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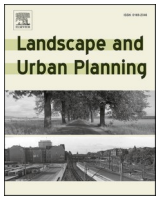

Research Paper

What's behind the barriers? Uncovering structural conditions working against urban nature-based solutions

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HIGHLIGHTS

- Barriers to urban NBS persist due to context-specific structural conditions.
- Trust in engineering practices underpins multiple barriers.
- NBS face competition over space, especially with housing developments.
- Mainstreaming NBS in urban infrastructure regimes requires context-sensitivity.
- This paper enriches 'regime heterogeneity' literature empirically and conceptually.

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ABSTRACT

Nature-based solutions (NBS) are a promising and innovative approach to address multiple sustainability challenges faced by cities. Yet, NBS are not integrated into mainstream urban development practices. Based on a qualitative comparative case study of Germany, Hungary, the Netherlands, Spain, Sweden, and the United Kingdom, this study shows how barriers to mainstreaming urban NBS are shaped by the structural conditions in urban infrastructure regimes, which offers an improved, context-sensitive understanding of why such barriers persist. We identify underlying structural conditions shaping seven key barriers to urban NBS: limited collaborative governance, knowledge, data and awareness challenges, low private sector engagement, competition over urban space, insufficient policy development, implementation and enforcement, insufficient public resources, and challenging citizen engagement. This study also advances an understanding of urban infrastructure regimes as complex, heterogeneous systems, made up of different functional domains that define the space available for sustainability innovations. Importantly, our case comparison reveals that similar barriers to NBS mainstreaming in planning processes are caused by different structural conditions across countries. For example, perceived causes of limited citizen engagement are low environmental awareness in Spain, a lack of resources to support participation in Hungary, and NIMBY-ism in the Netherlands. Our findings stress the importance of moving beyond 'silver bullet'-type approaches to addressing NBS mainstreaming barriers, towards systemic but context-sensitive responses, tailored to specific urban infrastructure regimes. This systematic understanding of barriers and their underlying structural conditions can help both scholars and practitioners identify promising pathways for the mainstreaming of NBS as an urban sustainability innovation.

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1. Introduction

The emerging concept of nature-based solutions (NBS) refers to natural solutions for dealing with multiple urban sustainability challenges (Dorst et al., 2019; Kabisch et al., 2017; Raymond et al., 2017). In the European policy domain, NBS are considered as innovative, cost-effective solutions that build on nature to simultaneously provide environmental, social, and economic benefits, thus representing a feasible transition path to sustainable development in Europe (European Commission, 2015; Maes & Jacobs, 2017). NBS are described as a transdisciplinary 'umbrella term' that can unite insights from similar concepts such as ecosystem services, green infrastructure and natural capital, but re-orienting these existing conceptualizations of nature more prominently in response to societal challenges (Albert et al., 2017, 2019; Dorst et al., 2019). In Europe, policy and research on NBS is most prominent in the urban realm, where NBS such as green roofs and facades, (pocket) parks and urban forests, urban agriculture, and green/blue urban drainage are all promoted as 'solutions' to a range of urban sustainability challenges (Frantzeskaki, 2019; Kabisch et al., 2016, 2017; Raymond et al., 2017). The integration of NBS into conventional urban development practices is advocated by urban policy-makers, practitioners and researchers (Faivre et al., 2017; Frantzeskaki, 2019; Lafortezza & Sanesi, 2019). With urban development practices and processes we mean those activities and institutions through which urban built environments and infrastructures are planned, developed and operated.

However, implementation of NBS is far from mainstream, in other words, not part of the 'usual' way in which urban development takes place. There are many barriers to the mainstreaming of NBS, that is, the uptake of NBS into dominant urban governance and planning mechanisms and structures, either through their integration into existing structures or through the transformation of these structures (cf. Wamsler & Pauleit 2016; Bush & Doyon 2019; Wamsler et al., 2020b).[1] These barriers include limited knowledge or funding resources (Kabisch et al., 2016; Sarabi et al., 2019; Seddon et al., 2020). Current literature outlines these and other barriers to NBS mainstreaming but fails to provide deeper understanding of the underlying, systemic conditions that give rise to these barriers. This hampers the development of effective and more comprehensive responses to address these barriers. A lack of resources for NBS, for instance, can be caused by internal competition for resources within a municipality, which in turn can have its origin in institutional policy silos (Droste et al., 2017). Alternatively, a lack of resources for NBS could also be caused by short-termism in public and private decision-making hampering the longer-term planning required for reaping the benefits of NBS (Seddon et al., 2020). If such conditions are not accounted for or altered, barriers to NBS mainstreaming will keep occurring. So far, however, published research about the structural conditions that shape barriers to NBS mainstreaming is largely absent (Kabisch et al., 2016; Sarabi et al., 2019; van der Jagt et al., 2020). Furthermore, in case such conditions *are* presented, this happens generically, even though they are likely specific to a country, region or city (e.g. local policies, natural resources) (Hansen & Coenen, 2015). While generic overviews of systemic barriers certainly help to direct efforts at NBS mainstreaming (Egusquiza et al., 2019; Sarabi et al., 2020), they tend to overlook such sensitivity to geographical and policy context, hampering tailored and possibly more effective approaches at a solution.

Drawing on urban studies scholarship and socio-technical transitions scholarship on 'socio-technical regimes', we use the idea of urban infrastructure regimes, defined as "the stable configurations of institutions, techniques and artefacts which determine 'normal' socio-technical developments in a city and thus shape general urban processes and the urban metabolism" (Monstadt, 2009, p. 1937), to develop a systemic and integrated understanding of the structural conditions that shape the barriers to mainstreaming urban NBS in Europe. Literature suggests the adoption and implementation of a new innovation like NBS is challenging because existing urban socio-technical regimes and the technologies, rules, norms, governance practices, traditions and rationales embedded in these are historically configured and resistant to change (Bulkeley et al., 2014; Fuenfschilling & Truffer, 2014; Geels, 2004; Monstadt, 2009). Following this conceptualisation, NBS can be considered to be an alternative, innovative approach to urban development (Kabisch et al., 2017; Lafortezza & Sanesi, 2019) that struggles to become mainstream due to mis-alignments with incumbent urban regime conditions, such as urban policy arrangements, funding procedures or material infrastructures.

