Catalyzing Sustainability Pathways: Navigating Urban Nature Based Solutions in Europe

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Abstract

The notion that pathways can be identified and followed towards more sustainable futures has become an increasingly prevalent idea across the science and policy of global environmental change. Focusing on the debate within literatures on socio-technical systems, we find that pathways are often tied to the concept of scaling up such that they are dependent on trajectories which extend from the geographically small to large scale or from singular incidences to widespread adoption. Building on relational approaches to scaling, in this paper we argue that sustainability pathways need to be conceived as emerging from the catalytic interaction of multiple and overlapping efforts to change the status quo. We suggest that pathways can be conceptualized as being composed of 'stepping stones': bundles of related interventions that seize or create opportunities to build momentum for the implementation of innovations, the form of which is not predetermined. Drawing on 243 interviews, participant observation, and document analysis examining urban nature-based solutions across six European countries and the EU, we identify 20 stepping stones that can be used to accelerate the uptake of urban NBS in European cities. In the case of urban NBS in Europe, we find that the capacity of stepping stones to generate catalytic change strongly depends on how they interact with one another. We illustrate that pathways are not given but rather assembled through key interventions that collectively generate the capacities and momentum needed to overcome inertia and generate new socio-material orders in which such interventions are normalized as mainstream responses to sustainability challenges.

Introduction

As scientists and policymakers search for solutions to sustainability challenges, there has been increasing talk of pathways – either those to which we must stick to remain within planetary boundaries (Leach et al., 2013) or the ways in which they can be forged to realise sustainability transitions (Geels et al., 2016; Geels and Schot, 2007). While in general the notion of pathways has been used "to conceptualise evolving trajectories of effects moving from the present towards (or away from) qualitatively more sustainable futures (however defined)" (Patterson et al., 2021, p. 4), distinctions can be made between approaches which focus on biophysical, socio-economic or socio-technical pathways both in terms of their intended focus and the extent to which they are portrayed as predetermined or unfolding over time (Rosenbloom, 2017).

Pathways often appear as smooth arcs towards future goals, where the key challenge is either to stay within the safe landing zone or to bend the curve away from undesirable outcomes (Foxon et al., 2010; Söderholm et al., 2011; Wiseman et al., 2013). However, such a vision of pathways as a coherent trajectory tends to overlook how they arise through "unfolding series of moments requiring interpretation and decision-making under uncertainty, often without

guarantee of clear or satisfactory outcomes" (Patterson et al., 2021, p. 4). Equally popular is the portrayal of pathways in the plural, as a set of different 'routes' a transition can take based on the timing and nature of interactions between niches, regimes, and landscapes (Geels and Schot, 2007). Yet as Rosenbloom (2017) identifies in a recent systematic review of the pathways concept, the nature of these junctures and the choices they entail has received relatively limited attention to date. For all their merit in providing more hopeful directions for sustainable futures, the notion of sustainability pathways is often used in a relatively deterministic way, such that reaching particular goals becomes just a matter of following the pathway set ahead or making the right decisions at key branching points in the system.

It has been within literatures on socio-ecological and socio-technical systems that approaches to pathways which are concerned with understanding their unfolding, co-evolutionary dynamics over time have emerged (Leach et al., 2010; Rosenbloom, 2017). Such perspectives point to "the multiple and interlocking causal processes involved in transitions" as well as the "tendency of powerful actors and institutions" (Rosenbloom, 2017, p. 43) to narrow down the range of possible pathways, "as particular forms of knowledge and system-framing, knowledge, professions, political interests, goals and values, organizational arrangements and bureaucratic routines mutually reinforce each other, creating particular pathways and marginalising others" (Leach et al., 2010, p. 376; see also Runhaar et al., 2020).

While the dynamics of socio-ecological and socio-technical change receive increasingly sophisticated attention, the notion of pathways itself remains relatively unexplored. Stripple and Bulkeley (2019, p. 53) suggest that within this body of work, the term pathway can be interpreted both as "an entity (the route or chain that is followed) and as a process (the way in which the path is forged)" with the consequence that its analytical value is limited. Implicitly, within both the multilevel perspective (MLP) and transition management approaches, pathways are tied to the idea of scaling up – transition pathways involve moving from niche-level innovations to regime-level change (Geels et al., 2017; Geels and Schot, 2007). Sustainability pathways are then perhaps best understood within this body of literature as those which enable the scaling of various sustainability innovations to take place. Though there is intuitive appeal to the concept of scaling up, at its root are a set of assumptions that call into question its robustness and practical potential. This approach assumes that innovations are separate from their context rather than intertwined and co-evolving, that transitioning is a process that can be deliberately steered, and that sustainability pathways depend on upscaling more or less homogenous innovations without tailoring them to specific contexts.

Building on the dynamics of sustainability pathways identified in socio-technical and socio-ecological perspectives, in this paper we problematize the implicit dependence on 'scaling' as the central means through which pathways can be forged and instead offer an alternative means focused on 'catalyzing' sustainable pathways. We argue that sustainability pathways need to be conceived as emerging from the catalytic interaction of multiple and overlapping efforts to change the status quo. Pathways are not given, predetermined routes, but instead are assembled through the alignment and coherence of key interventions. Key interventions take

advantage of opportunities to destabilize urban infrastructure regimes and cohere elements (technical, social, political, legal etc.) to generate capacity for new ways of doing things (McGuirk and Dowling, 2021).

We take as our empirical setting the development of urban nature-based solutions (NBS) in European cities, drawing on research conducted in six countries (Germany, Hungary, the Netherlands, Spain, Sweden and the United Kingdom (UK)) as well as at the level of the European Union (EU). Scientists and policy-makers consider urban NBS to be promising innovations based on their ability to simultaneously support economic, social and ecological outcomes (Dorst et al., 2019; Maes and Jacobs, 2017). We examine bundles of related interventions – which we call stepping stones – that enable the uptake of urban NBS. We find that where stepping stones are clustered in particular ways, momentum builds which enables NBS to become mainstream responses to urban sustainability challenges. In contrast, we observe that where individual interventions are implemented to support NBS without additional steps in place, they are often less effective. Our analysis points to the critical work of navigating and forging pathways for urban sustainability, recognizing that transitioning towards sustainability goals is a process of seizing multiple parallel, consecutive, and/or spontaneously arising opportunities rather than engineering deterministic pathways.

