosakowski 2016; Toxopeus and Maas 2017). Examples of successful nature-based urban crowdfunding are discussed in mainstream media but lack academic analysis so far (Newsworks.org, 2013; The Guardian, 2014). Hein et al. (2013) also highlighted coordinating with local communities to address a funding need on the long

term for biodiversity protection in a rural context.

Vogl et al. (2004) described an urban farming model in Austria called 'Selbsternte', which is a specific way of cultivating, harvesting and governing a plot of land. Although none of the 'self-harvesters' reported doing this for commercial purposes and only half think they got more out of the plot in cash value than they invested, they emphasized other benefits such as building relationships, relaxation and education as outcomes from their urban gardening activities (Vogl et al., 2004). In a survey of German citizens in Berlin, Specht et al. (2016) found that urban agriculture is socially more accepted on rooftops than on the ground due to competing land uses. The authors also found that urban green space (including urban agriculture) that allows for recreation and leisure for the general public are valued higher by citizens than urban green spaces that cannot be accessed.

3.4. Green-blue infrastructure

Green-blue urban spaces have characteristics similar to large urban infrastructural projects. For example, sustainable drainage systems such as roadside swales and wadis (lowered green areas or riverbeds that are dry, except when it rains) are set up as replacements of 'grey' infrastructure; they aim to use and enhance natural processes mimicking predevelopment hydrology (Perales-Momparler et al., 2016). Water infrastructure is embedded in policy and regulatory frameworks that limit risk taking and access to private capital markets, with privatisation potentially creating unacceptable risks for citizens (Kiparsky et al., 2013).

In a qualitative study about barriers to implementation of green-blue infrastructure in Newcastle, securing funding for initial investments and long-term maintenance was mentioned as a main barrier by more than half of the respondents (O'Donnell et al., 2017). They recognized that the initial funding required was lower or similar to 'grey' infrastructure, but longer term funding was needed to reap full benefits of blue-green infrastructure due to higher maintenance costs. Furthermore, specific characteristics of water (infrastructure) lead to misalignment of costs and benefits at different levels: re-use of water can be efficient at building level but can lead to faster deterioration of sewage infrastructure when the waste stream becomes increasingly solid (Kiparsky et al., 2013).

Some key strategies mentioned to overcome funding barriers were alternative funding mechanisms alongside municipal funding; working in partnerships; improved education and awareness raising of the local community as well as creation of multifunctional space as part of the investment while clarifying the additional benefits associated with green-blue infrastructure, such as improved air quality (O'Donnell et al., 2017). In the context of city-level stormwater management, Porse (2013) studied a public-private hybridization of governance (and investment) through setting up incentive programmes and municipal codes on maximum impervious land cover. Similarly, in the context of urban wetland management, municipal policy standards are seen as the crucial driver of wetland protection by urban developers (Schulte-Hostedde et al., 2007). One solutions discussed is develop policy that allows developers to replace lost wetlands on another new location ('wetland banking'). Another promising financial route for wetland protection in urban surroundings could be water charges, linking the services provided by wetlands more specifically to the water quality they provide (Schulte-Hostedde et al., 2007).

Specific to the context of green-blue infrastructure, financing decisions are partly risk-driven to mitigate flood or storm risks. However, not everyone is exposed to the same flood or storm risk, which can affect willingness to pay, both through public (taxation) and private funding. Large investments into green-blue infrastructure can be enabled by heterogeneous tax rates based on the unequally distributed benefits of certain local public goods to increase willingness to pay (Mullin et al., 2018). The authors of this paper built an agent-based model to indicate that property owners who reside close to the beach profit more from widening of beaches in terms of property value because of lower flood risk, and therefore would be willing to pay a larger share of local taxes for this purpose. Their results could apply to local public goods, more generally, but its success depends on 'the balance of public and private benefits that accrue from a local investment' (Mullin et al., 2018, p13). Another public-private local funding strategy for flood risk mitigation referred to in the literature is the London Urban Works Reserve Fund, initiated in 1989, which provides funds to urban developers to increase the size of their sewage system and include storm water management facilities (Schulte-Hostedde et al., 2007).

4. General barriers and strategies for financing urban NBS

Building on the literature on financing urban NBS across ecological domains and articles General relating to NBS in general, we identified two overarching barriers that form the main axes for the NBS financing barriers and strategies framework. The first barrier (Fig. 5 vertical axis) is coordination across public and private financiers. The second barrier (Fig. 5 horizontal axis) concerns valuation and accounting of benefits provided by urban NBS, necessary as a basis of a successful financing decision. Below, we show how the literature leads us to articulate these NBS finance barriers and which strategies are proposed.

