Cities 116 (2021) 103283

Contents lists available at ScienceDirect

Cities

journal homepage: www.elsevier.com/locate/cities

Structural conditions for the wider uptake of urban nature-based solutions – A conceptual framework

Hade Dorst[a,*], Alexander van der Jagt[a], Hens Runhaar[a,b], Rob Raven[a,c]

[a] Utrecht University, Copernicus Institute of Sustainable Development, Princetonlaan 8a, 3584 CB Utrecht, the Netherlands
[b] Wageningen University and Research, Forest and Nature Conservation Policy Group, Droevendaalsesteeg 3, 6708PB, Wageningen, the Netherlands
[c] Monash University, Monash Sustainable Development Institute, 8 Scenic Boulevard, Clayton, VIC 3800, Australia

ARTICLE INFO

Keywords:
Sustainable cities
Urban development
Urban planning
Sustainability transitions
Socio-technical regimes

ABSTRACT

In policy and practice, urban Nature-Based Solutions (NBS) are considered promising innovations for sustainable urban transformation. NBS are interventions that use nature to address multiple sustainability challenges simultaneously. As such, they present a novel perspective on urban land use and development. Yet their current uptake into urban development lags behind EU ambitions. Drawing from transitions studies, this paper suggests that the limited uptake of NBS innovation stems from structural conditions that keep urban development systems locked in their current state, thereby favouring traditional 'grey' development. With a systematic literature review, we identify preliminary structural conditions that likely affect the uptake of urban NBS, culminating in a framework of 'urban infrastructure regimes', which we then illustrate with two European examples of urban NBS. Our findings indicate the relevance of using a transitions studies perspective for generating insights into the structural conditions – knowledge base, policy paradigms, etc. – that underlie barriers and opportunities for NBS uptake. We particularly argue that identifying the state and obduracy of these conditions provides a deeper understanding of how NBS uptake takes place. Findings also suggest that nature-based innovations require a customised transitions framework that accounts for the role of physical geographies.

1. Introduction

The sustainable development of cities is one of the key challenges of our society (Kabisch et al., 2017; McCormick et al., 2013; Monstadt, 2009). Nature-Based Solutions (NBS) – an emerging concept that denotes the use, conservation, and restoration of nature to address ecological, social and economic sustainability challenges – can contribute to urban sustainability (Davies & Lafortezza, 2019; Kabisch et al., 2017; Lafortezza et al., 2018). NBS is an umbrella concept that incorporates different forms of nature-based interventions, such as green roofs and façades or sustainable drainage systems (Dorst et al., 2019). NBS are envisaged to address multiple sustainability challenges simultaneously, such as flood and heat risks, ecosystem degradation or urban regeneration. Discourses on NBS hold the promise of urban transformation, envisioning a systemic change in how cities are designed and built (European Commission, 2015; Faivre et al., 2017; Kabisch et al., 2017). Therefore, different stakeholders call for enabling the wider integration of NBS into urban development practice and policy (Cohen-Shacham et al., 2016; Faivre et al., 2017; Lafortezza & Sanesi, 2019).

Yet such wider integration is limited by several barriers, highlighted in NBS literature. For instance, current decision-making frameworks insufficiently take into account the value of natural resources and the range of co-benefits they can provide, hindering the wider market and policy uptake of NBS (Ossa-Moreno et al., 2017; Raymond et al., 2017). Other barriers are fragmented governance or limited funding (Sarabi et al., 2019; Seddon et al., 2020), or limited leadership or social networks (Kabisch et al., 2016). Such barriers tend to be introduced as factors working in isolation, which overlooks the fact that they are embedded in broader structures. A more integral, systemic perspective on such impeding mechanisms and their interactions is therefore necessary (van der Jagt et al., 2020). An improved understanding of how structural conditions in urban development create barriers to NBS uptake is also essential to identify actions that can be undertaken to overcome these barriers and enable further NBS implementation in cities (García Soler et al., 2018; Kabisch et al., 2016).

Our study therefore seeks to analyse how structural conditions shape barriers and also possible opportunities for NBS. Rather than empirically exploring such structural conditions, this paper aims to construct a

* Corresponding author.
E-mail addresses: h.m.dorst@uu.nl (H. Dorst), a.p.n.vanderjagt@uu.nl (A. van der Jagt), h.a.c.runhaar@uu.nl (H. Runhaar), rob.raven@monash.edu (R. Raven).

https://doi.org/10.1016/j.cities.2021.103283
Received 23 January 2020; Received in revised form 27 January 2021; Accepted 27 May 2021
Available online 9 June 2021

conceptual framework to guide such empirical research. By building on the transitions studies concept of *socio-technical regimes* we direct attention towards urban structural conditions and path dependencies in explaining NBS development trajectories. The notion of socio-technical regimes conceptualises how structural conditions reinforce the status quo of socio-technical development, such as the development of urban infrastructures and the built environment, which is the socio-technical environment NBS are to be integrated into or transform. Thereby, these structural conditions influence the uptake of alternative approaches by creating particular barriers and opportunities for innovation. This study combines a literature review with case illustrations to answer the research question '*Which structural regime conditions affect the uptake of urban NBS?*', resulting in a conceptual framework of 'urban infrastructure regimes'. This framework outlines the structural conditions relevant to urban development, which thereby likely explain opportunities for and barriers to NBS mainstreaming.

Theoretically, we apply and advance concepts novel to the analysis of NBS development, inspired by transitions theory. Socio-technical regime theories do not only offer a systems perspective, providing a more integral outlook on how barriers and opportunities come about through broader societal structures and processes, but explicitly address processes of change and transformation in socio-technical systems with a focus on innovation dynamics (Bulkeley et al., 2014; Geels, 2019; Patterson et al., 2017). This makes socio-technical regimes a suitable concept to explore the uptake of NBS. In practical terms, our study seeks to inform the design and wider implementation of urban NBS. In particular, we argue that the impact of the NBS concept can be improved if projects are not only locally successful, but also have transformative effects, such as changed regulations, norms, or mind-sets of actors in urban development. Constructing a framework of urban infrastructure regimes, we demonstrate which structural conditions may generate project-level barriers and opportunities for NBS and how these structural conditions interrelate. Thereby this study contributes to understanding if and how the transformative potential of NBS can be harnessed. Using two examples of NBS development, we subsequently explore the usefulness of this framework for analysing how barriers to, and opportunities for, the development of NBS come about.

The following section provides the theoretical background of this paper. Section 3 introduces our methodology. Section 4 presents and illustrates the resulting framework of urban infrastructure regimes. Section 5 discusses the implications of using this framework for understanding barriers and opportunities in NBS development and Section 6 provides a conclusion.

2. Theoretical background: socio-technical regimes to explain stability and transformation

Sustainability transitions studies offer theoretical insights into the societal transformations that occur in relation to the introduction of product or process innovations (Markard et al., 2012). It is suggested that the limited uptake of innovative approaches to providing societal functions may be caused by structural conditions, such as dominant policy or funding arrangements, prevailing knowledge paradigms or incumbent actor networks with vested interests (Fuenfschilling & Truffer, 2014; Geels, 2011). Notions of the structures that shape and reproduce socio-technical systems go back to insights from evolutionary economics, science and technology studies and sociology (Fuenfschilling & Truffer, 2014; Holtz et al., 2008). Notably, Hughes' (1987) foundational text on large technical systems proposes how such systems are both socially constructed as well as shape society. The concept of socio-technical regimes forms a central component of conceptualising the origins of stability and change in socio-technical systems (Fuenfschilling, 2019; Loorbach et al., 2017; Markard et al., 2012). A socio-technical regime forms the material and institutional environment that guides actors' behaviour and cognition, is produced and reproduced in their actions and thereby stabilises a socio-technical system (Fuenfschilling & Binz, 2018; Geels, 2011; Holtz et al., 2008). Established regime structures form a selection environment for innovation. Their inertia may prove a source of barriers to the uptake of innovative approaches that deviate from regime norms and routines. Conversely, when socio-technical regimes are unstable, windows of opportunity emerge for innovation and transformation ('regime shifts') (Fuenfschilling & Truffer, 2014;Smith, 2007 ; Smith & Raven, 2012).