This study systematically analyses how barriers to urban NBS are generated by the structural conditions of the socio-technical regime that shape urban development. We address two knowledge gaps: (1) uncovering the deeper structural origins of barriers that explain why NBS are not considered as mainstream interventions in urban development practices and (2) geographically contextualising these structural conditions. Such a well-grounded, systematic understanding of barriers and their underlying structural conditions can help both scholars and practitioners to identify promising pathways for the mainstreaming of NBS as an urban sustainability innovation. In sum, this study addresses the question: which structural conditions in urban development generate barriers to urban NBS mainstreaming, and how?

The next section presents our analytical framework of urban infrastructure regimes, followed by our methodology. The results section presents prominent barriers to NBS mainstreaming and associated underlying conditions. The discussion section reflects upon these findings and on the added value of taking a socio-technical regime perspective on NBS mainstreaming. The paper closes with a summary and conclusion.

2. Structural conditions in urban infrastructure regimes

2.1. Identifying structural conditions

We define barriers as project-level problems that arise from the misalignment between NBS characteristics (e.g., they are growing, living interventions; they present multi-functional solutions) and conditions in the urban infrastructure regime (cf. Schuitmaker, 2012; Eisenack et al., 2014). We use the notion of socio-technical regimes to conceptualise how structural conditions exist as a result of historic development, systemic reproduction, and path dependency (Fuenfschilling & Truffer, 2014; Geels, 2004; Holtz et al., 2008; Schuitmaker, 2012). The socio-technical regime accounts for the stability of an existing socio-technical system and represents the set of rules, embedded in institutions and infrastructures, that shapes practices within a socio-technical system (Rip & Kemp, 1988). A successful – i.e. a continually reproduced – structural condition of a regime can prove to be a barrier to innovative approaches that *deviate* from this regime condition (Schuitmaker, 2012).

Yet, the regime concept must be specified in relation to the socio-technical system of interest – in our case the development of urban infrastructures and built environments. Which structural conditions are relevant therefore depends on the functional purpose and context of such a system. Additionally, the concept is typically used to understand processes of systemic change related to socio-technical innovation, whereas nature-based innovation involves multi-functional and place-based characteristics (Kabisch et al., 2016; Raymond et al., 2017; van der Jagt et al., 2020).

Therefore, we first developed an analytical framework that allowed

[1] We acknowledge that in the literature also other conceptualisations of mainstreaming are employed, for instance as the deliberate efforts to change urban infrastructure regimes in favour of NBS (see e.g. Uittenbroek et al., 2014a, b). We examine the structural conditions in urban infrastructure regimes that prevent the mainstreaming of NBS and hence employ a more static perspective.

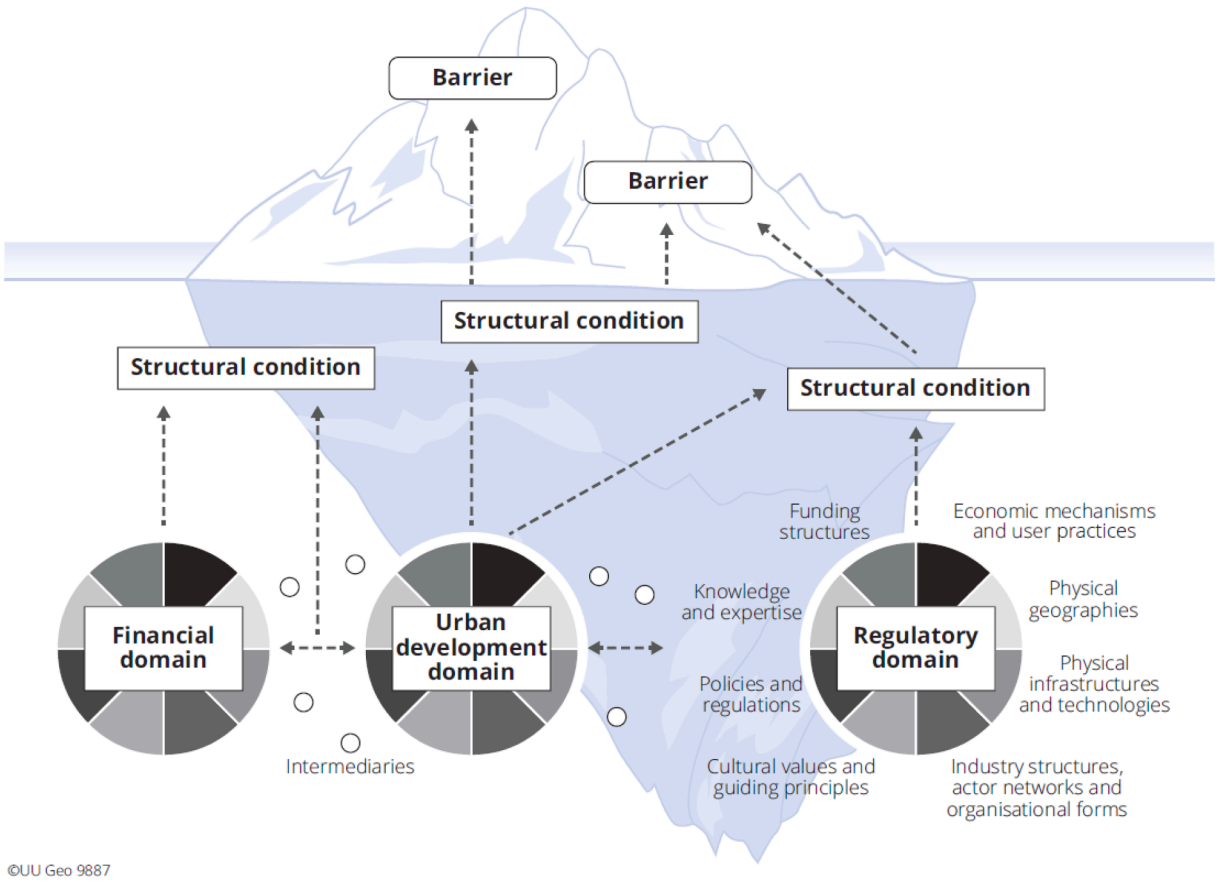

Fig. 1. Analytical framework of urban infrastructure regimes.