5. Barrier 1: coordination across public and private financiers for urban NBS

5.1. Unpacking barrier 1

Although urban infrastructure is traditionally seen as the domain of (local) government, public investment into sustainable urban infrastructure often lacks behind in the context of rapid urbanization (Koppenjan and Enserink 2009). This can be seen in the light of broader developments and evolving narratives over the past decades, often referred to as 'new public management', where the government takes a step back to outsource to, or partner with, private entities in the expectation of more efficient and innovative delivery modes of public services (Helm 2010); a development that has also been critiqued as unnecessary neoliberal reform (Harvey 1989; Boase 2000). Similarly, others point at the prioritization of local governments and private project developers for profit-making activities, favouring investments into real estate development above public infrastructure (Koppenjan and Enserink 2009). The lack of public financing for urban NBS has also been attributed to limited municipal spending autonomy and lack of fiscal transfers to a local level, leading to municipal budget constraints and low NBS public investment levels (Droste et al., 2017).

The lack of public funding for urban NBS makes the entry of private and citizen investors attractive and sometimes even unavoidable (Koppenjan and Enserink 2009; Helm 2010). Even if public funding is potentially available, NBS often represent local public goods, benefiting some citizen groups more than others, which can lower citizen willingness to pay through taxation (Besley and Coate 2003; Mullin et al., 2018). Public actors need political support for their actions (to win the next election), which hampers their risk appetite, whereas private bodies have a higher incentive to provide standard solutions at reliable profits than to present innovative solutions (Klijn and Teisman 2003). The inclusion of private investors for infrastructure investment is often motivated by efficiency reasoning—they arguably embody improved incentive systems for faster and better delivery of such public services (Warner and Hefetz 2008; Helm 2010)—and levying user charges would create better incentives between providers and consumers (Helm 2010). Furthermore, private actor involvement allows for better risk sharing of long-term, illiquid infrastructure investments (Adair et al., 2000).

The bulk of the literature that we reviewed emphasizes different ways to balance and coordinate public and private finance for infrastructure investments based on the above arguments. Multiple challenges are articulated that relate to this public-private collaboration,

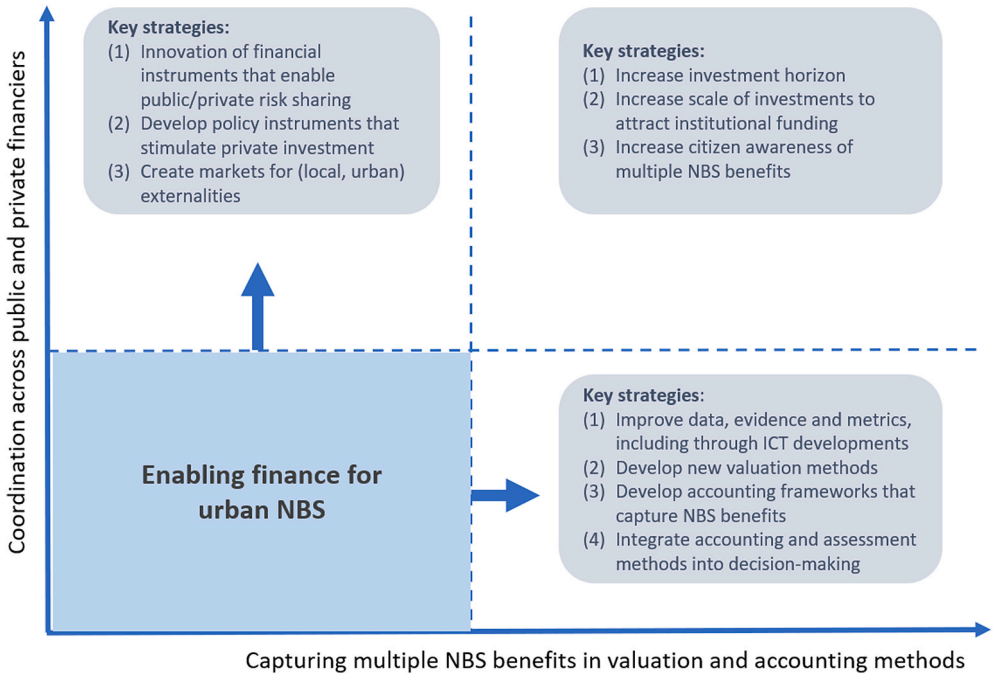

Fig. 5. A framework of barriers and strategies for urban NBS finance.