Differentiating between different heuristic dimensions of a socio-technical regime may enhance an understanding of how barriers and opportunities for sustainable innovation come about. Such dimensions represent the mutually reinforcing structures which together form a selection environment for socio-technical innovation (Smith, 2007; Smith & Raven, 2012). A definitive – or agreed-upon – list of regime dimensions is lacking in the literature, but several overlapping dimensions have been proposed as part of regime conceptualisations (most prominently by Geels, 2002; Smith, 2007; Geels, 2011; Smith & Raven, 2012; Fuenfschilling & Truffer, 2014) and are listed in Table 1.

Relevant to the integration of urban NBS innovation in urban development are 'urban infrastructure regimes', i.e. the socio-technical regimes that shape urban development: the "*stable urban configurations of institutions, techniques, and artifacts which determine 'normal' socio-technical developments in a city and thus shape general urban processes and the urban metabolism*" (Monstadt, 2009, p. 1937). Networks of urban infrastructures and the built environment (roads, railways, waterways, buildings etc.) and associated routines and practices can be thought of as socio-technical systems, socially and technically constituted and held in place by socio-technical regimes (Bulkeley et al., 2010, 2014; Carroli, 2018). Although an urban infrastructure regime is, similar to many other types of socio-technical regimes (Holtz et al., 2008), challenging to delineate, we take it to represent the institutional and material selection environment for urban innovation – with a particular focus on urban NBS – in development processes of urban infrastructures and the built environment.

The regime dimensions in Table 1 have not been explicated in much detail, if at all (Ghosh & Schot, 2019); perhaps because their interpretation is specific to particular socio-technical systems. Indeed, NBS are different from the technological innovations usually analysed in the context of socio-technical transitions studies. The NBS concept is considered innovative as it presents an approach to rethinking urban development (Kabisch et al., 2017; Lafortezza et al., 2018; Matthews et al., 2015). Several characteristics set NBS apart from more 'common' urban planning, implementation and maintenance practices. The NBS approach uses living nature as urban sustainability interventions, offers multifunctionality, and has an explicit solution-orientation, and therefore requires integrated governance approaches and adaptation to local socio-ecological conditions (Davies & Lafortezza, 2019; Dorst et al., 2019; Keeler et al., 2019). As such, this tentative list of analytical dimensions needs further exploration of the literature honing in on structural conditions in urban development, and their influence on NBS innovation in particular. This exploration serves to provide more detail on these dimensions as well as to enhance the relevance of current conceptions of socio-technical regimes for urban development in relation to nature-based innovation. Hence, the tentative list above provides us with a point of departure to construct a framework of 'urban infrastructure regimes' in Section 4. But first, we will elaborate on our methods.

3. Methodology

We constructed a framework of urban infrastructure regimes to uncover which structural conditions influence NBS integration using a systematic review of literature on urban socio-technical development. Subsequently, we used two examples of urban NBS development to illustrate the relevance of this framework for understanding barriers and opportunities for urban NBS mainstreaming. These two steps are visualised in Fig. 1 and further detailed below.

Table 1
Conceptualisations of socio-technical regime dimensions in transition studies literature ordered – to the extent possible – based on similarity.

Synthesised analytical dimensions	Geels (2002)	Smith (2007)	Geels (2011)	Smith and Raven (2012)	Fuenfschilling and Truffer (2014)
Technologies and infrastructures	Technology; infrastructure (p. 1262)	Technologies and infrastructures (p. 429)	Technological regime (p. 27)	'Dominant technologies and infrastructures form a (material) selection environment, for example, through articulated technical standards and infrastructural arrangements' (p. 1026)	Dominant technology (p. 778)
Industrial structure and relations	Industry structure (p. 1262)	Industrial structure (p. 429)	(Industry mentioned, but not as explicit sub-regime, p. 28)	'Established industry structures form a selection environment through, for example, established network relations, industry platforms, strong user-producer interactions, shared routines and heuristics, existing capabilities and resource allocation procedures' (p. 1026)	Organisational form; main actor types (p. 778)
Cultural values and significance	Symbolic meaning of technology (p. 1262)	Cultural, symbolic meanings underpinning practices; guiding principles (p. 429)	Socio-cultural regime (p. 27)	'The cultural significance attached to a specific regime forms a selection environment through, for example, its widespread symbolic representation and appreciation; cultural values and widespread stabilised representations' (p. 1026)	Influential values; mission; sector logic (e.g. market, engineers, state) (p. 778)
Policy and regulations	Policy (p. 1262)	Policy and regulations (p. 429)	Policy regime (p. 27)	'Public policies and political power form a selection environment through, for example, prevailing regulations, policy networks and relations with incumbent industries' (p. 1026)	(Regulation mentioned but not as explicit regime element, p. 780)
Knowledge and expertise	Techno-scientific knowledge (p. 1262)	The knowledge base for the regime (p. 429)	Science regime (p. 27)	'Guiding principles and socio-cognitive processes in the established knowledge base are geared towards incremental knowledge development rather than paradigmatic shifts. Path-breaking innovations are rejected because insufficient resources are attributed to new knowledge development, RD&D and so on, and academic and private research institutes perceive disincentives because of a lack of dedicated journals, conferences and research groups' (p. 1026)	Type of expertise (p. 778)
User practices and market mechanisms	User practices and application domains (markets) (p. 1262)	User relations and markets (p. 429)	User and market regime (p. 27)	'Markets and dominant user practices form a selection environment through stabilised market institutions, supply and demand, price mechanisms, user preferences and routines' (p. 1026)	
Funding structures					Funding source (p. 778)

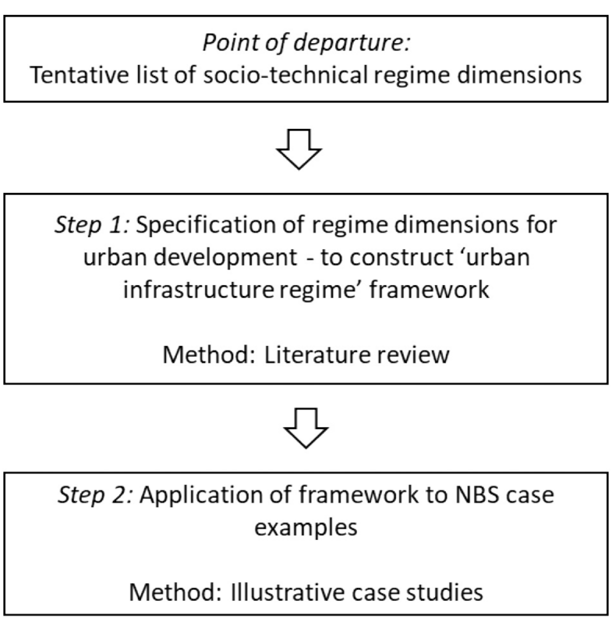

Fig. 1. Research approach.

3.1. Step 1: literature review

By way of a systematic review of literature that discusses transitions in the context of urban infrastructures and the built environment, we sought to expand our understanding of which structural conditions constitute an urban infrastructure regime. A Scopus search[1] of urban development and transitions literature yielded 64 articles; 33 articles remained after an assessment of their relevance based on titles and abstracts as the main corpus for this review. Five more articles, identified by following up on relevant references in the articles already included, were added during the review based on their apparent relevance. The outcomes of this review, combined with the socio-technical regimes dimensions in Table 1, resulted in a framework of urban infrastructure regimes, presented in Section 4.1.