us to examine the structural conditions that enable and constrain NBS mainstreaming, which integrates elements from existing regime frameworks by Fuenfschilling & Truffer (2014), Geels (2011), Smith (2007), and Smith and Raven (2012). This included the following dimensions: 1) *physical infrastructures and technologies*; 2) *industry structure, actor networks, and organisational forms*; 3) *cultural values and guiding principles*; 4) *policies and regulations*; 5) *knowledge and expertise*; 6) *economic mechanisms and user practices*; 7) *funding structures;* and 8) *physical geographies.* For this study we apply and further refine the framework of urban infrastructure regimes, taking into account the interlinkages between different functional domains in the development and operation of cities.

2.2. Multi-domain urban infrastructure regimes

Regimes are not homogeneous, monolithic phenomena (Fuenfschilling & Truffer, 2014; Genus & Coles, 2008; Holtz et al., 2008). Moreover, the various structural conditions that constitute a regime are not always harmoniously aligned, and may sometimes be conflictive (Fuenfschilling & Truffer, 2014; Geels, 2011; Holtz et al., 2008). In the case of urban socio-technical regimes such assumptions of homogeneity are particularly problematic and incomplete. Viewed through a socio-technical systems lens, cities are hubs of networked infrastructures, where the various infrastructural systems rely on each other and co-evolve in close relation to urban development and urban space; urban infrastructure regimes therefore likely encompass rule-sets linked to different socio-technical systems (Næss and Vogel 2012; Wolfram and Frantzeskaki 2016; Binz, Coenen, Murphy, & Truffer, 2020). Not only do cities harbour a multitude of networked infrastructures for different societal functions (energy, mobility, food, etc.) but also 'multi-modal mixes' of technologies and the regimes associated to the use of these technologies – single owned family homes exist next to rental apartments, car infrastructures exist next to other forms of mobility, etc. (McPhearson et al., 2016; Næss & Vogel, 2012). Yet, with a few notable exceptions concerning specific cities (Ghosh & Schot, 2019; van Welie et al., 2018), conceptualisations of such a multi-system perspective on socio-technical regimes in urban contexts are still underdeveloped (Wolfram et al., 2016).

To adequately capture the complexities and particularities of the urban structural conditions that hamper NBS mainstreaming, we draw from perspectives on regime heterogeneity, i.e. the simultaneous and semi-coherent existence of different rationalities within a regime (Fuenfschilling & Truffer, 2014). In this paper, we conceptualise regime heterogeneity in terms of the existence of different functional domains, representing particular regime functions around which social groups specialise. These domains themselves also exhibit mutual differences in regime-like qualities; they are internally coordinated through shared institutional rules, language, norms, preferences, and perceptions (Fuenfschilling & Truffer, 2014; Geels, 2004). In this study, we propose that the urban infrastructure regime includes, as key constituents, the domains of (1) urban development, (2) regulation and policymaking, and (3) finance (including insurance). Distinguishing different functional domains within a regime acknowledges the interdependencies and interactions between different actors and institutional settings involved in providing societal functions (Holtz et al., 2008).

We focus on these three domains specifically because these are key functional domains for the development and management of urban infrastructures, green spaces and the built environment. Any urban intervention is designed and physically constructed by a variety of actors in what we term the urban development domain. Their actions are guided by regulatory measures implemented through the regulatory domain and facilitated by the availability of resources through the finance domain (Droste et al., 2017; Lützkendorf et al., 2011). We

conceptualise these domains to have a societal function that extends beyond urban development, e.g. the broader regulatory system does not only concern the planning and regulation of the urban built environment and infrastructures but also pertains to various other sectors and societal spheres. In other words, these domains are the critical underpinnings to the functioning of urban infrastructure regimes, but also operate according to their own distinctive logics, path-dependencies, and evolutionary dynamics. Conceptually this illuminates that while there may be unwanted inconsistencies and misalignments between, for example, the policy focus or the financial service offerings influencing the mainstreaming of NBS, overcoming them may require a more substantial engagement with the inner-workings of those domains. For instance, while a siloed organisation of policy may be undesirable for the mainstreaming of NBS, the silos may work very well for those policy focus areas around which these silos have emerged in the first place.

We note that differences between structural conditions in specific domains lead to heterogeneity in structural conditions within the overarching urban infrastructure regime. In practice, the domains will overlap; actors can be active in multiple domains, for example urban planning consultants, commercial real estate owners/investors or knowledge brokers. However, the domains can be distinguished analytically based on their overall logics and functions and involvement in the provision of urban infrastructures and the built environment. The urban development domain encompasses the interests, practices, technologies of the urban development industry who are engaged in the provision of infrastructure and housing in cities – e.g. design, construction, maintenance, renovation. The regulatory domain is concerned with urban regulation, policy-making, strategising, agenda-setting, political decision-making and planning, etc. Finally, the financial domain is concerned with the financing, investment, and insurance of the urban built environment – e.g. provision of loans to finance construction and greening, cost recovery/exploitation and financial risk-sharing.

With regard to the finance domain, we note here that while funding and access to resources is often identified as an important enabler of sustainability transitions (e.g. Rode et al., 2019), several scholars have already recently started to identify and conceptualize the financial system as a separate functional domain with its own selection environment, actors, practices, rules and routines (Geddes & Schmidt, 2020). Mainstream selection processes in the financial sector, such as risk assessment methodologies, can prevent the break-through of innovations (Smith & Raven, 2012) like NBS. Carrying out detailed analyses of how the financial system supports or prevents access to resources to realize sustainability transitions is therefore the key argument for conceptualizing a financial regime alongside other domains, in an effort to align the workings of the financial system with sustainable development objectives (Geddes & Schmidt, 2020).