sometimes countering the arguments to involve private actors (Klijn and Teisman 2003; Helm 2010; Loftus & March 2016). First, privatisation of public infrastructure can lead to higher than envisioned costs for citizens, as evidenced in the case study on the privatisation of London's desalination plant (Loftus & March 2016). Based on three Dutch case studies of large public-private urban investment partnerships, Klijn and Teisman (2003) found that although long-term cooperation between public and private parties are generally set up to allow for efficient risk, cost and benefit sharing, successful partnerships are often hampered by complexity of actor composition, institutional factors and strategic choices for both public and private actors. The quasi-market structure, often characterized by one buyer and a few sellers, is an imperfect substitute for public control and requires active government involvement and citizen engagement to ensure efficient and fail-free delivery of public services and to prevent underinvestment by private parties (Warner and Hefetz 2008). To address this fact that private investors may not invest adequately in the delivery of public services, government needs to not only monitor, but also credibly commit that investors will recoup their sunk costs (Helm 2010).

There are not just societal drawbacks of private investment in public infrastructure. Other disadvantages of private investors in urban regeneration are operational and bureaucratic challenges related to real estate and infrastructural investments, such as conflicting tax and grant schemes, uncertainty regarding contamination of sites, and delay in planning schemes (Adair et al., 2000). Also, urban regeneration projects are often perceived by private investors as high risk due to a lack of information about the underlying value of assets (McGreal et al., 2000). Furthermore, volatile rental markets create insecurity regarding expected profits. In reaction to these challenges, researchers found evidence of risk-reducing measures, such as public loan guarantee schemes (Schilling and Logan 2008).

While much of the literature deals with coordination and governance between public and private financiers into (green) urban infrastructure, the difficulty of coordinating investments *within* governments is pinpointed in the context of urban NBS as well (Droste et al., 2017). The multiple benefits that are generated by NBS make it difficult to finance, as all need to be considered to show the 'superiority' of the NBS as an intervention as opposed to other (grey) infrastructure investments (Droste et al., 2017). However, each department within a local government often has a singular societal objective, which by itself renders NBS an unattractive investment option.

5.2. *Key strategies to barrier 1*

Different solutions and innovations are proposed in the literature to successfully coordinate and govern investments into (green) urban infrastructure, often applicable to urban NBS. First, the local character of public goods created by urban NBS may benefit from heterogeneous tax rates per geographical location of the household, bringing citizen costs in line with the benefits they are receiving, for example, in the context of flood prevention (Mullin et al., 2018). Others suggest carefully building a 'tripartite' model for urban sustainability, focusing on keeping the flow of costs and benefits to the public, businesses and citizens in balance with each other (Khare et al., 2011), illustrated with examples from water conversation, energy, and sustainable transportation. This is in line with Schilling and Logan (2008) who suggest creating a diverse group of partners and financiers from state money to foundation grants and local bonds. They also suggest creating a land bank to carry the initial risk of preparing land in weak or volatile real estate markets to encourage private investment and create momentum for area revitalization (Schilling and Logan 2008).The idea of starting with a demonstration or pilot phase is often mentioned to lower the risks for private investors to step in, for example, in the context of large scale urban regeneration (Schilling and Logan 2008).

Several innovative private and public funding solutions for urban regeneration have been suggested by Huston et al. (2015). First, capturing land value uplifting from urban NBS could occur directly through lease charges and connection fees or indirectly using tax schemes, usually through a land property special purpose vehicle. Second, alternative financing schemes based on crowdfunding could play a role in creating sound public-private partnerships (Vasileiadou et al., 2016). Social/environmental impact bond schemes can shift the risk of reaching social or environmental milestones from taxpayers to private bondholders. Tax increment financing (TIF) allows for property gains due to infrastructure investments to be used as a basis to capture ex-post project benefit streams.

6. Barrier 2: valuation and accounting for the multiple benefits of urban NBS

6.1. Unpacking barrier 2

A second major topic in the literature on finance for (sustainable) urban regeneration and NBS is the inability of dominant valuation and accounting methodologies to value and account for benefits created by NBS interventions (Bockarjova et al., 2020). Authors emphasize the difficulty of translating NBS benefits into monetary units, creating underinvestment into and overexploitation of natural resources (de Groot et al., 2012; Hein et al., 2013). Also, some scholars criticize the common aim of creating better reporting and accounting frameworks, arguing that such reporting creates a disconnect to the real challenge of taking care of our natural capital and may instead reinforce business as usual (Milne and Gray 2013).