Theoretical framework: From scaling up to catalytic pathways for transition

For much of the literature on socio-technical and socio-ecological sustainability pathways, scaling up is an inherent, if often implicit, component. Particularly when it comes to questions of urban sustainability, where experimentation is now recognized as a significant response to societal challenges (Bulkeley et al., 2015; Evans et al., 2016; Karvonen, 2018), pathways that are able to generate transformative change are those capable of carrying (niche) innovations to scale, including 'scaling up' or "widening of the scale of operation" (Hughes et al., 2020, pp. 8–9) and 'scaling out' or "the expansion geographically of a pilot project from the city to other jurisdictions, including other cities and other levels of government" (Hughes et al., 2020, pp. 8–9). This focus on the need to scale up urban experimentation to realize transformative change is also echoed across policy and practitioner communities (Nagorny-Koring, 2019). Yet sustainability transitions are not always simple processes of upscaling predefined innovations. Particularly in the case of nature-based innovations, the dependence on local, physical characteristics requires tailoring (Dorst et al., 2019). As Fastenrath et al. (2020, p. 63) suggest in their analysis of NBS, "despite its inflationary usage, it is unclear what 'scaling-up' of NBS actually means, how it is steered and managed; and what benefits and potential challenges of a scaled approach can entail." Even in the face of the considerable efforts placed on such forms of scaling by transnational intermediaries and networks, research finds that "little is known about ... how successful experiments and innovations travel across contexts or about how they are transferred" (Peng et al., 2019, p. 303; see also Smeds and Acuto, 2018).

Studies point to the complexity of the work involved in seeking to scale up experimentation. Hughes et al. (2020, p. 289) found that scaling up is not a matter of policy learning, but rather

requires continuous navigation of “the political, financial, technical, and institutional challenges to innovation” encountered. Similarly, Peng et al. (2019) established that contextualization was required to scale up experiments in Shanghai, involving the generation of new social, economic and institutional configurations through experimentation itself and going beyond learning from successful examples. Within the field of socio-technical transitions, scaling up is seen as the result of “successful experiments, that is where actors are able to provide the right level of protection, nurturing or empowerment to enable innovations to become established” (Bulkeley, 2019, p. 30). However, there has been limited attention paid to how it is that “enlightened ideas” move out of such enclaves or “how complex trans-local relationships support that process” (Bouzarovski and Haarstad, 2019, p. 258), in turn limiting our understanding of the ways in which pathways for sustainability are generated. In part, such limitations can be traced back to the “general tendency in transition studies to implicitly suppose that transition processes play out (and can be analysed) within the boundaries of pre-given, and often formal, geographical categories” in turn leading to a rather limited conceptualization of scale within the field (Binz et al., 2020, p. 2).

In the remainder of this section, we explore how key assumptions about the nature of scaling up limit our understanding of these dynamics. Instead, we suggest that adopting a relational perspective can yield new insights into how sustainability pathways are generated. We argue for an approach which focuses more on the internal dynamics of forging sustainability pathways and argue that sustainability pathways are shaped through the alignment of key interventions (i.e. ‘stepping stones’) that can collectively generate enough momentum to overcome inertia and generate new socio-material orders by fostering catalytic change that cascades through interconnected systems.

Mobilising experimentation

Despite the intuitive appeal of the concept of scaling up as a means to explain and organize pathways for sustainability, at its root we find there are a set of assumptions that call into question both its conceptual robustness and practical potential. First, as Binz et al. (2020, p. 2) point out in their review of the ways in which the ‘geographies of transition’ are treated in the field, the concept of scaling up relies on “pre-given, and often formal, geographical categories” that are treated as “territorial containers”, a position at odds with many individual research contributions in transition studies that focus on the interdependencies between geographical scales and, more fundamentally, “contradicts state of the art theorizing in human geography, where multi-scalar, relational, and constructivist understandings of scale and socioeconomic processes predominate.” There is a predominance of “linear and hierarchical scalar ontologies” (Bouzarovski and Haarstad, 2019, p. 260) within transition studies. As a result, pathways are conceived as promising routes through which experimentation that takes place at the small or local scale can be translated to scales at which they hold more significance (e.g. from local to national) or as those which are capable of extracting experiments from particular contexts and

multiplying them elsewhere. In this approach, the social and material contexts within which such experimentation takes place are at best regarded as a mere passive background or, at worst, a set of barriers or conditions that must be overcome. In contrast, relational approaches to scale suggest that transformative change can be achieved without reliance on climbing a scaffolding provided by pre-given hierarchies. An experiment across multiple countries to address energy poverty, for example, might spur politicization to introduce novel ideas into energy efficiency debates, create space for dissensus, and change understandings about household energy usage (Bouzarovski and Haarstad, 2019).

A second, related, assumption in the debate on scaling up is that experiments are spatially and temporally discrete, an approach which neglects the continuous dynamics through which the urban milieu and particular interventions are made and maintained. Considering experimentation in relational terms raises further questions about the nature of scaling. For Bouzarovski and Haarstad (2019, p. 257) a relational perspective requires that we attend to the processes of politicization, enrolment, and hybridization ("the co-constitution of human and non-human agencies") that are immanent to the work of scaling in practice. While the literature on socio-technical systems points to the importance of the interaction between social and material elements in the co-production of innovations and the co-evolution of the systems (regimes) within which they are embedded (i.e. one shapes the other iteratively) (Hughes, 1987; Moors et al., 2004), relational perspectives emphasize that such entities are fundamentally co-constituted (i.e. one is part of the other). Viewing the urban as comprised of multiple constellations, precarious achievements of social and material entities that are "ready to untangle at a moment's notice" (Graham, 2010, p. 11) opens up the question of how such interventions come to generate potential for change. Rather than change being generated through social mechanisms such as networks of actors transferring findings to other settings, recognizing that urban conditions are always-in-the-making points to the importance of understanding how experimentation harnesses, disrupts, and reconfigures the socio-material capacities of the urban to generate new kinds of potential for change.

Third, within debates on scaling up, the power to orchestrate the transformative potential of urban experimentation is (implicitly) assumed to operate externally. Power is conceptualized as held by one or more entities that have the 'power to' extract, extend and expand experimentation from its original context and ensure that it counts elsewhere (Castan Broto and Bulkeley, 2018). As Stripple and Bulkeley (2019) note in their analysis of the ways in which power has been theorized in transition studies, despite an increasing diversity of approaches "these debates are animated both by questions over how agents outside the regime accumulate sufficient resources to challenge incumbents and by the contestations that emerge between different actors/alliances in the process of transition." As a result, power is predominantly theorized as the capacity of discrete actors and agency "limited to individual actors and institutions, or alliances thereof, rather than emanating from the socio-material dynamics with which transitions studies are ostensibly concerned" (Stripple and Bulkeley, 2019, p. 55). Yet, if

we conceptualize power "not as a capacity that exists outside of social/material relations, but as generated through them – as immanent to those relations and inseparable from its effects" (Bulkeley, 2019, p. 24) (see also Allen, 2003; Bulkeley, 2012; Foucault, 2000; Li, 2007) – then it is within the socio-material dynamics of experimentation that possibilities for transformative change are to be found.