A coding scheme comprising the structural dimensions listed in Table 1 (first column) was used to review this corpus using the qualitative data analysis software NVivo. To keep an open visor as to whether other structural conditions were also perceived important for transition dynamics in urban development we added an open coding category ('other'). We define 'structural' conditions as the distinct system of social and physical processes and factors involved in the reproduction and

[1] TITLE-ABS-KEY (("urban development" OR "urban planning" OR "urban infrastructure" OR "built environment") AND ((socio-technical OR socio-technical) AND transition*)) AND (LIMIT-TO (DOCTYPE, "ar")) date 25–11-19.

reinforcement of actors' behaviour and decision making (Fuenfschilling & Binz, 2018; Holtz et al., 2008). Furthermore, we are primarily interested in how urban infrastructure regime structures shape innovation with NBS. As such, our review emphasised those conditions that are suggested or expected to be relevant to NBS innovation.

3.2. Step 2: illustrative examples of NBS project development

We illustrated the framework with two examples of NBS development: Little France Park in Edinburgh, the United Kingdom, and the Leidsche Rijn water system in Utrecht, the Netherlands, the results of which are presented in Section 4.2. These illustrations are based on case study work as part of the NATURVATION research project on innovating with and governing urban NBS (Kiss et al., 2019).

Data collection focused on the circumstances under which the NBS emerged and structural conditions that shaped their development trajectories (Kiss et al., 2019). Semi-structured interviews were conducted with 6 key informants for the Little France Park case and 7 for the Leidsche Rijn water system case – e.g. public authorities, NGOs, community members, development companies (see Table 3 in the Appendix for interview data). Additionally, relevant policy documents, such as municipal greening strategies and planning visions, were identified to provide background information and context for the case studies. Our analysis of the interview transcripts in NVivo was guided by the framework dimensions that followed from the literature review in step 1 (Table 2). Table 4 (in the Appendix) provides more detail on the research questions we used to analyse the data.

Several motivations guided our selection of these examples:

- Although the projects are not representative for all potential NBS manifestations, they represent good examples of multifunctional urban NBS development, as in both cases natural assets were central to delivering multiple project objectives.
- Urban NBS are noted to be difficult to scale up (Kabisch et al., 2016; Kronenberg et al., 2017; Wamsler et al., 2017), yet these two projects are relatively large-scale spatial development projects that integrated NBS principles. They thereby present counterintuitive case profiles (somewhat akin to the notion of 'extreme cases', which represent unusual values on a variable of interest (Gerring, 2006)). We hope that a focus on such 'extreme' examples provides a thorough test of the usefulness of the framework.
- The two projects contrast in the relative 'ease' of their development trajectories. Little France Park represents an ongoing development fraught with conflict and uncertainty. The Leidsche Rijn water system has experienced relatively minor barriers and is perceived by its stakeholders as successful regarding both its development process and delivery against sustainability targets. Analysing such contrasting trajectories also provides an opportunity to test how well a transitions lens 'works' in understanding barriers as well as opportunities for NBS development.

In sum, these case examples are not exhaustive, but illustrative; their function is to reflect on the use and usefulness of an urban infrastructure regime lens for NBS. The illustrations of regime mechanisms were extracted from the original case study material.

Table 2
Key dimensions of urban infrastructure regimes.

Regime dimensions	General description
Physical infrastructures and technologies	The physical infrastructures and technologies that shape decision-making on urban development
Industry structure, actor networks, and organisational forms	Institutionalised actor roles and responsibilities, and the organisational forms (networks, platforms) and rules (formal and informal) that shape interaction
Cultural values and guiding principles	Main targets, objectives and priorities articulated in the regime, as well as underlying values, rationales and principles that shape actor strategies in urban development
Policy and regulations	Influential policies and regulations and their role in shaping urban development
Knowledge and expertise	(Expert) knowledge that underpins the regime's functioning and decision-making processes, and the technologies (e.g., tools, procedures and models) to use and enhance that knowledge and support knowledge exchange
Economic mechanisms and user behaviour	Perceived supply and demand for types of urban development (e.g. innovative and/or sustainable) and the ways in which these perceptions shape decision-making processes
Funding structures	Availability and types of funding necessary to continue regime practices, as well as instruments to raise funding
Physical geographies	The broader physical geography of urban areas, including natural resources and environmental conditions

4. Results: exploring the influences of the urban infrastructure regime on NBS development

4.1. A conceptual framework of urban infrastructure regimes

Table 2 outlines our results: a synthesis of the dimensions that stabilise urban development as presented in the literature on transitions in urban development. It is important to reiterate here that our review focusses on those urban development dimensions that are expected to influence NBS in particular, and therefore do not necessarily represent structural conditions for all types of innovation in urban development. A significant difference to the tentative list of synthesised dimensions we explored this literature with (Table 1), is that we added *physical geographies* as a separate dimension. This dimension emerged from our review as an influential category of structural conditions for NBS innovation in urban development. In addition, the other regime dimensions have been rephrased, if relevant, to better capture the aggregated contents emerging from the review. We discuss each dimension in more detail below.

4.1.1. Physical infrastructures and technologies

Physical urban infrastructures and the built environment form the material core of what it is that needs adaptation and transformation to achieve more sustainable cities. Urban infrastructures consist of physical components such as water pipes, sewers, electricity and transport technologies, or waterworks (Monstadt, 2009). An obdurate built environment – representing 'sunk investments' and long life spans; whether obsolete or still functioning urban infrastructures – affects the agency and behaviour of urban dwellers and determines the path dependency of future developments (Eames et al., 2013; Haarstad, 2016; Næss & Vogel, 2012). Even though these physical forms are constituted through social processes, "*the fixed form these things then assume have a powerful influence upon the way that social processes can operate*" (Harvey, 1997, 21). In the European context, the optimisation or modernisation of these infrastructures is therefore often favoured over their complete alteration, and new technologies tend to exist alongside remnants of 'older' urban infrastructure regimes (Carroli, 2018; Eames et al., 2013). The condition of physical infrastructures in cities steers political choices. For instance, housing shortages may crowd out other urban sustainability issues on the agenda (Wihlborg et al., 2019). In this way, physical infrastructures and technologies may give rise to structural barriers to NBS, in particular if an NBS has a poor physical fit with the design of prevailing urban infrastructures.

4.1.2. Industry structure, actor networks, and organisational forms

Urban development involves a variety of actors, among which property developers, local authorities, investors, engineers, etc. (Eames et al., 2013; Monstadt & Wolff, 2015). The collective determination and execution of goals through interactions between these actors is a key component of urban infrastructure regimes (Monstadt, 2009). The organisation of urban development processes, such as the alignment of time-frames of key activities (Moss & Hüesker, 2019), is integral to such interactions. Sectoral organisational structures form a selection environment through, for instance, established network relations, industry platforms and shared routines (Smith & Raven, 2012). The social and power relations between urban development stakeholders and the ways in which they organise themselves (such as through the C40 cities network around urban climate adaptation transitions (Bulkeley et al., 2014; Eames et al., 2013)) enable mutual understanding and trust and determine roles and identities within the stakeholder landscape. Such relations, and the political and economic exchanges and contestations involved in them, thereby shape and maintain common practices within the socio-technical system or provide opportunities for innovation (Foong et al., 2017; Huang et al., 2018; van Welie et al., 2018). One example of how organisational structures form a condition that shapes barriers to innovations such as NBS is when tasks and responsibilities (and budgets) are 'siloed', leading to fragmented urban planning and development efforts (Eames et al., 2013; Wihlborg et al., 2019).