Due to the urban infrastructure context and in line with existing evidence on finance for sustainability transitions, both public financial players (e.g. state investment banks, public grants/investment programmes) and private financial actors (e.g. banks, insurers, rating agencies) are studied. While the financial domain is thus conceptually carved out, in the empirical context we do find some overlap with the regulatory and urban development domains, from which some financial elements (e.g. subsidies by governments, investments by the real estate sector) cannot – and should not – be fully disentangled.

Fig. 1 shows our conceptualisation of the urban infrastructure regime, its constituent domains, and how these bring about structural conditions that generate barriers to NBS mainstreaming. The arrows represent hypothetical connections.

3. Methodology

3.1. Research design and data collection

This study is based on a qualitative, comparative case study methodology to allow for exploratory, in-depth analysis of the phenomenon of interest (Krehl & Weck, 2020). We used multiple cases to study similarities and differences in structural conditions influencing NBS mainstreaming between different countries. We selected six European countries as cases: Germany, Hungary, the Netherlands, Spain, Sweden, and the United Kingdom. These cases were selected based on the expectation that they would represent variation in structural conditions, based on indications of national differences in institutional and planning contexts (Nadin & Stead, 2008). Selecting multiple countries enabled an exploration of the extent to which different contexts matter in terms of how structural conditions influence urban NBS mainstreaming.

As we argued in the previous section, we regard urban infrastructure regimes as configurations with stable and dynamic components, encompassing structural conditions that favour practices that fit within a regime but can prohibit innovative approaches that deviate from this regime. Successfully mainstreaming innovative urban NBS depends on understanding and overcoming these barriers. We applied this framework to analyse our six European cases. Each case comprised three embedded units of analysis: the urban development, the regulatory and the financial domain. Each domain was analysed using the eight regime dimensions previously mentioned to allow for categorisation of structural conditions.

3.2. Data collection

The data was collected as part of an EU Horizon 2020 research project (NATURVATION) on structural conditions, barriers, opportunities and pathways for NBS mainstreaming (Dorst et al., 2018). Data was collected through semi-structured interviews with key regime domain representatives in the six European countries, supplemented with a desk study of relevant grey and policy documents (e.g. regulations, strategies, action plans, mission statements, policy evaluation and assessment studies, legislation), and placements (participant observation) at stakeholder organisations. Data collection per domain was organised using the analytical framework (Fig. 1) and guided by the following questions:

- *Structural conditions:* What are the dominant structural conditions of the regulatory/financial/urban development domains concerning the provision and operation of urban infrastructures and built environments, specifically concerning the possible integration of urban NBS?
- *Barriers and opportunities:* What are key barriers and opportunities for NBS resulting from these conditions and what were (potential) strategies to overcome or seize these?

From June 2018 to October 2019, we interviewed a total of 208 respondents (Germany: $N = 36$; Hungary: $N = 38$; Spain: $N = 35$; Sweden: $N = 33$; the Netherlands: $N = 40$; the United Kingdom: $N = 26$). Some interviews provided information on multiple domains but per case each domain analysis drew upon at least 9 interviews. Interviewees were approached based on their role in one of the three domains, including representatives of government and advisory organisations in the regulatory domain, banks, investors and insurance companies in the finance domain, and architects, landscape architects, development companies and engineering consultancies in the urban development domain.

3.3. Data analysis

Data analysis was done through thematic analysis (Braun and Clarke 2012) using the dimensions of the analytical framework (Fig. 1) for coding and analysis. This was done for each of the domains within the six cases. We prepared case study narratives outlining the relevant structural conditions, barriers, and opportunities influencing NBS mainstreaming. Next, we conducted a case comparison using the following procedure: 1) the identification of cross-case barriers; and 2) the identification of the case-specific structural conditions linked to

Table 1
Barriers observed across multiple cases.

Barrier	Explanation
1. Limited collaborative governance	NBS deliver multiple benefits simultaneously and tend to cross organisational and jurisdictional boundaries. The joint action needed to invest in and develop NBS is considered challenging and/or lacking.
2. Knowledge, data and awareness challenges	There is limited awareness of the relevance of urban NBS for several policy goals as well as a lack of knowledge and knowledge exchange on urban NBS performance.
3. Low private sector engagement	Actors in the urban development sector are sceptical about costs, performance, and profitable business models of NBS and are therefore less willing to engage or invest.
4. Competition over urban space	NBS may compete with other urban functions and sustainability innovations over land use in dense urban environments.
5. Insufficient policy development, implementation and enforcement oriented at NBS	NBS policy development, enforcement, and monitoring are sometimes insufficient and/or challenging.
6. Insufficient public resources (incl. maintenance challenges)	NBS implementation, maintenance, and mainstreaming often suffer from a lack of public funding and municipal capacity.
7. Citizen engagement challenges	The necessary citizen engagement to align NBS to environmental, physical and social context is insufficient and/or challenging.

these barriers.

To identify prevalent barriers, all constraints identified in the case study reports were first clustered across domains based on thematic comparability for each case (e.g. relating in a generic sense to problems such as policy silos, knowledge gaps, etc. (cf. Braun & Clarke, 2012)). For example, the barriers 'more integrated budgets are needed at the municipal level to prompt more integrated decision-making benefiting NBS' and 'there is a lack of a strong 'culture of cooperation'…' in the Hungary case were clustered under 'limited collaborative governance'. Second, through iteration we arrived at a list of thematic clusters of barriers across cases, e.g. the barrier clusters relating to 'limited collaborative governance' were grouped across countries. Both steps involved interpretation and discussion among the researchers involved and iteration to come to a final aggregated set of cross-case barriers to NBS mainstreaming.

These aggregated barriers were subsequently traced back to relevant underlying conditions for each separate case. For example, 'diverse professions are involved in urban development, but engineering expertise often dominates' is expected to be one of the conditions to have contributed to the barrier of 'limited collaborative governance' in the British case. These links do not always imply direct causality ('A leads to B'). Rather, they identify why a certain factor has become a barrier to NBS; the conditions explain why barriers are persistent.