The matter-of-fact qualities of the idiom of scaling up can therefore be seen to include assumptions about the ways in which society is ordered and how change takes place that are far from universally held across the social sciences. Shifting perspective to encompass a relational account of the urban means seeing cities, interventions like NBS, and the governance arrangements that surround them as created and changed "through the various types of relationships that constitute them — socially, politically, and materially" (Grandin et al., 2018, p. 16). This conceptualization not only challenges the notion of scaling up in metaphorical terms but raises more profound questions about whether it is possible to identify, let alone follow, pre-determined pathways towards sustainability outcomes. Faced with contradictory and ill-defined places where the normal way of doing things has been disrupted, practitioners and policy-makers try to navigate to a new socio-material order in ways that are "seldom informed by a preconceived, consensus-driven strategic vision or pathway" (Jensen et al., 2015, p. 558). As Patterson et al. (2021, p. 5) suggest, turning our attention to "path-creation rather than path-following" means recognizing in turn that desirable and transformative pathways are often ambiguous and difficult to identify far into the future, with the consequence that "the implementation of sustainability pathways cannot be fully planned in advance".

Opening Up Sustainability Pathways

Literatures on socio-technical transitions have focused on how scaling can be achieved from successful experiments that are developed in protected conditions, relying on social actors with sufficient power and resources to extract and translate them beyond their initial setting. Instead, relational perspectives suggest that experimentation's capacities for transformative change are to be found in the apertures they open up within existing urban infrastructural regimes. As Castan-Broto and Bulkeley (2018, p. 75) argue, this opening takes place, amongst other means, through:

> "…the creation of new spaces of authority; the development of calculative means to facilitate the intervention; the inscription of new practices in material devices; the engagement with unruly materiality through demonstrations; and the questioning of established ways of acting within particular devices."

In turn, it is the socio-material configuration of experimentation itself that "realises new kinds of capacities and capabilities" (Bulkeley et al., 2016, p. 16) through which transformative change

can take place, for it is through this set of conjunctions that power – as a facilitative, enabling capacity that is immanent to socio-material relations – is generated (Allen 2010).

Experimentation then creates what Patterson et al. (2021, p. 4) term “fuzzy action moments.” Similar to the ‘action situations’ identified by Ostrom (2005) as “complex interactional structure of a jointly dependent situation involving multiple actors” (Patterson et al., 2021, p. 4), fuzzy action moments can be dispersed across the urban governance setting but are crucially considered to have a temporal dimension as an “ongoing series of relatively discrete but often ill-defined (i.e. fuzzy) moments, which may (or may not) permit intervention towards urban sustainability transformations.” Equally, while similar to the concept of windows of opportunity, fuzzy action moments are distinct in referring to “a ‘bundle’ of connected activities occurring over a continuous period of time linked to a certain decision or initiative” (Patterson et al. 2021: 4). This bundle is bounded in time and issue focus, but it could, for example, span the formation of a policy, investment in infrastructure, and new operations and maintenance practices (Patterson et al. 2021). Experimentation, as both a set of decisions and initiatives, creates fuzzy action moments which generate new conditions within which there is a need to adjudicate between expectations, interests, obligations and different forms of knowledge, in turn creating “ongoing, albeit irregular, moments of possibility for urban action towards transformation” (Patterson et al., 2021, p. 5).

Focusing on the relational and indeterminate nature of urban interventions, Patterson et al. (2021) importantly draw attention to the ways in which experimentation opens up decision-making and institutional spaces. Yet such an analysis misses the important socio-material constitution of such interventions and the ways in which these dynamics generate (and close down) the possibilities for sustainability pathways. To this end, the openings that urban experimentation generates can be productively thought of as ‘junctions’ in the terms defined by Jensen et al. (2016: 557): “sites where conventional boundaries and interdependencies among material systems and social practices are transgressed, where the established order and identity of the urban fabric has become unstable.” For example, interventions which seek to create green roofs transgress what it is that roofs are conventionally supposed to do (i.e. shelter inhabitants from the elements) by introducing new functions, such as flood management and climate protection. These functions not only change the socio-material assemblages of roofs but also their agency within the urban fabric (as emergent sites for wildlife habitat) and their connections to other material systems (water management).

Urban experimentation can generate openings by disrupting the established order of the urban fabric and can bring together new socio-material relations that generate the facility for change. However, creating an opening does not necessarily mean a change in the status quo. An experiment may introduce nature-based water management (rain gardens) into several streetscapes in a city, for example. In piloting gardens for water management rather than sewers, there would be opportunities to establish formal working relationships between the local

government roads and the parks departments and for multiple disciplines (e.g. ecologists to engineers) to negotiate tradeoffs between their different disciplinary standards and practices. This could be accompanied by the reorganization of planning rules, department structures, and citizen expectations so that all future road works incorporate NBS for water management. It is also possible, however, that the pilot results only in the replication of a dozen gardens around the city without changing urban planning routines for roads and water management. Despite the disruption of the pilot, created by replacing sewers with nature, existing knowledge practices, budget line items, professional standards, infrastructure products etc. are still oriented towards conventional sewers and roads. Creating an opening does not necessarily lead to systemic change, unless experimentation can generate enough momentum to disrupt and reconfigure these multiple capacities and practices. A crucial aspect of our argument is that the challenge is to trigger catalytic change so that the interconnected and overlapping socio-material constellations that make up the urban are disrupted and redirected towards the desired change, rather than reinforcing the status quo. We argue that this requires building momentum from multiple, simultaneous interventions and seizing opportunities as they appear.