A key question that emerges within this theme is how to weigh long-term public value against (lack of) private short-term cash flows. A long timeframe and large scale are often needed to capture benefits from infrastructural NBS investments, such as investments in sustainable urban drainage systems and urban parks. However, discounting of future values implies that the long-term benefit is often not weighted strongly in current financing decisions, which leads to economic, sustainability and ethical considerations (Guerry et al., 2015). Current application of environmental impact valuations by financial decision-makers is described by some as incomplete and disassociated, used for justifying nature-based wealth accumulation (Bracking 2012; Milne and Gray 2013).

Although adjustment of accounting frameworks is seen as a promising route for upscaling NBS (and will be discussed in the next section), actual decision models for investment may change slower than expected due to persisting conventions and resistance to alternative investment strategies by traditional financial players such as pension funds (Clark 1998). Lack of entry of large, traditional players such as these may slow the scaling up of sustainable housing and urban infrastructure investment (Clark 1998). This raises the issue of which actors will be adopting these adjusted accounting—and ultimately, decision—frameworks.

6.2. Key strategies to barrier 2

Many articles in our review highlighted developing workable accounting and valuation methods that are able to capture the multiple benefits of NBS (e.g. natural capital accounting, cost benefit analyses, tree valuation, valuation of ecosystem services). The authors focused on developing assessment frameworks that allow the diversity and timeframe of benefits to be taken into account in investment decision-making. Improved accounting methods, which include the variety of NBS benefits that are expected to increase their ability to generate funds.

Researchers suggest adjustment of valuation procedures to include appraisal of factors such as quality of life and job creation (McGreal et al., 2000; Adair et al., 2000) and linking NBS more explicitly to the benefits they create (Schulte-Hostedde et al., 2007). For example, NBS are conceived through the lens of natural capital, ecosystem services, and ecological footprint to calculate the delivered value of ecosystems (Wackernagel et al., 1999; Monfreda et al., 2004; Nesshöver et al., 2017). Accounting for the value of ecosystems is undertaken both at a national level (Wackernagel et al., 1999) and firm level (Milne and Gray 2013) aimed at improving the governance and management of natural resources.

The concepts of natural capital (accounting) and the provision of ecosystem services are seen to increase the ability of financial decision makers to allocate funds towards nature-based solutions by providing a clear accounting framework for communicating NBS benefits (Nesshöver et al., 2017). An example of such accounting frameworks is "inclusive wealth", which aims to measure human, social, manufactured as well as natural capital (Guerry et al., 2015). Improved performance metrics should allow for better monitoring of ecosystem services and impact assessment of environmental policies and programmes (Schaefer et al., 2015). Furthermore, ecosystem service valuation is a crucial factor in creating environmental markets, exemplified by sulphur dioxide trading, wetlands mitigation banking, and nutrient trading (Schaefer et al., 2015). Markets such as those for wetlands (where wetlands that are removed for urban development can be replaced by 'new' wetlands elsewhere) raise the concern that ecosystems cannot simply be duplicated, and ecological loss is inevitable (Schulte-Hostedde et al., 2007).

With regard to the methods used to improve valuation of and accounting for NBS, several approaches were revealed. In one approach, researchers provided quantitative evidence of the costs and benefits of different types of NBS as the context of green roofs (Carter and Keeler 2008; Claus and Rousseau 2012). By identifying the costs and benefits of green roof interventions and using this to determine their net present value, they showcase the need for public finance in the form of subsidies to make green roofs an attractive investment for real estate investors (Carter and Keeler 2008; Claus and Rousseau 2012). A similar cost-benefit approach is taken to value urban trees (McPherson 2007). Taking it a step further, some studies translate a cost-benefit approach into a workable assessment model (Nelms et al., 2005).

The hedonic pricing method is another approach used in the context of valuing NBS, in particular in the context of urban trees, water, and open space. Hedonic pricing is a form of statistical analysis whereby a component of a price is related to a particular attribute. In the case of NBS valuation, the incidence of different types of nature in a certain area are related to house prices (Luttik 2000; Dimke et al., 2013). Scholars find a positive correlation between tree cover and house prices (Dimke et al., 2013) and different levels of positive correlation for various types of green (and blue) spaces in the vicinity of houses (Luttik 2000). The drawback of hedonic pricing, however, is that it only allows measurement of some components of the total economic value and from residents only.