Both the interviewees' explanations and the interpretations of the researchers provided the foundations for tracing the conditions underpinning each barrier. These conditions were identified through an iterative process of triangulation across different data sources, initial drafting, interpreting and testing ideas about relations, and critical and collective re-interpretation of emerging results in research team meetings (Stake, 2010). We complemented interviewees' understandings of structural conditions with our own interpretations because individual stakeholders often had a fragmented view of the urban regime and because the logic of regime-level structural conditions was not always self-evident to interviewees (Schuitmaker, 2012). This analysis resulted in a system overview per case of barriers and underlying structural conditions (see Appendix for case-specific data visualisations).

4. Results

This section first presents a summary (Table 1) of the identified barrier clusters, followed by a description of how these are underpinned by various structural conditions. Due to the high number of relevant structural conditions identified, only a selection of structural conditions is described below for illustrative purposes. An extensive system overview of the structural conditions identified is presented in the Appendix.

4.1. Barrier #1: Limited collaborative governance

NBS deliver multiple sustainability benefits simultaneously and rely strongly on action by stakeholders operating across different organisational and jurisdictional boundaries. This implies that joint action is needed to invest in and develop NBS. If not done successfully, it poses the risk that no single stakeholder group feels responsible for championing NBS, which limits their uptake in urban development. Limited collaborative governance was observed as a barrier in all cases, which often resulted from a complex stakeholder landscape and silos in project management and the governmental organisation, with responsibilities and budgets divided over various government agencies and departments with a stake in urban NBS development. For instance, a representative of the Swedish Ministry of Enterprise and Innovation stated: *"It's very sectorial, either you're a transport planner or you're an urban planner, but there's a lot of things to do to combine both things still… People try to understand each other and maybe they also talk [to each other] a lot, but in the end it's very sectorial because also the budget systems, they are still very silo-oriented"*.

While at the surface this appears to be mostly an issue specific to the regulatory domain, silos were not only experienced in governmental organisations. In Germany, a representative of the urban development domain marked the fact that stakeholders have different investment horizons as a key constraining structural condition: *"The entire building industry is incredibly fragmented. [Stakeholders] have very different returns on their investment horizons; the investor wants to do something after five years, whereas the operator focuses much more on operation and expenditure."*

Furthermore, the finance and urban development domains emphasised the prominence (and dominance) of engineering expertise when compared to other types of expertise. The imbalance in the value attributed to different types of knowledge in urban development may further contribute to distorted power relations across domains; the dominance of one type of expertise is likely not incidental but reflects power relations between actors.

Our analysis revealed that different types of structural conditions at a country (case) level underpinned the same collaborative governance barrier. As the systemic visualisations of the Spain and Hungary cases show (Figs. 5 and 3, respectively), for example, limited communication between parties and inflexible departmental organisations (linked to bureaucracy in Spain and a hierarchical government structure in Hungary) were indicated to be underlying structural conditions. In Sweden and the Netherlands (Figs. 6 and 4), the problem was reported to derive from stakeholders finding it difficult to 'think out of the box' and look beyond their tasks and responsibilities.

Findings also indicate that structural conditions are interacting in complex ways, as visualised with arrows in the country case diagrams (Appendix); a structural condition does not stand alone and necessarily underpin a barrier in a straightforward way. In Sweden (Fig. 6), for instance, many practitioners preferred grey infrastructure solutions because these were experienced as easier to implement, which may be grounded in two other structural conditions: (1) the municipal organisation is already structured around providing and maintaining grey infrastructure and (2) the current financing structures for NBS, which often rely on funding from different budgets, were complicated. The way that municipal governments are often set up to provide and maintain grey infrastructures also means that ecological expertise tends to be

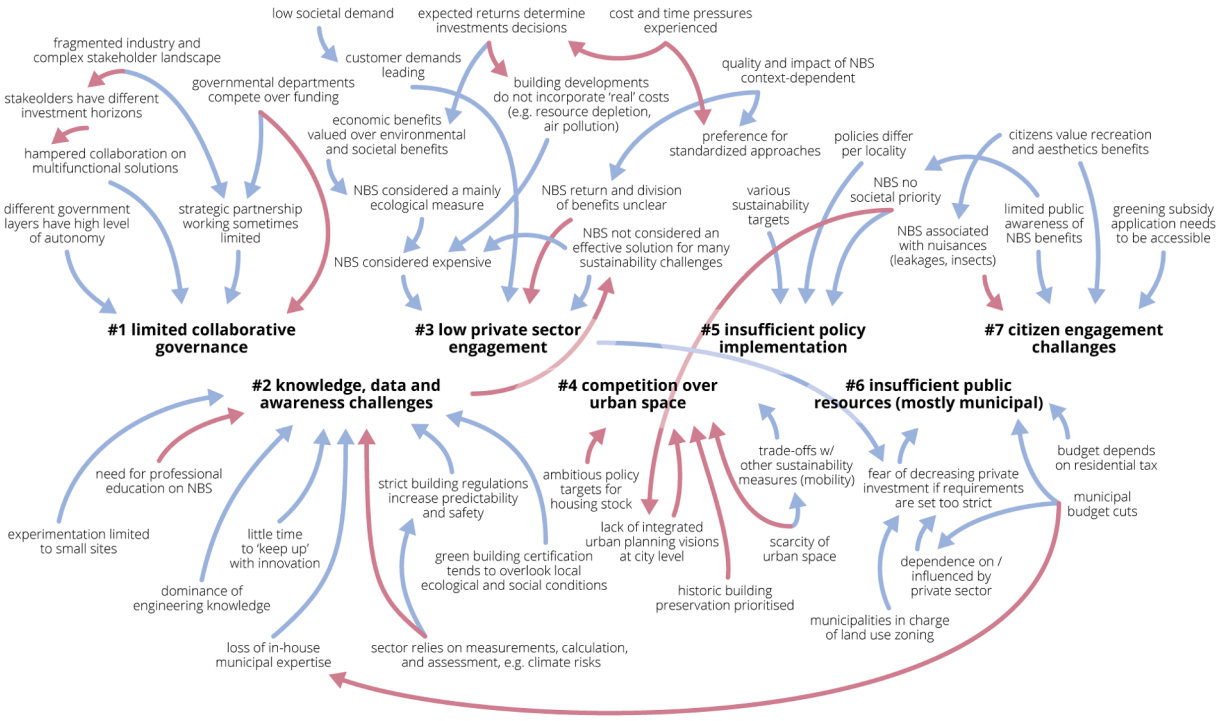

Fig. 2. Systemic visualisation of the structural conditions affecting NBS mainstreaming in Germany.