Fostering catalytic change

Diverse mechanisms can build momentum and here we explore two sets of dynamics. One set of dynamics emerges when actors initiate and support the right sustainability experiment in the right context. Analyzing the dynamics of mobilizing experiments, Castan-Broto and Bulkeley (2018) argue that experiments are generative (of power, knowledge, meaning) by throwing into question established parameters and the boundaries of existing socio-material assemblages and mobilizing a new set of socio-material relations. Electric cars, for example, open up new relations between electricity providers, households, vehicle retailers, urban planners and so on, which generate questions about what it means to be mobile, who provides electricity, and how public space should be used that ricochet through the urban infrastructure regime. Particular kinds of experiments have characteristics that provide this immanent potential, but this potential is also relational. Not all experiments will create an opening in all places, every time. A ball at the top of a hill has the capacity to roll down based on its position (relational potential) and the geometry of the ball (immanent potential) (Bulkeley et al., 2020; Easterling, 2014). Building momentum requires selecting interventions that have the potential to generate new socio-material relations given their immanent properties and relational potential in a specific time and place (context).

Another set of dynamics emerges through the enrollment of social and material entities. Momentum towards change is built as experiments are embedded into circulations comprising a system – in our case, the system of interest is the urban infrastructure regime (Castan Broto and Bulkeley, 2018). One of the ways that this embedding can take place is through amplification, where experiments gather and enroll publics (Castan Broto and Bulkeley, 2018; Lam et al., 2020). Here the reach and resonance of the experiment is seen not only as a matter

of elements of experimentation being taken up elsewhere, but of these actors and situations coming to form part of the experiment itself (Castan Broto and Bulkeley, 2018). It is also crucial to think about the ways that socio-material networks come to shift ground and realign in the wake of experimentation (Castan Broto and Bulkeley, 2018). For example, organisations and professional networks may adopt principles or standards that serve to shift their everyday practices and identities, in turn serving to realign their role in the (multilevel) urban milieu. Relatedly, Bernstein and Hoffmann (2019) have found that harnessing political dynamics to enroll social and material entities builds support for a new way of doing things. The three political mechanisms for systemic change that they identify are norm change (e.g. discursive shifts in what is thought to be in the public interest), coalition building (e.g. coalitions of economic and political support), and capacity building (e.g. capacity through material, institutional, or cognitive means) (Bernstein and Hoffmann, 2019). They identify the importance of catalytic change as a crucial internal dynamic that can forge pathways to decarbonization specifically (Bernstein and Hoffmann, 2019).

Assembling stepping stones to catalyze sustainability pathways

Together these insights suggest that sustainability pathways emerge from catalytic change. Dynamics emerging from implementing the right socio-technical innovation in the right context and enrolling social and material entities in an experiment create momentum towards change when they foster catalytic change that cascades through interconnected systems. We argue that sustainability pathways need to be conceived as emerging from the catalytic interaction of multiple and overlapping efforts to change the status quo. Pathways are not given, predetermined routes, but instead are assembled through the alignment and coherence of key interventions. Key interventions take advantage of opportunities to destabilize urban infrastructure regimes and harness capacities to generate new ways of doing things. To represent their inter-relatedness and assemblage to forge pathways, we call these key interventions ‘stepping stones’. Stepping stones are able to gather the emergent capacities of experimentation to catalyze systemic change by creating momentum.

Governance capacity for a new way of doing things is achieved when technical, social, political, legal etc. elements are cohered together such that they gain legitimacy to exercise authority (McGuirk and Dowling, 2021). Processes and devices can act as mediators to cohere urban governance capacity (McGuirk and Dowling, 2021). In our argument, stepping stones mediate new connections and capacities emerging through experimentation. They successfully create sustainability pathways when they cohere and generate sufficient momentum to cascade through the systems in which the experiment is embedded. Collectively, stepping stones can generate the capacities and momentum that are needed to overcome the inertia of existing urban infrastructure regimes and generate new socio-material orders where such interventions are normalized as mainstream responses to sustainability challenges (Fig. 1).

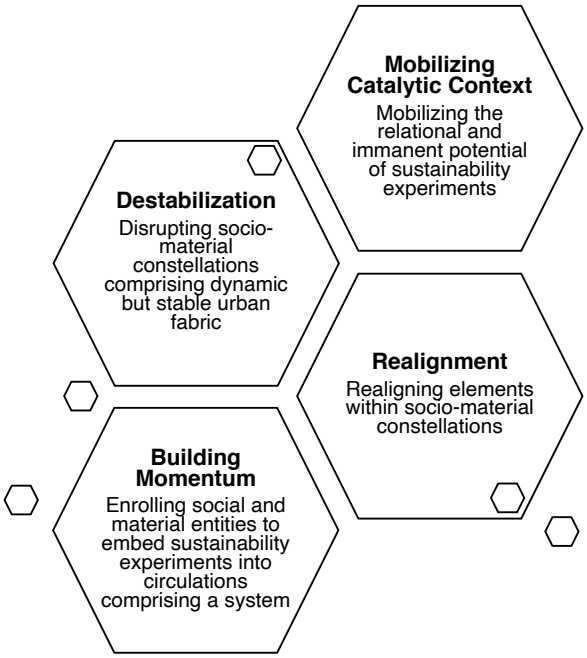

Figure 1. Catalyzing systemic change using stepping stones: in the right context, stepping stones can collectively destabilize and realign socio-material orders if they generate enough momentum to overcome the inertia of existing systems and normalize experiments as mainstream responses to sustainability challenges.

In the next section, we explain our methodology for identifying key stepping stones that can accelerate the uptake of urban NBS in European cities. We then explain and provide examples of the 20 stepping stones for urban NBS identified in this research. The following section presents two comparative examples to illustrate how clusters of stepping stones can generate momentum (or not) towards a new more sustainable way of doing things before a final discussion and conclusion.

Methodology

We build our argument upon qualitative case studies of the development of urban NBS in Europe. Defined as “solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience” (European Commission, 2020), urban NBS are the focus of increasing attention from research and policy circles. For their advocates, NBS are multifunctional, capable of delivering a wide range of benefits to people and nature (Raymond et al., 2017; Seddon et al., 2020); they are also inclusive, involving social, ecological, and technological innovations initiated by different urban actors that contribute to sustainable development. Due to their ability to address various urban sustainability challenges simultaneously, there are increasing calls to accelerate the wider uptake of NBS in urban development and governance (e.g. Frantzeskaki, 2019; Kabisch et al., 2016). Hence, exploring how pathways for the wider uptake of NBS can be formed is critically important.