Although hedonic pricing and cost benefit analysis uses existing data to extract a (partial) value of different types of NBS, there is also extensive literature that—through different methods—aims to proxy the total economic value of (non-market) goods like urban NBS by eliciting them from individuals in different ways. Some studies used the contingent valuation method to measure citizen willingness to pay for urban trees and parks (Tyrväinen 2001; Brander and Koetse 2011); others carried out citizen surveys (Kilchling et al., 2009; Zhang and Zheng 2011) or choice modelling (Hanley et al., 2002).

The popularity and potential biases of different valuation methods are subject to heated debates in the literature (Mahieu et al., 2014). Also, the valuation outcomes between methods—that is, hedonic pricing and contingent valuation—are not directly comparable, as they estimate different things (Brander and Koetse 2011).

Helm (2010) proposes a more fundamental change in the valuation of urban infrastructure investments. He suggests they should not be depreciated like traditional asset investments, but instead should be treated as infinite, with renewal and maintenance replacing depreciation costs. This approach may fit well with the physical features of green NBS, which grow rather than depreciate, if maintained well.

As a basis for adjusted accounting and valuation procedures, extensive information harvesting for better risk analytics is recommended. New sources of funding for biodiversity conservation should employ new information technology to improve monitoring and verifying contractual arrangements, which will make value more easily measurable (Hein et al., 2013).

7. Conclusion: a framework for enabling urban NBS finance

Although nature-based solutions (NBS) play a crucial role in the long-term resilience of cities across the globe, their upscaling faces several barriers, notably a lack of finance. Our literature review reveals key barriers and strategies that are being undertaken for upscaling NBS

finance, both at a general level and for different ecological domains.

We identified two main underlying barriers for NBS finance. The first key challenge is how to balance and coordinate public and private finance for a particular urban NBS (vertical axis, Fig. 5). The second key challenge is how to value and account for the multiple benefits delivered by NBS: metrics often do not exist, or conventional valuation and accounting practices of the actors involved do not include these benefits (horizontal axis, Fig. 5). Many of the strategies we encountered in the literature are geared at improving our ability to account for and value the diverse benefits accruing from urban NBS investment on the one hand, and towards developing concrete instruments and policies that allow the risk and return of NBS investment to be taken up and shared among public and private players.

With respect to the reported strategies, two aspects stand out in our analysis. First, there are many studies that aim at enabling valuation of the variety of NBS benefits through different methods. We have not yet encountered a generally accepted accounting and valuation framework that could be used in practice by financiers. This indicates that although substantial work is being done, there is still a substantial barrier to upscaling urban NBS based on a full valuation of their benefits. Secondly, strategies to coordinate public and private finance for urban NBS are often aimed at finding a way to enable the sharing of costs (and risks) with actors who also directly obtain benefits. This often goes beyond general taxes and more towards identifying specific private (and public) parties who benefit and therefore should be encouraged to invest through financial instruments or policies. While this approach is understandable, and to some extent seems fair that costs are brought in line with the incidence of benefits, it raises the crucial issue of socio-economic justice when the ability to pay for NBS is lacking for vulnerable parts of the population (Kabisch et al., 2016; Toxopeus et al., 2020). The inflow of private finance for NBS development, targeted at well-off urban citizens, raises concerns about urban nature being implemented to progress a neoliberal 'green growth' agenda while failing to deliver widespread socio-economic benefits (Haase et al., 2017; Kotsila et al., 2020).

8. Limitations and avenues for future research

Our study has several limitations. While the review is systematic, we performed a narrative synthesis due to the heterogeneity of the underlying literature. This could be improved as the NBS literature emerges. Also, we delved into four ecological domains, whereas there are more domains that could be studied separately for urban NBS, such as derelict urban areas and green that is connected to grey infrastructure, like railways and streets. We also acknowledge that it is beyond the scope of this paper to systematically analyse all possible public/private finance combination and their effect on upscaling urban NBS.

This literature review lays the basis for empirical follow-up studies on the dynamics and potential upscaling of urban NBS through increased access to finance. Our review highlights the challenge of coordination and balancing public/private finance, and further research should investigate the involvement of private actors in upscaling NBS in more detail. In particular, empirical research can help understand the conditions that can shape successful public-private finance and governance, while also taking into account the justice implications of involving private actors to upscale urban NBS (Toxopeus et al., 2020). Other follow-up studies could set up a systematic review on the sources of finance for (different types of) NBS and expand the number of ecological domains (including a development/adjustment of valuation and accounting methods for the multiple benefits of urban NBS), as well as compare and contrast the diversity of financing needs of urban NBS to the findings in other sustainability domains, such as innovative clean energy (Polzin et al., 2017).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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