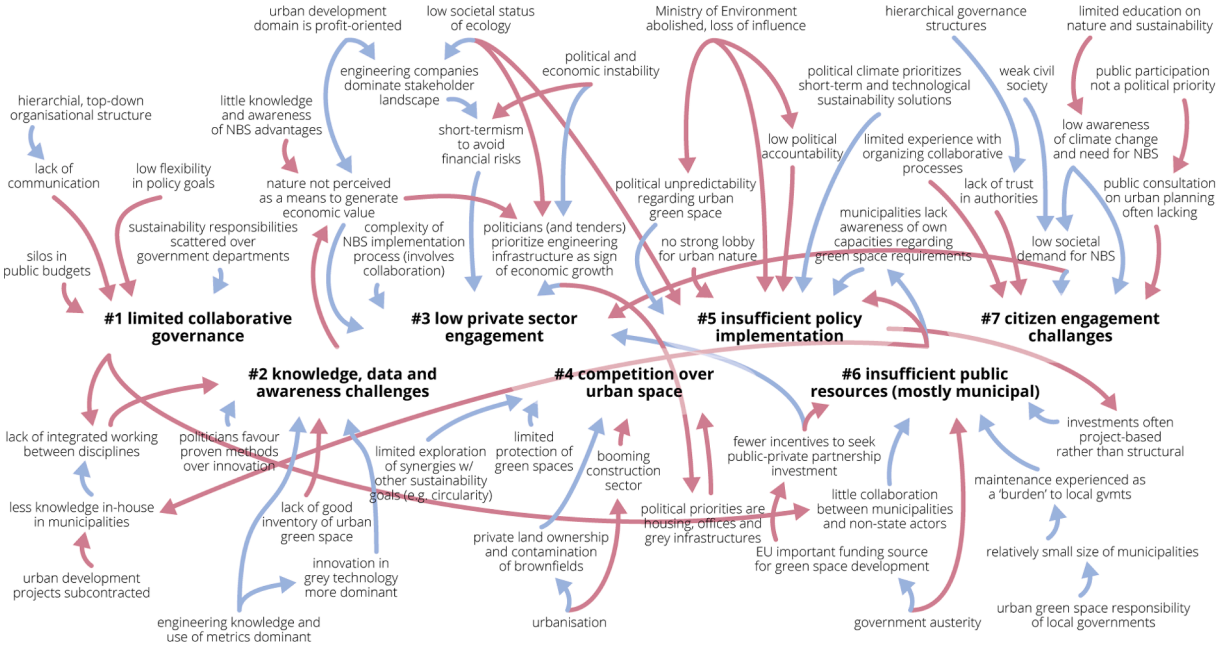

Fig. 3. Systemic visualisation of the structural conditions affecting NBS mainstreaming in Hungary.

'added' at the final stages of development processes, making it difficult to negotiate trade-offs.

4.2. Barrier #2: Knowledge, data and awareness challenges

In all cases we observed a limited awareness of the potential of urban NBS for relevant and related policy goals (climate change issues, biodiversity, economic regeneration, etc.) as well as a lack of knowledge and knowledge exchange on urban NBS performance (e.g., technical knowledge, evidence of benefits). A focus on grey technology and engineering expertise, particularly in the urban development and financial domains, hampered the development and use of other types of knowledge (e.g. ecological knowledge). As a representative in the British urban development domain stated, more traditional engineered solutions are often sought to avoid risks related to innovative solutions: "*Definitely there's a problem with over-engineering, and we struggle to find decent engineers who don't just do the sums and go, 'You need this big tank to deal with attenuation.' It's just a risk thing.*"

Furthermore, the performance of NBS is context-specific. Yet actors in the urban infrastructure regime, across different domains, rely on quantified evidence, calculation, and standardisation for achieving economies of scale and scope. This type of data is difficult to develop for