We examine the urban infrastructure regimes that shape the uptake of NBS in cities. Urban infrastructure regimes are "the stable configurations of institutions, techniques and artefacts which determine 'normal' sociotechnical developments in a city and thus shape general urban processes and the urban metabolism" (Monstadt, 2009, p. 1937). Urban infrastructure regimes are comprised of different domains that are interdependent and interrelated, each of which consists of a unique set of rules, norms, traditions, and rationales that shape how people think and act (Dorst et al., 2021; Fuenfschilling and Truffer, 2014; Holtz et al., 2008). We focus on three functional domains of urban infrastructure regimes: the *regulatory* domain involves the governance, regulatory, and legal frameworks that determine urban planning and infrastructure decision making; the *finance* domain relates to the availability of capital funding and willingness in the financial sector to invest their resources into NBS as well as the capacity of the insurance industry to take into account the value of NBS interventions; and the *urban development* domain involves the interests, practices, technologies of the urban development industry involved in the provision of infrastructures and housing in cities (Dorst et al., 2022). Each of these domains has a variety of actors and dynamics that operate in relation to the economy, knowledge, artefacts, governance, and community. For example, particular 'economic' instruments or regulations are identified by actors in the finance domain as critical to the adoption of NBS (Dorst et al., 2022). Hence, these three domains provide different lenses through which to understand urban infrastructure regimes.

Case studies were undertaken in the Netherlands, Sweden, the United Kingdom (UK), Spain, Germany, Hungary, and the European Union (EU). Each case study involved a desk study of relevant grey literature and policy documents, interviews with key actors of the three domains (243 interviews in total; Sweden: *N*=33; UK: *N*=26; Germany: *N*=36; Hungary: *N*=38; the Netherlands: *N*=40; Spain: *N*=35; EU: *N*=35), and participant observation through placements of researchers at relevant organisations, networks, or events. Data collection was conducted between June 2018 and November 2019, covering various types of NBS in cities and a broad range of potential sustainable development goals to which NBS can contribute. For the Dutch case, we also drew on a local case study of the Leidsche Rijn water system, which included seven semi-structured interviews with urban stakeholders and a document analysis.

Building on practice-based evidence drawn from the six European countries and the EU level, we first identified key barriers and opportunities for mainstreaming NBS in the regulatory, urban development, and finance domains respectively (see the overview provided in van der Jagt et al. (2020)). The lead researcher for each domain independently grouped findings from the cross-case analysis into bundles of actions that could transcend domain boundaries to enable the implementation urban NBS. Such domain-specific analysis led to the identification of key bundles of actions that are promising for promoting NBS uptake, resulting in a total of 48 stepping stones comprised of 21 in the regulatory domain, 11 in the urban development domain, and 16 in the finance domain. To address overlaps among these domain-specific stepping stones, an iterative analysis and discussion process jointly among the project team resulted in synthesis and identification of clusters of broader, related actions across domains. As a result,

we identified 20 stepping stones (Table 1) that can be used to accelerate the uptake of urban NBS in European cities. [1]

Stepping stones that promote urban NBS uptake

A key finding of our research is the identification of 20 stepping stones (Table 1), each of which represents a bundle of similar interventions that seize or create opportunities to build momentum for the implementation of urban NBS. Each stepping stone can generate positive change towards the uptake of NBS, but we expect that the potential effect of each individual stepping stone can be significantly reinforced when they are aligned with others to overcome barriers or allow the full range of opportunities to be realised. In the next section, we illustrate this using specific examples found in our data collection. The relevance and importance of individual stepping stones varies depending on the challenge actors are seeking to address and on the context (Xie et al., 2020).

[1] This process has been elaborated in (reference removed for review)

Table 1. 20 stepping stones for mainstreaming NBS and their descriptions (adapted from Xie et al. (2020)).

	Name	Description	Examples
1	Provide a **public mandate**	The mainstreaming of nature-based solutions can benefit from policy-makers and investors giving a clear mandate for nature-based solutions to be included in urban development through tender and procurement policies, policy instruments (e.g. land use planning guidance), and where possible mandatory regulation.	The National Planning Policy Framework in England recommends Sustainable Urban Drainage Systems (SuDS) as part of new urban development.
2	Regulate for **No Net Loss**	No-net-loss / net gain regulation for urban nature (biodiversity) has the potential to generate greater interest in nature-based solutions across Europe. Developing harmonised regulation across Europe with strong monitoring and sanctioning to increase effectiveness has the potential to support nature-based solutions mainstreaming.	Biodiversity offsetting regulation in Germany mandates developers to minimize the loss of natural habitat in their developments, while offsetting any negative impacts that occur.
3	Include in **contractual requirements**	Utilities (e.g. water, waste, energy) and network service providers (e.g. road and rail authorities, waterway authorities) are either publicly owned or operate on long-term contracts that are bound by regulatory requirements for service provision. Including nature-based solutions as required for the delivery of mandated functions (e.g. water quality treatment) or for the upkeep of land-holdings (e.g. train sidings, roadside verges) provides an important avenue for mainstreaming.	Water utilities in England need to meet water quality standards, which increases support for SuDS.
4	Align with **strategic priorities**	Positioning urban nature-based solutions as generating benefits for prioritized policy goals through generating narratives and evidence (i.e. climate change mitigation & adaptation, circular economy and healthy urban living) can widen their relevance and community of practice.	The creation of the Green Deal Green Roofs facilitated by the Dutch government, signalled its perceived importance as an intervention in densifying cities in response to climate change.
5	Create **intermediaries**	In order to overcome institutional silos within both public and private sector organisations, new organisational forms that work across these divisions are required. Intermediary units can either be established within organisations or outside (by external bodies) and provide co-ordination between departments as well as platforms for innovation.	In the city of Barcelona, the Urban Ecology Directorate was created to bring together the Mobility, Environment and Planning departments to coordinate delivering the city's climate change plans.
6	Generate **partnerships**	Stimulating partnerships between public, private and third sector organizations for the co-design, development and maintenance of urban nature-based solutions is critical for generating initial action on the ground and increasing support for mandatory urban greening policies.	The Water System Task Force collaborated with a broad range of actors, including community representatives, scientists, engineering firms and landscape architects in