4.1.3. Cultural values and guiding principles

The adoption of innovation in urban development is enabled or constrained by the objectives and priorities embedded in the urban infrastructure regime, as well as the underlying values, rationales and principles that shape actors' strategies (Eames et al., 2013). As the urban environment is shaped by a variety of actors, their way of perceiving buildings and cities, as well as wider cultural and lifestyle shifts, shape their subsequent objectives and actions (Guy & Henneberry, 2000). Visions around potential urban futures tend to shape present-day decision-making on urban development (Dijk et al., 2018). Such visions can "*provide a reference point through which networks can be built, gaining commitments to 'participate', orienting the actions of potential participants and constituencies, and persuading potential participants of the desirability of transition*" (Hodson et al., 2012, 795). For instance, sustainability principles and values around climate adaptation or energy have been gaining traction in urban development discourses (Bulkeley et al., 2014). Such principles and values can translate into norms for action and thereby create momentum for the adoption of particular technologies (van der Jagt et al., 2020), such as NBS, or alternatively, constitute critical barriers if more narrow value frames around, for instance, economic efficiency of urban development prevail over or exclude the ecological and social values of NBS.

4.1.4. Policy and regulations

Such visions and expectations for urban futures, as well as political priorities, are reflected in urban policy (McPhearson et al., 2016; Papasozomenou et al., 2019). Urban planning, which encompasses both strategising and regulating (e.g. through administrative and legislative regulations, subsidy programs, procurement programs, policy goals, or problem agendas (cf. Ghosh & Schot, 2019)) guides decision-making across levels of government and stakeholder interests and determines the direction of urban development in the medium and long term (Carroli, 2018; Healey & Barrett, 1990; Ince & Marvin, 2019; Quitzau et al., 2012). Spatial planning can protect space for innovation and experimentation but also constrain change by reinforcing the status quo (Carroli, 2018; Foong et al., 2017; van Duuren et al., 2019; Wihlborg et al., 2019). Furthermore, policy and regulation is typically drafted for existing problems and current technologies and approaches; innovative approaches therefore often experience a mismatch or require novel policy paradigms to mitigate the risks involved in their development.

4.1.5. Knowledge and expertise

The established, dominant knowledge bases and expertise that informs decision-making processes, plus the methods (e.g. R&D, research) and instruments (e.g. tools, models and procedures, such as technical reports) used to sustain and advance that expertise, as well as the professions that maintain such expertise, also determine urban development processes (Bulkeley et al., 2014; Newton, 2012). Expert knowledge can stabilise or challenge political discourses and shape conceptualisations of the issues at stake as well as of their potential solutions (Dijk et al., 2018). The knowledge bases and expertise that are dominant in a regime typically have to evolve to better integrate novel solutions to contemporary societal challenges (Eames et al., 2013; Wihlborg et al., 2019). Indeed, planning for urban sustainability increasingly recognises the necessity of a diversity of knowledges to be included rather than having dominant knowledge frames perpetuated (Wijsman & Feagan, 2019). Knowledge and particularly its wider dissemination can also raise awareness and understanding of why change is necessary (van der Jagt et al., 2020; van Duuren et al., 2019; Wihlborg et al., 2019).

4.1.6. Economic mechanisms and user behaviour

Economic mechanisms – i.e. relations between supply and demand (commercial as well as around public goods), competition, market composition and size – affect how the urban environment is developed, with a significant role for local and supralocal governments to shape such mechanisms and correcting 'market failures' (Bolton & Foxon, 2013; Ghosh & Schot, 2019). The perceived demand – or lack thereof – for sustainable innovations in urban development, as well as citizen behaviour, preferences and routines regarding urban infrastructures and buildings shape decision-making processes in the urban infrastructure regime (cf. Ghosh & Schot, 2019; Smith & Raven, 2012). For instance, the enhanced public interest in sustainability increases opportunities for sustainable urban infrastructures like NBS (cf. van Duuren et al., 2019). Furthermore, urban sustainability discourses frequently reflect economic growth ideologies, and by extension the commodification of urban nature as a sustainability 'solution' is sometimes also criticised (Kotsila et al., 2020).

4.1.7. Funding structures

Funding arrangements and financial resources (including land ownership) are an essential regime component. The flows of capital through resources tie actors in urban development into structural relations (Healey & Barrett, 1990). Urban development involves significant financial investment (Hodson et al., 2012; Huang et al., 2018). Considerations regarding costs and profit, and the structures that produce those (e.g. austerity, subsidies or the lack of a viable business case), determine actors' behaviours in urban development and thereby the likeliness of regime change; NBS tend to be 'undervalued' as a result of existing value assessment tools, as not all benefits are measurable (Raymond et al., 2017).

4.1.8. Physical geographies

One category of structural conditions emerged from the review which did not entirely fit the tentative list of structural conditions identified in transition studies (Table 1): physical geography conditions (i.e. the natural environment, ecological characteristics and relationships). The innovation paths of urban infrastructure and built environment systems are likely not only shaped by the existing physical infrastructures, but also by the broader physical geography of urban areas and socio-ecological relations (Haarstad, 2016; Monstadt, 2009; van der Leer et al., 2018). Geographic characteristics, varying from climatic conditions to natural resources, have been suggested to affect socio-technical developments in the urban environment (Foong et al., 2017; Huang et al., 2018). Indeed, the urban is sometimes also conceptualised as an ecology (Endlicher et al., 2007). This dimension seems particularly relevant for analysing NBS barriers: for instance, the growth of vegetation and flow of water is influenced by factors such as soil conditions and rainfall (van der Jagt et al., 2020).

4.2. Illustrating the framework

We illustrate the framework by exploring how structural conditions have shaped certain project-level barriers or opportunities in two cases of NBS development. As the goal of this exploration is to assess the relevance and usefulness of an urban infrastructure regime perspective on NBS uptake, we only present some of the most salient structural conditions here; Appendix A shows a more extensive overview of structural conditions influencing the two cases.

4.2.1. Little France Park

Little France Park is a parkland including bioswales and an active travel route in Edinburgh. Even though it has been part of urban planning for over two decades and is only halfway developed at the time of writing, it is now re-envisioned as a pilot project of delivering multiple benefits through nature, such as health and wellbeing, water storage and biodiversity (Int. #4). Its redevelopment is also hoped to contribute to social cohesion between the different user groups present in the area: citizens of the socio-economically disadvantaged Craigmillar area, employees and clients of the hospital, and staff at the Science Park adjacent to the parkland (Int. #6). An important barrier to Little France Park's development was the persistence of conflicting visions over land use; should it be used for housing development or to increase biodiversity, climate change adaptation and public health? Not only did opinions differ among stakeholders, but disagreement between municipal departments around plans for the site were arguably the biggest obstacle (Int. #6).

Little France Park, Edinburgh. Photo by author.

This barrier partly originated from conflicting regime *values and guiding principles*. Initial developments at Little France Park were solely aimed at river restoration to prevent flooding. One interviewee notes how a certain 'engineering mindset' prevailed that did not necessarily take into account broader benefits to society (Int. #3) and thus formed a barrier to the implementation of this NBS, prioritising river restoration over other potential benefits of the parkland. Consequently, local community perceptions of the area as being 'not usable' and 'unattractive' (Int. #5) fuelled the municipal concerns about further park developments.

Economic mechanisms and user behaviour also contributed to this conflict. Edinburgh is growing and so are pressures on the housing market, making Little France Park an attractive site for housing development (Int. #6). The adjacent neighbourhood of Craigmillar has been characterised by social deprivation for years; some local residents believe that neighbourhood expansion would provide opportunities for more public facilities in the neighbourhood (e.g. schools, libraries) (Int. #5). Further adding to the public demand for housing, project developers have made promises around the creation of new amenities to local residents – a clear example of how regime actors are actively exerting selection pressures on development (Int. #1).