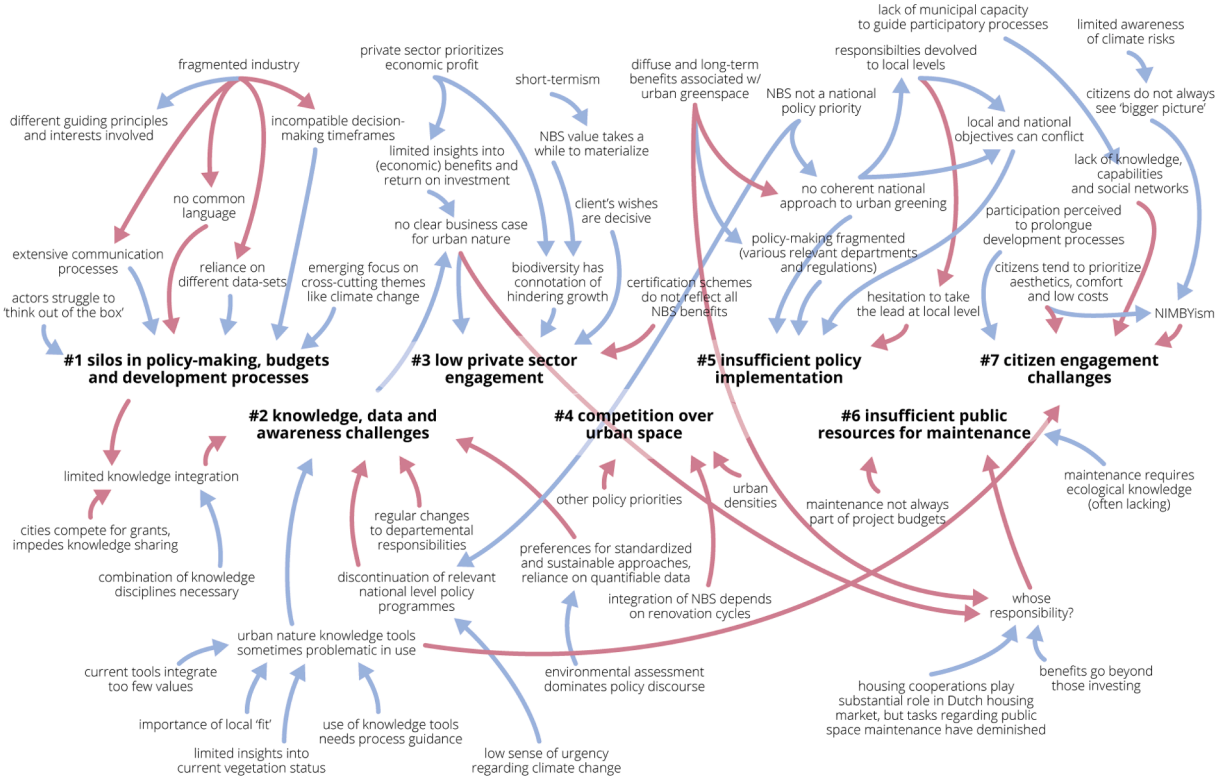

Fig. 4. Systemic visualisation of the structural conditions affecting NBS mainstreaming in the Netherlands.

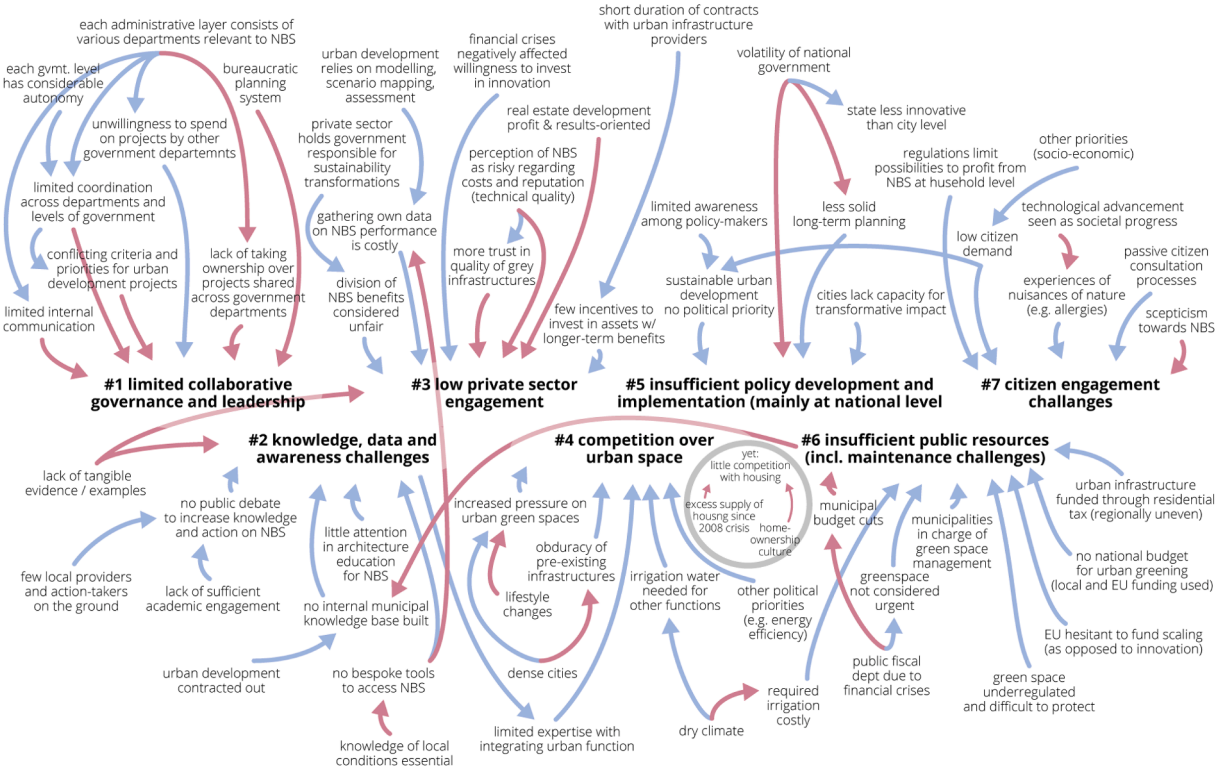

Fig. 5. Systemic visualisation of the structural conditions affecting NBS mainstreaming in Spain.

context-sensitive NBS performance, as is standardisation of the NBS approach and assessment (e.g. through certification).

Again, this barrier is underpinned by different structural conditions, which vary across countries. In the Netherlands, knowledge gaps were attributed to the problematic use of assessment tools, leading to an incomplete view of NBS performance (Fig. 4 shows the complete set of identified underlying conditions contributing to this barrier). For example, the TEEB City tool does not allow for recording information on