			coordinating the planning and implementation of SuDS in Leidsche Rijn, the Netherlands.
7	Establish **demonstration projects**	Demonstration or pilot nature-based solutions projects, often involving research, can create shared learning and knowledge development as well as providing tangible demonstrations of how nature-based solutions can work in practice, creating confidence amongst partners about their potential.	To develop evidence about the benefits of green-blue roofs, Rooftop Revolution, universities, water providers and housing corporations in Amsterdam launched the RESILIO project to demonstrate and monitor smart blue-green roofs.
8	Engage **insurance sector**	Engage the insurance sector to support upscaling of urban nature-based solutions based on their risk reduction needs and damage cost expertise	To decrease roof damage cost payouts, Interpolis, a Dutch insurance firm, stimulates green roof uptake through national marketing campaigns and by offering collective buying power, lowering the price of green roofs.
9	Facilitate **community-based action**	Facilitate and support community-based action for local urban nature-based solutions through improving citizen awareness and support.	Madrid implemented a policy allowing residents to apply to develop urban public gardens in areas labelled as green zones, enabling the rise of urban agriculture.
10	Provide **economic incentives**	Provide economic incentives (tax cuts, subsidies) to support the development and uptake of nature-based solutions.	Many municipalities in the Netherlands offer subsidies for green roofs within their city boundaries for the water management value, ranging between 25-50%.
11	Develop **markets**	Positioning nature-based solutions as a sustainability solution offering wide societal and reputational benefits can support the development of demand for nature-based solutions projects which in turn can stimulate supply.	In England, homeowners are often seeking access to high quality green space and developers are increasingly recognizing that incorporating nature-based solutions can increase the value of real estate.
12	Build **co-financing arrangements**	Build governance arrangements between the public and private sectors to enable co-funding for nature-based solutions development and maintenance.	A local crowdfunding platform – Voor je Buurt (For your Neighborhood) – in the Netherlands plays a key role in bringing together several funding streams for co-financing NBS.
13	Work with **investment cycles**	Integrating urban nature-based solutions into infrastructure projects and renovation cycles increases their (multi)functionality and can save costs by reducing the need for additional outlay and drawing on existing budgets.	Rooftop Revolution is working with a database called 'DAKOTA' that shows the planning of roof replacements of all housing corporations in the Netherlands, which allows them to reach out to the corporations at the right moment – 1-2 years before the roof needs replacing. This lowers costs for roof

			greening, since it can be taken up as part of the bigger renovation budget.
14	Stimulate **institutional investment for risk reduction**	Institutional investment for urban nature-based solutions is likely to be forthcoming based primarily on their climate risk reduction value (adaptation and mitigation), and specific data/modelling may be required to realise this potential.	The EU Taxonomy includes green roofs as a criterion for green investments in the context of sustainable buildings.
15	Target areas of **low land value**	Nature-based solutions can face competition from other land-uses which provide a higher return on investment. Using urban space with a lower value (opportunity cost) can suit some forms of nature-based solutions and provide a more cost-effective means of urban greening (e.g. street green, pocket parks and building-integrated green).	In Hamburg, Germany, using roofs for greening is one way of reaching climate adaptation objectives while densifying the city to address housing shortages.
16	Improve **data & monitoring**	Mainstreaming nature-based solutions will require the development of evidence on the performance of urban nature-based solutions, through the use of 'big data' and new assessment tools that can support effective monitoring, evidence-building and assessments of their effectiveness in addressing key urban goals.	Projects like RESILIO (Amsterdam) and LIFE@Urban Roofs (Rotterdam) create data for detailed cost-benefit analyses of green roofing.
17	Advance **valuation models**	Making the case for nature-based solutions requires that we develop and disseminate valuation models that specify the different (monetized) benefits and costs of nature-based solutions, to facilitate public and private investment decisions.	i-Tree, a tree valuation software developed in the US, has been taken up by municipalities in Europe such as Utrecht to quantify the value of (different types of) urban trees.
18	Grow **practitioner expertise**	Make practitioner-oriented expertise on urban nature-based solutions available to facilitate integration of nature-based solutions in the actual urban development process (i.e. practitioner guides and collaborative design).	National and international engineering firms were approached to co-design the Leidsche Rijn water system in the Netherlands.
19	Incorporate in green **investment products**	Include urban nature-based solutions into (existing and new) green/ impact/ sustainable investment products in order to enable projects to access this source of finance.	In Sweden, local governments are developing green bond offerings to fund sustainable infrastructure projects.
20	Promote **certification schemes**	Integrate urban nature-based solutions criteria into green certification schemes, in particular for buildings, based on recognition of the contribution nature-based solutions can make towards sustainability goals.	The 'Building with Nature' Accreditation Scheme in the UK uses voluntary green infrastructure standards to ensure new housing development also benefits nature.

3

How do stepping stones work? Exploring pathways through SuDS and green roofs

Individually, each of the stepping stones represent key interventions that can improve NBS uptake, but when they are aligned with one another to create a pathway they can generate greater momentum for mainstreaming NBS than individual interventions alone. Given that stepping stones can be assembled in different ways, there can be multiple mainstreaming pathways for urban NBS. In this section, we explore potential pathways using two comparative examples on large-scale sustainable urban drainage systems (SuDS) (England and the Netherlands) and two on green roof programs (the Netherlands and Germany). These are intended as illustrative examples of how, in some cases, stepping stone clusters can generate momentum towards a new, more sustainable, way of doing things. All stepping stones are highlighted in bold.

Sustainable urban drainage systems in England and the Netherlands

On the topic of SuDS, we compare two cases – England (as part of the UK case) and the Netherlands. SuDS systems mimic natural systems using swales, permeable surfaces, wetlands etc. to collect and clean water. In England, a policy framework **provides a public mandate** that encourages the integration of sustainable urban drainage systems into new development. Planning regulations at the national level (e.g. the National Planning Policy Framework guiding new development), as well as local government policies, have encouraged the integration of SuDS. Although technically not mandatory, planning recommendations and associated standards in England provide sufficient leverage for the widespread integration of SuDS in major urban development projects. SuDS have been of particular interest to urban planners because of their potential to reduce flooding and, more recently, enhance biodiversity (van der Jagt, et al., 2020). In this way, SuDS **align with strategic priorities.** Although developers have been concerned that integrated SuDS will negatively impact profits on new developments by taking up land space that otherwise would have been housing, some developers are starting to recognize an opportunity to **develop markets** by selling homes for a higher price since SuDS add nearby green space. For example:

> "We're currently working on the Manchester Northern Gateway project which is entirely focused on making a corridor in a big city more developable by making it more resilient so by creating green interventions that will reduce flood risk, that will make it a healthier, better place to live with the ultimate objective being developers can sell their properties for more and they can build more there" (Development Industry Representative)

At the same time, there has been increasing interest in SuDS from water utilities, which supply water and sewerage services and have **contractual requirements** to meet water quality standards. Water utilities are increasingly interested in meeting water quality standards using SuDS, since it allows them to also contribute to enhancing climate change resilience (van der Jagt, et al., 2020). This has created a broader coalition of support for SuDS.