Finally, lack of funding was indicated to be another major barrier to the development of Little France Park. Underlying *funding structures*, such as municipal budget cuts and austerity, were indicated as the main cause (Int. #3; Int. #4; Int. #10). Relatedly, issues around securing land ownership contributed to uncertainty about the project's future, leading to a diminished trust with external funding stakeholders, who eventually pulled out of the project (Int. #3; Int. #6).

In sum, Little France Park provides an example of how several socio-technical regime conditions, such as the manifestation of established funding structures, supply and demand mechanisms, and dominant values and guiding principles, have conjointly created a less favourable environment for its development.

4.2.2. Leidsche Rijn water system

The Leidsche Rijn water system in Utrecht, the Netherlands, is a sustainable, nature-based and closed-loop surface water system to provide clean and clear surface water, support biodiversity and climate adaptation. It is part of the ongoing expansion of Utrecht with a new urban district providing around 30,000 new homes between 1997 and 2025. The system includes components such as bioswales, ecological water banks, a network of canals, buffer lakes, dams with water gates, water pump stations, and permeable paving. Although the development process was relatively uncomplicated due to its greenfield status, there was some contestation over the fact that a new neighbourhood was developed on what was formerly a rural landscape and part of the national ecological network. Moreover, by adding a new neighbourhood on the city's edge, the project has also not been able to align with current sustainability ambitions to increase urban densities to accommodate growth, i.e. to grow inward rather than outward.

Bioswale in Leidsche Rijn. Source: Yvonne van Megen, Utrecht municipality.

However, overall the development process has been reflected upon by the municipality as relatively successful. An important feature to the projects development trajectory was the strong municipal negotiating position vis-à-vis developers to enforce the implementation of the experimental water system (Int. #11).

A structural condition that enabled such a strong negotiating position in the first place was the site's greenfield status, with few obdurate man-made *physical infrastructures* standing in the way of development (Int. #15).

Another regime dimension of importance here were *physical geography* conditions. The relatively large scale of Leidsche Rijn project facilitated a particular governance approach: a semi-independent municipal project team was established which included a water system task force. This task force could function relatively independently from prevailing perceptions on how to manage an urban water system (Int. #10). It is important to note that different stakeholders attested that this strategy of a relatively independent governing structure could only be held up by strong project-internal leadership (Int. #8; Int. #10), which highlights that regime conditions do not affect project development trajectories in isolation but conjointly with project-internal characteristics and processes. This leadership was then wielded to influence regime actors to facilitate project development, further indicating the two-sided interaction between regime conditions and NBS project-level dynamics.

Additionally, local soil conditions and the presence of waterways influenced how the nature-based water system was constructed. Moreover, the poor water quality in the area indirectly also motivated policy-making on water quality, creating opportunities for alternative solutions and hence NBS development (Int. #11; Projectbureau Leidsche Rijn, 1997).

Furthermore, this case shows the influences of favourable *policy conditions*, which in turn have informed *regulations* favourable to this project. In the early 1990s, a national-level policy (known as VINEX) prioritised large-scale greenfield housing developments. Although such policies were not at all aimed at NBS development, in combination with policy discourses on sustainable building and clean water, this policy paved the way for the relatively large-scale implementation of nature-based innovation in the Leidsche Rijn development (Int. #10). Trickling down from more high-level political ideas, local policy then stimulated project developers to integrate sustainability elements into their designs (Int. #10).

In sum, the relative ease with which the project consortium could deliver upon its ambitions can partly be explained by the configuration of a set of socio-technical regime conditions that have, in contrast to Little France Park, created a relatively favourable environment for their activities.

4.3. Using the urban infrastructure regime framework: what does it reveal?

Constructing and applying a framework of urban infrastructure regimes has enhanced our understanding of how barriers and opportunities for NBS are shaped by structural conditions. At a conceptual level, the framework articulates the relevant dimensions of urban infrastructure regimes and provides a new, comprehensive lens through which we can interpret opportunities and barriers for the uptake of NBS. Empirically it provides deeper explanations of particular barriers and opportunities for NBS development derive from structural conditions that characterise the urban development systems in place. It highlights the necessity of being aware of factors that lie beyond the internal organisation of an NBS project but are generated by broader social, political, economic and institutional structures, which coordinate but are also produced and reproduced by actors concerned with urban development. For instance, in the Leidsche Rijn case it appears from the surface that the project bureau took a powerful position in negotiating with developers, who as a result took on an experimental project. Their position benefitted greatly from having a large greenfield site at their disposal and a prevailing national clean water discourse to which they aligned their plans. Arguably, would these structural conditions have been absent, the choices of these actors may have been otherwise and the integration of NBS may have been more challenging or different in nature.

Furthermore, the systemic perspective shows that conditions co-produce particular barriers or opportunities. For example, a combination of conflicts over development plans (*industry structure*, *guiding principles*) and difficulties with securing land ownership (*financial structures*) resulted in funders withdrawing from the Little France Park project. Indeed, although for analytical purposes we have distinguished different regime dimensions, they are interconnected through shared rules and norms, infrastructures and actors. Thereby they also coevolve; 'through their interaction the interacting elements themselves also change' (Loorbach et al., 2017, 608); if it were not for critical water quality conditions or the availability of a large greenfield site to develop (*physical geographies)*, there would arguably have been no policies and political actions (*policy and regulations*) towards developing the land sustainably or at such a large scale. In sum, the structural conditions that shaped the development trajectories of Little France Park and the Leidsche Rijn water system do not work in isolation.

The literature review and case illustrations confirm that the regime dimensions proposed by transitions scholars (Table 1) are relevant, but our findings indicate that *physical geographies* also matter. Indeed, NBS literature shows the importance of considering local socio-ecological conditions for NBS implementation because of their influence and dependency on such conditions (Andersson et al., 2017; Keeler et al., 2019; Nesshöver et al., 2017; van der Jagt et al., 2020). Our distinguishing physical geographies as another type of structural conditions for innovation primarily underlines our understanding of social, technological, and natural systems being interwoven, as is also put forth in socio-ecological systems thinking (Ahlborg et al., 2019; Folke, 2006).

5. Discussion

This study explored if and how a socio-technical regime perspective could support a better understanding of how barriers and opportunities for NBS uptake come about. Below, we reflect on the need to enhance socio-technical regime perspectives to better comprehend the peculiarities around the uptake of nature-based innovations.

5.1. The urban infrastructure regime: semi-coherent and heterogeneous

In our study, we assumed the urban infrastructure regime to be the dominant structure to affect the uptake of urban NBS. As such (and also for analytical purposes) we assumed it to exist as a coherent whole; a major condition for delineating the regime as a heuristic is for the assemblage of materials and institutions to form a logically coherent structure, even though indeed regimes are difficult to delineate in practice (Holtz et al., 2008). Yet we encountered instances where this regime did not seem to represent an entirely coherent rule-system. For instance, both cases showed interactions between the municipality and project developers where these parties acted upon opposing guiding principles. Municipalities could be considered a 'regime' actor in urban development because of their generally central role in visioning urban development plans and stipulating regulations (Boyer, 2014; Gustafsson & Mignon, 2019). In the case studies, the development companies were also representing urban infrastructure regime rules and reproducing these in their actions. As such, it appears different regime logics were at play in both cases (cf. Fuenfschilling & Truffer, 2014): one revolving around - simply put - delivering economic value in the form of housing (represented by the development companies), and another more focused on also taking into account ecological and social benefits (to which the municipalities were more inclined). So rather than speaking of 'the' urban infrastructure regime, we suggest it may be more appropriate to speak of a semi-coherent urban infrastructure regime that includes different actors acting based on partly different logics (cf. Fuenfschilling & Truffer, 2014). The apparent lack of regime coherence mirrors notions of regime multiplicity in urban contexts which indicate that regimes in urban areas are indeed incoherent, heterogeneous entities (Eames et al., 2013; Ghosh & Schot, 2019; Næss & Vogel, 2012; van Welie et al., 2018; Wolfram & Frantzeskaki, 2016), yet with identifiable and path-dependent properties that explain observable patterns of directionality in urban development. We recommend future research into the effects of regime-(in)coherence on the uptake of NBS, for instance regarding how it may produce or is the product of skewed power relations between the actors involved in urban development.