The **public mandate** for the SuDS case in The Netherlands – the Leidsche Rijn water system in Utrecht planned in the 90s – was provided by the national clean water policy framework. The main ambition of the project was to use SuDS and other NBS to provide clean surface water to the projected 30,000 residents of the newly developed urban district 'Leidsche Rijn' at a time where proximate rivers and canals were still impacted by heavy metals and other pollutants. A significant part of The Netherlands is situated in a river delta, making the country a European frontrunner in clean water regulation since the 70s. The strong sustainable development discourse (**provide a public mandate**) at the national level, combined with the **growth of practitioner expertise**, were key contributors to the development of the large-scale clean water system:

> "Dutch engineering firms were insufficiently equipped to deal with the challenge [of designing the water system]. Therefore, we formed a coalition between our own engineering firm in Utrecht and two firms from Germany. And together they were called IQ. It became a conglomeration of advisory agencies, international and national" (Senior Advisor for the green environment)

Another important stepping stone was provided by the large scale and prestige of the housing project, **providing economic incentives** to developers to implement experimental measures such as the SuDS. Initially, the combination of these stepping stones catalyzed other stepping stones – a Water System Task Force involving municipalities, the province and a water board with on-site premises was **created as an intermediary** (Kiss et al., 2019). This intermediary **generated partnerships** to coordinate the planning and implementation of the water system, involving a large number of engineering consultancies, landscape architects, scientists and relevant local NGOs (Kiss et al., 2019). Despite this, the highly successful water system was never emulated at this scale and level of integration in later urban development projects in the Netherlands. The main reason is that water quality strongly improved following the implementation of ambitious EU clean water regulation, most notably the Water Framework Directive, which reduced upstream discharge of pollutants in rivers. This removed one of the key stepping stones: the **public mandate** for utilizing NBS to improve water quality. While a **public mandate, economic incentives, an intermediary**, and **partnerships** collectively destabilized water management practices and realigned socio-material orders sufficiently to enable one large experimental SuDS project, insufficient momentum was generated to catalyze change and normalize SuDS as a mainstream water treatment strategy in the Netherlands.

In both the England and the Netherlands cases, the key stepping stone was the **provision of a public mandate**. Creating a public mandate is arguably a powerful stepping stone given that it 'enforces' a new normal upon social and material entities, provided that actors continue to operate within the boundaries of established regulations and recommended planning practices. However, the effects were different with England achieving some success in mainstreaming SuDS into urban development and the Dutch case failing to build sufficient momentum to do so. In the UK case, some developers responded to the **public mandate** by taking advantage of opportunities to **align with strategic priorities** for climate resilience and flood risk reduction to

develop markets. Whereas initially the issue of clean surface water brought SuDS into **alignment with strategic priorities** in the Dutch case, this was not maintained after water quality across the country strongly improved following the implementation of ambitious EU- and national-level regulation. In addition, housing policy was devolved in 2010, resulting in smaller urban development projects with less economic incentives and space for experimental measures. Hence, alignment with other strategic priorities such as climate action did not take place, although SuDS are increasingly used for this purpose recently. There were likely also missed opportunities around **developing markets** due to limited public awareness of the unique water system in Leidsche Rijn, and around **improving data & monitoring.** Heeding these aspects could have increased public demand for SuDS. Activating a broader cluster of stepping stones, such as the above, would likely have built momentum, enabling SuDS to become more mainstream.

Green roofs in the Netherlands and Germany

Green roofs are increasingly implemented in Europe but their uptake varies across countries. In the Netherlands, the implementation of green roofs across cities was supported by a variety of actors and actions, brought together by a national **partnership** programme called the 'Green Deal Green Roofs' and the emergence of specialized **intermediaries** (van der Jagt, et al., 2020). The 'Green Deal Green Roofs' partnership was facilitated by the Dutch government, signaling the alignment of NBS with the country's **strategic priorities** in responding to climate change. The Green Deal brought together municipalities and water boards from different regions in the Netherlands, many of which were **providing a public mandate** for green roofs at a regional level, for example through green procurement (e.g. of bus stands in Utrecht), and/or **economic incentives**, like green roof subsidies for water retention. The partnership also facilitated networking, knowledge sharing and helped to drive **market development**. In Rotterdam, another **partnership -** including the municipality - received an EU grant to **advance valuation models** for green roofs.

> "We fulfil a connecting role. [..] it is about what value does it have for whom and how can we make the business case work, together. Municipalities, waterboards, users, property owners etc. In the Green Deal we have since 2014 set up a process to look with all roof stakeholders at how we can improve the structural conditions. How can we turn risks into opportunities? We called that the development of a societal business model; not just economic but also societal value capture." (Network coordinator Green Deal Green Roofs)

The development of the green roof market across Dutch cities was also propelled by **intermediaries**, such as Rooftop Revolution, which are hired by municipalities to support the uptake of green roofs in their city. Together with housing corporations and municipalities, they coordinate and establish **demonstration projects** such as RESILIO. Such projects also serve to **improve data and monitoring** on the effectiveness of green roofs. Rooftop Revolution also **works with investment cycles** by making use of a database called 'DAKOTA' which provides

an overview of the planning of roof replacements by housing corporations in the Netherlands, allowing them to reach out to the corporations at the right moment, lowering the cost for roof greening. Moreover, **an insurance firm**, Interpolis, started promoting green roofs through national marketing campaigns and by orchestrating collective buying power, thus **developing markets** which they expect will decrease the amount of roof damage costs that they need to cover (van der Jagt, et al., 2020).

> "So we are moving forward down the business value chain to see if we can help people prevent damages [by promoting green roofs]. That's also something we can make money on. And maybe our insurance premiums will go down because we have fewer claims. And then the other hand our prevention services pay-out will go up." (Business development manager, insurance firm)

Germany is known as a world leader in green roof technologies. Recent green roof development has mainly been fuelled by the **provision of public mandates**. In 2017, about fifty percent of towns and cities higher than 10,000 inhabitants had made green roofs a compulsory measure for new developments in at least one of the areas covered by a Binding Land Use Plan in 2016/17 (Herfort 2017). At the same time, compulsory measures crowd out the possibility to offer subsidies. The mandatory character in combination with the high cost of green roofs and absence of subsidies cause developers and building owners to adopt extensive green roofs with limited water-holding capacity and biodiversity value. Conversely, intensive green roofs, with better water buffering and biodiversity potential, are more prevalent in the Netherlands. In some frontrunner cities, like Hamburg, higher quality green roofs are subsidized (**economically incentivised**) to support wider uptake (Xie et al., 2020).