Furthermore, our research focused on structural conditions, but did briefly touch upon the active roles played by certain actors aiming to implement and possibly mainstream NBS projects in face of these regime structures (e.g. the local government agency that was responsible for the implementation of the Leidsche Rijn water system and the organisation that coordinated the partnership for the Little France Park developments). Future research could identify if and how actors in NBS development and mainstreaming processes act strategically in face of structural conditions to shape them, providing a more dynamic view towards structural change of urban infrastructure regimes through, e.g., institutional entrepreneurship (Fuenfschilling, 2019; Geels, 2020).

Lastly, in view of the fact that we only presented two cases to illustrate our framework, we recommend follow-up, larger-N studies to further refine the set of structural conditions in urban infrastructure regimes that provide barriers to and opportunities for NBS uptake, and to shed light on which of these dimensions offer opportunities and pathways for NBS mainstreaming.

5.2. Policy implications

The findings send an important signal to policy-makers and other professionals in urban planning and development. To accelerate the integration of NBS into mainstream urban development, this study first and foremost demonstrates the relevance of taking a systems perspective, by taking into account the structural conditions in urban development that underpin barriers and opportunities for NBS innovation and the interrelations between these conditions. Emphasising interdependencies between these conditions, using a systems perspective of urban infrastructure regimes enables a more integrative outlook onto the conditions that are most pressing when it comes to NBS implementation. Furthermore, the systemic interlinkages between structural conditions in urban development call for a holistic governance approach that takes these interdependencies into account. For actors aiming to increase NBS uptake, this implies that to solely address the reconfiguration of the most pressing structural condition (e.g. restructuring funding arrangements) may not be sufficient, as it needs to be considered in relation to other structural conditions (e.g. stakeholder configurations and their value orientations). In sum, policy interventions for NBS mainstreaming must be based on a context-specific analysis of the structural conditions that explain the existing barriers.

6. Conclusion

This paper has set out to illustrate how structural conditions hinder or enable the wider uptake of NBS into processes of urban development by giving rise to specific barriers or opportunities. We drew upon transitions studies to describe structural conditions and the way these, in interplay, influence the wider implementation and uptake of NBS. Investigating the role of system variables indicates the relevance of looking beyond the project-level to identify potential NBS development pathways. In doing so, the regime dimensions identified as important must be viewed and examined in conjunction: structural conditions do not 'work' in isolation. Furthermore, our findings indicate that NBS require a different understanding of socio-technical regimes than other types of innovation. To better understand the barriers to NBS development and opportunities for enabling its wider implementation, we suggest to also take physical geographies into account in addition to the traditional components of socio-technical regime frameworks. Finally, urban infrastructure regimes appear to be semi-coherent, so rather than speaking of a singular, clear-cut urban infrastructure regime it may be more appropriate to consider its heterogeneity, which likely also affects the identification of potential trajectories for the uptake of urban NBS.

CRediT authorship contribution statement

Hade Dorst – Conceptualisation, Methodology, Investigation, Writing - Original Draft; **Alexander van der Jagt** – Conceptualisation, Methodology, Writing - Review & Editing, Supervision; **Hens Runhaar** – Conceptualisation, Writing - Review & Editing, Supervision; **Rob Raven** – Conceptualisation, Writing - Review & Editing, Supervision.

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.

Acknowledgements

This research was funded by the European Union's Horizon 2020 research and innovation programme under grant agreement No. 730243 and participating partners in the NATURVATION research project. We are furthermore grateful for the contributions of Harriet Bulkeley, Helen Toxopeus, Friedemann Polzin, Sandra Naumann and Matthew Bach to the initial phases of the framework conceptualisation.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cities.2021.103283.

References

Ahlborg, H., Ruiz-Mercado, I., Molander, S., & Masera, O. (2019). Bringing technology into social-ecological systems research-motivations for a socio-technical-ecological systems approach. *Sustainability (Switzerland), 11*(7). https://doi.org/10.3390/su11072009.

Andersson, E., Borgström, S., & McPhearson, T. (2017). Double Insurance in Dealing with extremes: Ecological and social factors for making nature-based solutions last. In H. K. Kabisch, J. Stadler, & A. Bonn (Eds.), *Nature-based solutions to climate change adaptation in urban areas. Linkages between science, policy and practice* (pp. 51–64). Springer. https://doi.org/10.1007/978-3-319-56091-5_4.

Bolton, R., & Foxon, T. J. (2013). Urban infrastructure dynamics: Market regulation and the shaping of district energy in UK cities. *Environment and Planning A, 45*, 2194–2211. https://doi.org/10.1068/a45575.

Boyer, R. (2014). Sociotechnical transitions and urban planning: A case study of eco-cohousing in Tompkins County, New York. *Journal of Planning Education and Research, 34*, 451–464. https://doi.org/10.1177/0739456X14554037.

Bulkeley, H., Castán Broto, V., Hodson, M., & Marvin, S. (Eds.). (2010). *Cities and low carbon transitions* (1st ed.). Routledge https://doi-org.proxy.library.uu.nl/10.4324/9780203839249.

Bulkeley, H., Castán Broto, V., & Maassen, A. (2014). Low-carbon transitions and the reconfiguration of urban infrastructure. *Urban Studies, 51*, 1471–1486. https://doi.org/10.1177/0042098013500089.

Carroli, L. (2018). Planning roles in infrastructure system transitions: A review of research bridging socio-technical transitions and planning. *Environmental Innovation and Societal Transitions, 29*, 81–89. https://doi.org/10.1016/j.eist.2018.06.001.

Cohen-Shacham, E., Walters, G., Janzen, C., & Maginnis, S. (2016). *Nature-based solutions to address global societal challenges. Nature-based solutions to address global societal challenges*. Gland, Switserland: IUCN. https://doi.org/10.2305/iucn.ch.2016.13.en.

Davies, C., & Lafortezza, R. (2019). Transitional path to the adoption of nature-based solutions. *Land Use Policy, 80*, 406–409. https://doi.org/10.1016/j.landusepol.2018.09.020.

Dijk, M., de Kraker, J., & Hommels, A. (2018). Anticipating constraints on upscaling from urban innovation experiments. *Sustainability, 10*, 2796. https://doi.org/10.3390/su10082796.

Dorst, H., van der Jagt, A., Raven, R., & Runhaar, H. (2019). Urban greening through nature-based solutions – Key characteristics of an emerging concept. *Sustainable Cities and Society, 49*. https://doi.org/10.1016/J.SCS.2019.101620. Elsevier: 101620.

Eames, M., Dixon, T., May, T., & Hunt, M. (2013). City futures: Exploring urban retrofit and sustainable transitions. *Building Research and Information, 41*, 504–516. https://doi.org/10.1080/09613218.2013.805063.

Endlicher, Wilfried, Langner, Marcel, Hesse, Markus, Mieg, Harald, Kowarik, Ingo, Hostert, Patrick, … Wiegand, Claudia (2007). Urban ecology - Definitions and concepts. In *Shrinking Cities: Effects on Urban Ecology and Challenges for Urban Development* (pp. 1–15). Internationaler Verlag der Wissenschaften.

European Commission. (2015). *Towards an EU research and innovation policy agenda for nature-based solutions & re-Naturing Cities*. Luxembourg: Publications Office of the European Union. https://doi.org/10.2777/765301.

Faivre, N., Fritz, M., Freitas, T., de Boissezon, B., & Vandewoestijne, S. (2017). Nature-based solutions in the EU: Innovating with nature to address social, economic and environmental challenges. *Environmental Research, 159*, 509–518. https://doi.org/10.1016/j.envres.2017.08.032.

Folke, C. (2006). Resilience: The emergence of a perspective for social-ecological systems analyses. *Global Environmental Change, 16*, 253–267. https://doi.org/10.1016/j.gloenvcha.2006.04.002.

Foong, D., Mitchell, P., Wagstaff, N., Duncan, E., & McManus, P. (2017). Transitioning to a more sustainable residential built environment in Sydney? *Geo: Geography and Environment, 4*, 1–11. https://doi.org/10.1002/geo2.33.

Fuenfschilling, L. (2019). An institutional perspective on sustainability transitions. In F. Boons, A. McMeekin, & L. Fuenfschilling (Eds.), *Handbook of sustainable innovation* (pp. 219–236). Edward Elgar. https://doi.org/10.4337/9781788112574.00020.

Fuenfschilling, L., & Binz, C. (2018). Global socio-technical regimes. *Research Policy, 47*, 735–749. https://doi.org/10.1016/j.respol.2018.02.003.

Fuenfschilling, L., & Truffer, B. (2014). The structuration of socio-technical regimes - conceptual foundations from institutional theory. *Research Policy, 43*, 772–791. https://doi.org/10.1016/j.respol.2013.10.010.

García Soler, N., Moss, T., & Papasozomenou, O. (2018). Rain and the city: Pathways to mainstreaming rainwater harvesting in Berlin. *Geoforum, 89*, 96–106. https://doi.org/10.1016/j.geoforum.2018.01.010.

Geels, F. (2002). Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and a case-study. *Research Policy, 31*, 1257–1274. https://doi.org/10.1016/S0048-7333(02)00062-8.

Geels, F. (2011). The multi-level perspective on sustainability transitions: Responses to seven criticisms. *Environmental Innovation and Societal Transitions, 1*, 24–40. https://doi.org/10.1016/j.eist.2011.02.002.

Geels, F. (2019). Socio-technical transitions to sustainability: A review of criticisms and elaborations of the multi-level perspective. *Current Opinion in Environmental Sustainability*. https://doi.org/10.1016/j.cosust.2019.06.009. Elsevier BV.

Geels, F. W. (2020). Micro-foundations of the multi-level perspective on socio-technical transitions: Developing a multi-dimensional model of agency through crossovers between social constructivism, evolutionary economics and neo-institutional theory. *Technological Forecasting and Social Change, 152*. https://doi.org/10.1016/j.techfore.2019.119894. Elsevier Inc.: 119894.

Gerring, J. (2006). Case study research: Principles and practices. In *Case Study Research: Principles and Practices*. https://doi.org/10.1017/CBO9780511803123.

Ghosh, B., & Schot, J. (2019). Towards a novel regime change framework: Studying mobility transitions in public transport regimes in an Indian megacity. *Energy Research and Social Science, 51*, 82–95. https://doi.org/10.1016/j.erss.2018.12.001. Elsevier.

Gustafsson, S., & Mignon, I. (2019). Municipalities as intermediaries for the design and local implementation of climate visions. *European Planning Studies*, 1–22. https://doi.org/10.1080/09654313.2019.1612327, 0. Taylor & Francis.

Guy, S., & Henneberry, J. (2000). Understanding urban development processes: Integrating the economic and the social in property research. *Urban Studies, 37*, 2399–2416. https://doi.org/10.1080/00420980020005398.

Haarstad, H. (2016). Where are urban energy transitions governed? Conceptualizing the complex governance arrangements for low-carbon mobility in Europe. *Cities, 54*, 4–10. https://doi.org/10.1016/j.cities.2015.10.013. Elsevier Ltd.

Harvey, D. (1997). Contested cities: Social process and spatial form. In N. Jewson, & S. MacGregor (Eds.), *Transforming cities*. Routledge. https://doi.org/10.4324/9780203991305.

Healey, P., & Barrett, S. M. (1990). Structure and agency in land and property development processes: Some ideas for research. *Urban Studies, 27*.

Hodson, M., Marvin, S., Robinson, B., & Swilling, M. (2012). Reshaping urban infrastructure: Material flow analysis and transitions analysis in an urban context. *Journal of Industrial Ecology, 16*, 789–800. https://doi.org/10.1111/j.1530-9290.2012.00559.x.

Holtz, G., Brugnach, M., & Pahl-Wostl, C. (2008). Specifying "regime" - a framework for defining and describing regimes in transition research. *Technological Forecasting and Social Change, 75*, 623–643. https://doi.org/10.1016/j.techfore.2007.02.010.

Huang, P., Castán Broto, V., & Liu, Y. (2018). From "transitions in cities" to "transitions of cities": The diffusion and adoption of solar hot water systems in urban China. *Energy Research and Social Science, 36*, 156–164. https://doi.org/10.1016/j.erss.2017.10.028. Elsevier.

Hughes, T. P. (1987). The evolution of large technological systems. In W. Bijker, T. Hughes, & T. Pinch (Eds.), *The social construction of technological systems: New directions in the sociology and history of technology*. MIT Press.

Ince, R., & Marvin, S. (2019). Constructing domestic retrofit as a new urban infrastructure: Experimentation, equitability and contested priorities. *Local Environment, 24*, 825–842. https://doi.org/10.1080/13549839.2019.1648401. Taylor & Francis.

Kabisch, N., Frantzeskaki, N., Pauleit, S., Naumann, S., Davis, M., Artmann, M., , … Knapp, S., et al. (2016). Nature-based solutions to climate change mitigation and adaptation in urban areas: Perspectives on indicators, knowledge gaps, barriers, and opportunities for action. *Ecology and Society, 21*. https://doi.org/10.5751/ES-08373-210239. art39.

Kabisch, N., Korn, H., Stadler, J., & Bonn, A. (2017). *Nature-based solutions to climate change adaptation in urban areas: Linkages between science, policy and practice*. https://doi.org/10.1007/978-3-319-56091-5.

Keeler, B. L., Hamel, P., McPhearson, T., Hamann, M. H., Donahue, M. L., Meza Prado, K. A., , … Bratman, G. N., et al. (2019). Social-ecological and technological factors moderate the value of urban nature. *Nature Sustainability.*. https://doi.org/10.1038/s41893-018-0202-1.

Kiss, B., Sekulova, F., & Kotsila, P. (2019). *International comparison of nature-based solutions. Naturvation project report*.

Kotsila, P., Anguelovski, I., Bar, F., Langemeyer, J., Sekulova, F., & Connolly, J. J. (2020). *Nature-based solutions as discursive tools and contested practices in urban nature's neoliberalisation processes*. https://doi.org/10.1177/2514848620901437.

Kronenberg, J., Bergier, T., & Maliszewska, K. (2017). The challenge of innovation diffusion: Nature-based solutions in Poland. In N. Kabisch, H. Korn, J. Stadler, & A. Bonn (Eds.), *Nature-based solutions to climate change adaptation in urban areas* (pp. 291–306). Springer. https://doi.org/10.1007/978-3-319-56091-5_17.

Lafortezza, R., Chen, J., van den Bosch, C. K., & Randrup, T. B. (2018). Nature-based solutions for resilient landscapes and cities. *Environmental Research, 165*, 431–441. https://doi.org/10.1016/J.ENVRES.2017.11.038. Academic Press.

Lafortezza, R., and G. Sanesi. 2019. Nature-based solutions: Settling the issue of sustainable urbanization. Environmental Research 172. Academic Press: 394–398. doi:https://doi.org/10.1016/J.ENVRES.2018.12.063.