> "One measure will affect the other. The moment you want to say that you will really make this [green roofs] big you can say as a city: we will pin it down in the land use plan or in the building permit. But then the option to provide a subsidy is gone. So a logical response of the real estate sector is: we don't want green roofs to become mandatory because then we lose the subsidies." (City planner, Germany)

In the Netherlands, **partnerships formation** and **intermediary creation** were identified as stepping stones enabling catalytic change in the roofing landscape. In Germany, the provision of a **public mandate** was important in promoting the adoption of green roofs in cities but is unlikely to catalyze the systemic change needed for sustaining high-quality green roofs. This comparison shows that in different contexts, different stepping stone clusters can enable the implementation of the same type of NBS, but with different outcomes in terms of destabilization, realignment, and building momentum to overcome the status quo. In the Netherlands, **generating partnerships** and **creating intermediaries** supported the implementation of green roofs by a variety of actors, while in Germany, **providing a public mandate** and **aligning with strategic priorities** promoted the wide adoption of green roofs, albeit in a more centralized way.

Discussion: Assembling stepping stones that catalyze momentum

The examples of SuDS and green roofs show how particular combinations of stepping stones can build momentum for urban NBS to become mainstream responses to urban sustainability challenges. They reveal that different stepping stone combinations seem effective at promoting similar types of NBS in different contexts. Also, a stepping stone (or combination thereof) can destabilize socio-material constellations comprising urban infrastructure regimes, creating an opening and an opportunity to do things differently. For example, the **public mandate** in the Netherlands and in the UK for SuDS introduced the idea of water management using natural systems rather than sewers. The capacity of stepping stones to yield change by sufficiently realigning socio-material elements and building momentum depends on the stepping stones assembled around them and the socio-material conditions of a particular urban infrastructure regime. This is consistent with the suggestion by Patterson et al. (2021) that sustainability pathways involve processes of path creation rather than path following: finding a 'menu' of possible options that can support the integration of NBS into urban development rather than 'copy-pasting' interventions from elsewhere. Pathways are not predetermined routes but instead assembled through the alignment and coherence of key interventions.

Stepping stones mediate new connections and capacities emerging through experimentation (McGuirk and Dowling, 2021). Combinations of stepping stones successfully create sustainability pathways when they destabilize and cohere new socio-material alignments and catalyze sufficient momentum to cascade through the systems in which the experiment is embedded. The examples show how stepping stones can actively initiate the emergence of other ones. The green roof case for instance showed that in the Netherlands **generating partnerships** and **creating intermediaries** supported a set of other stepping stones, including **providing economic incentives**, **improving data and monitoring**, **engaging the insurance sector** etc. Where individual interventions are made to try and support NBS without further steps in place, they are often less effective. Clustering stepping stones in particular ways builds momentum by enrolling social and material entities to embed sustainability experiments into circulations comprising a system, which enables NBS to become mainstream responses to sustainability challenges in cities.

Diverse mechanisms can build momentum and we theorized that two sets of dynamics are important: the right sustainability experiment in the right context and enrolling social and material entities. Regarding the former, perhaps the Dutch SuDS case did not build momentum because the relational potential of NBS for water treatment had changed after the pollution issue was addressed and **strategic priorities** shifted. Regarding the latter, the same case showed how a **public mandate** for SuDS successfully introduced the idea of using natural systems for water management but did not result in new water management standards or norms. The challenge is to trigger catalytic change using multiple simultaneous interventions so that intersecting and overlapping circulations are disrupted and realigned towards the desired socio-material order where experiments are normalized as mainstream responses to sustainability challenges, rather than reinforcing the status quo.

The examples also enable a first reflection on 'missing' stepping stones. Although the promotion of green roofs has been relatively successful in the Netherlands, our analysis found that since it is voluntary, some real estate developers opt out and overall coordination and guidance is lacking. To further promote green roofs in the Netherlands, enhancing the **public mandate** could be effective since previous comparative research suggests that green roof uptake is higher in cities where governments take an active role and green roof adoption is mandatory (Mees et al., 2013). The resulting increase in the demand for green roofs can in turn **create markets**, triggering a new stepping stone. These reflections provide some insight into how to identify and combine purposeful interventions to build momentum along sustainability pathways.

Conclusion

In this paper, we argue that the often linear way in which pathways for sustainability transitions are conceived in terms of scaling up is problematic because of the deterministic assumptions made about space, scale, and the socio-material dynamics that constitute change. Our case of urban NBS in Europe shows that the degree to which urban NBS are mainstreamed strongly depends on the alignment of interventions that collectively generate momentum to overcome inertia in specific socio-material assemblages. We find that such interventions, stepping stones, carry both immanent and relational potential which can be used to create opportunities to build momentum for change in particular contexts. Generating pathways for sustainability requires aligning these interventions such that they collectively foster catalytic change. In this way, our findings demonstrate how it can be the case that even when experiments reach significant scale in terms of spatial extent or reach, transitions away from business as usual can still be challenging to achieve. Our findings also point to the ways in which even seemingly insignificant or 'small scale' changes can generate catalytic effects when interventions are aligned in ways that destabilize and realign existing socio-material orders to build new momentum towards change.

Building on this conceptualization of pathways to sustainability, research in this field could further analyze its applicability in other societal domains such as energy or mobility. Research could also identify which kinds of stepping stones are vital to achieve change, as well as generate insights about the possible synergies and trade-offs involved in catalyzing transitions in response to diverse challenges. Further work is also needed to establish which actors have the capacity under diverse (urban) conditions to generate the kinds of interventions that are needed and, importantly, to bring these into alignment to realize catalytic change. Two particular issues are of significance here. First, for the most part, the catalytic forms of change identified in our analysis have been largely coincidental rather than strategic, such that a question arises as to which kinds of actors may have the capacities to intermediate and align interventions in a more purposeful manner. Second, many of the interventions we have identified rely on actors with significant stakes in existing political/economic orders, raising questions as to whether, even when change is catalytic in terms of its environmental outcomes, interventions may serve to retrench existing interests and serve to further exclude marginalized communities from both processes of change and the benefits they can bring. To this end, further analysis is needed as to whether such processes of change can not only be effective but also just.

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