Loorbach, D., Frantzeskaki, N., & Avelino, F. (2017). Sustainability transitions research: Transforming science and practice for societal change. *Annual Review of Environment and Resources, 42*, 599–626. https://doi.org/10.1146/annurev-environ.

Markard, J., Raven, R., & Truffer, B. (2012). Sustainability transitions: An emerging field of research and its prospects. *Research Policy, 41*, 955–967. https://doi.org/10.1016/j.respol.2012.02.013.

Matthews, T., Lo, A. Y., & Byrne, J. A. (2015). Reconceptualizing green infrastructure for climate change adaptation: Barriers to adoption and drivers for uptake by spatial planners. *Landscape and Urban Planning, 138*, 155–163. https://doi.org/10.1016/j.landurbplan.2015.02.010. Elsevier B.V.

McCormick, K., Anderberg, S., Coenen, L., & Neij, L. (2013). Advancing sustainable urban transformation. *Journal of Cleaner Production, 50*, 1–11. https://doi.org/10.1016/j.jclepro.2013.01.003.

McPhearson, T., Iwaniec, D. M., & Bai, X. (2016). Positive visions for guiding urban transformations toward sustainable futures. *Current Opinion in Environment Sustainability*. https://doi.org/10.1016/j.cosust.2017.04.004.

Monstadt, J. (2009). Conceptualizing the political ecology of urban infrastructures: Insights from technology and urban studies. *Environment and Planning A, 41*, 1924–1942. https://doi.org/10.1068/a4145.

Monstadt, J., & Wolff, A. (2015). Energy transition or incremental change? Green policy agendas and the adaptability of the urban energy regime in Los Angeles. *Energy Policy, 78*, 213–224. https://doi.org/10.1016/j.enpol.2014.10.022. Elsevier.

Moss, T., & Hüesker, F. (2019). Politicised nexus thinking in practice: Integrating urban wastewater utilities into regional energy markets. *Urban Studies, 56*, 2225–2241. https://doi.org/10.1177/0042098017735229.

Næss, P., & Vogel, N. (2012). Sustainable urban development and the multi-level transition perspective. *Environmental Innovation and Societal Transitions, 4*, 36–50. https://doi.org/10.1016/j.eist.2012.07.001. Elsevier B.V.

Nesshöver, C., Assmuth, T., Irvine, K. N., Rusch, G. M., Waylen, K. A., Delbaere, B., , … Jones-Walters, L., et al. (2017). The science, policy and practice of nature-based solutions: An interdisciplinary perspective. *Science of The Total Environment.*. https://doi.org/10.1016/j.scitotenv.2016.11.106.

Newton, P. W. (2012). Liveable and sustainable? Socio-technical challenges for twenty-first-century cities. *Journal of Urban Technology, 19*, 81–102. https://doi.org/10.1080/10630732.2012.626703.

Ossa-Moreno, J., Smith, K. M., & Mijic, A. (2017). Economic analysis of wider benefits to facilitate SuDS uptake in London, UK. *Sustainable Cities and Society, 28*, 411–419. https://doi.org/10.1016/j.scs.2016.10.002.

Papasozomenou, O., Moss, T., & García Soler, N. (2019). Raindrops keep falling on my roof: Imaginaries, infrastructures and institutions shaping rainwater harvesting in Berlin. *Journal of Environmental Policy and Planning, 21*, 358–372. https://doi.org/10.1080/1523908X.2019.1623658. Taylor & Francis.

Patterson, J., Schulz, K., Vervoort, J., van der Hel, S., Widerberg, O., Adler, C., Hurlbert, M., Anderton, K., et al. (2017). Exploring the governance and politics of transformations towards sustainability. *Environmental Innovation and Societal Transitions, 24*. https://doi.org/10.1016/j.eist.2016.09.001. Elsevier.

Projectbureau Leidsche Rijn. (1997). *Nieuwe stad, schoon water. Het watersysteem van Leidsche Rijn*. Utrecht. https://doi.org/10.1017/CBO9781107415324.004.

Quitzau, M. B., Hoffmann, B., & Elle, M. (2012). Local niche planning and its strategic implications for implementation of energy-efficient technology. *Technological Forecasting and Social Change, 79*, 1049–1058. https://doi.org/10.1016/j.techfore.2011.11.009. Elsevier Inc.

Raymond, C. M., Frantzeskaki, N., Kabisch, N., Berry, P., Breil, M., Nita, M. R., … Calfapietra, C. (2017). A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas. *Environmental Science and Policy, 77*, 15–24. https://doi.org/10.1016/j.envsci.2017.07.008. Elsevier.

Sarabi, S., Han, R., Vries, & Wendling. (2019). Key enablers of and barriers to the uptake and implementation of nature-based solutions in urban settings: A review. *Resources, 8*, 121. https://doi.org/10.3390/resources8030121.

Seddon, N., Chausson, A., Berry, P., Girardin, C. A. J., Smith, A., & Turner, B. (2020). Understanding the value and limits of nature-based solutions to climate change and other global challenges. *Philosophical Transactions of the Royal Society, B: Biological Sciences, 375*, 20190120. https://doi.org/10.1098/rstb.2019.0120.

Smith, A. (2007). Translating Sustainabilities between green niches and socio-technical regimes. *Technology Analysis & Strategic Management, 19*, 427–450. https://doi.org/10.1080/09537320701403334.

Smith, A., & Raven, R. (2012). What is protective space? Reconsidering niches in transitions to sustainability. *Research Policy, 41*, 1025–1036. https://doi.org/10.1016/j.respol.2011.12.012.

van der Jagt, A. P. N., Raven, R., Dorst, H., & Runhaar, H. (2020). Nature-based innovation systems. *Environmental Innovation and Societal Transitions, 35*, 202–216. https://doi.org/10.1016/j.eist.2019.09.005. Elsevier B.V.

van der Leer, J., van Timmeren, A., & Wandl, A. (2018). Social-ecological-technical systems in urban planning for a circular economy: An opportunity for horizontal integration. *Architectural Science Review, 61*, 298–304. https://doi.org/10.1080/00038628.2018.1505598. Taylor and Francis Ltd.

van Duuren, van Alphen, Koop, & de Bruin. (2019). Potential transformative changes in water provision systems: Impact of decentralised water systems on centralised water supply regime. *Water, 11*, 1709. https://doi.org/10.3390/w11081709.

van Welie, M. J., Cherunya, P. C., Truffer, B., & Murphy, J. T. (2018). Analysing transition pathways in developing cities: The case of Nairobi's splintered sanitation regime. *Technological Forecasting and Social Change*. https://doi.org/10.1016/j.techfore.2018.07.059.

Wamsler, C., Pauleit, S., Zölch, T., Schetke, S., & Mascarenhas, A. (2017). Mainstreaming nature-based solutions for climate change adaptation in urban governance and planning. In N. Kabisch, H. Korn, J. Stadler, & A. Bonn (Eds.), *Nature-based solutions to climate change adaptation in urban areas* (pp. 257–273). Springer. https://doi.org/10.1007/978-3-319-56091-5_15.
Wihlborg, M., Sörensen, J., & Alkan Olsson, J. (2019). Assessment of barriers and drivers for implementation of blue-green solutions in Swedish municipalities. *Journal of Environmental Management, 233*, 706–718. https://doi.org/10.1016/j.jenvman.2018.12.018.
Wijsman, K., & Feagan, M. (2019). Rethinking knowledge systems for urban resilience: Feminist and decolonial contributions to just transformations. *Environmental Science and Policy, 98*, 70–76. https://doi.org/10.1016/j.envsci.2019.04.017.
Wolfram, M., & Frantzeskaki, N. (2016). Cities and systemic change for sustainability: Prevailing epistemologies and an emerging research agenda. *Sustainability, 8*, 144. https://doi.org/10.3390/su8020144.