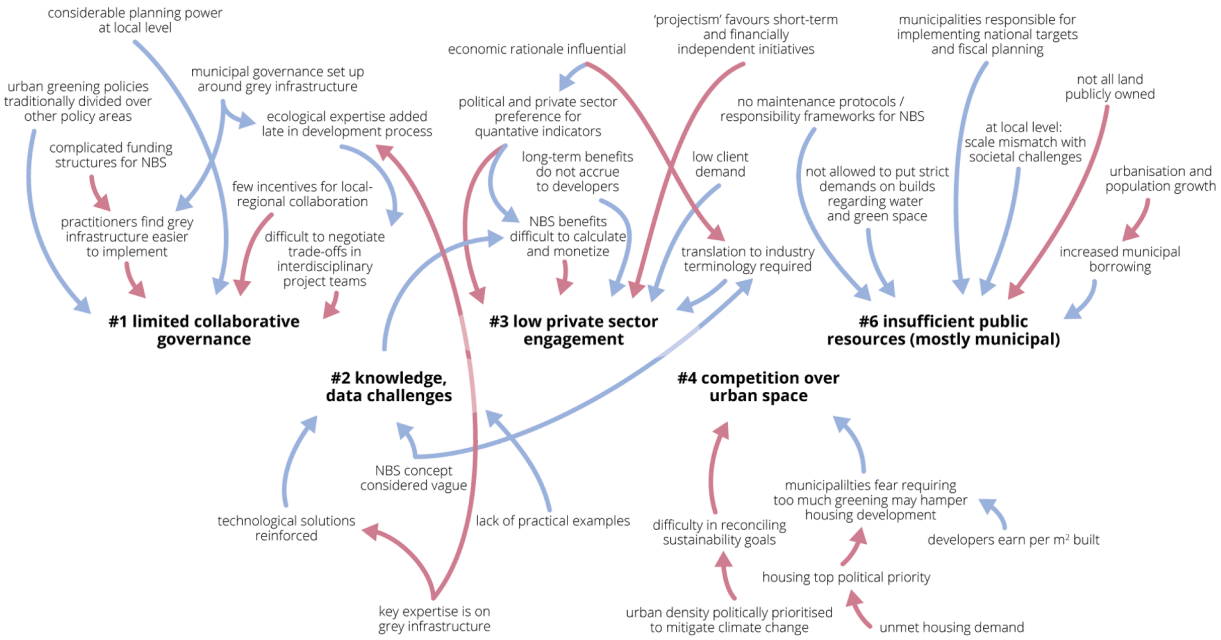

Fig. 6. Systemic visualisation of the structural conditions affecting NBS mainstreaming in Sweden.

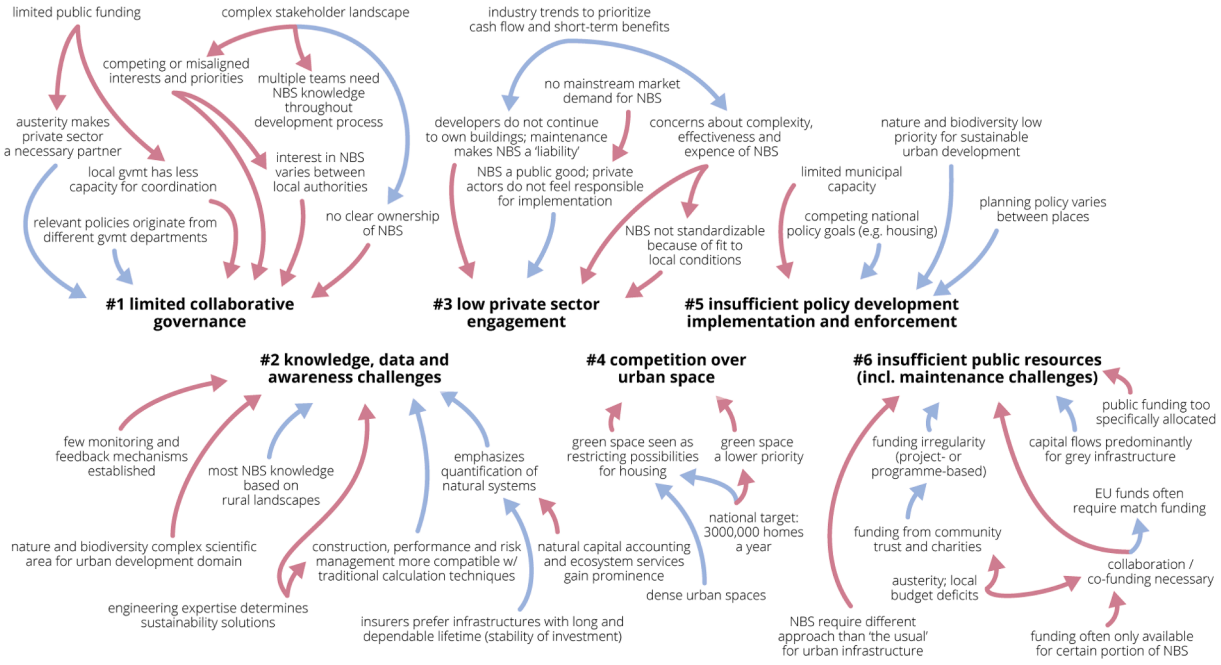

Fig. 7. Systemic visualisation of the structural conditions affecting NBS mainstreaming in the UK.

Table 2
Legend for regime visualisations.

#3	Barrier
→	indication of linkage supported by concrete data points (e.g. quotes or working paper report)
→	inference of linkage based on researcher's interpretation

the type of vegetation, environmental data is not available at the micro-level relevant to cities and it does not take into account relevant background information such as local population density. In the United Kingdom (Fig. 7), conditions underpinning the lack of knowledge, data and awareness included a general lack of monitoring of NBS performance after their development and the lack of a comprehensive NBS metric for the urban context. A UK ecological consultant expressed this in the following way: *"If the development is subject to a BREEAM assessment, they are required and committed to implementing management and monitoring of the nature-based solutions that they have to deliver as a consequence of planning. But there's zero enforcement of those conditions"*.

In Germany and Hungary, the main problem reported was that knowledge and expertise on urban NBS design were available, but not in the right places. This is due to a lack of knowledge exchange and integration between stakeholders and the prioritisation of grey technology innovation (in Hungary). Other underlying structural conditions, as

shown in Fig. 1 (Hungary) and 2 (Germany), are the limited professional education provided on NBS in some urban development disciplines, a lack of time (or prioritisation) in development processes to engage with and learn about innovations (in Germany), limited municipal knowledge on NBS benefits, and the dominance of engineering knowledge (in both countries). In Hungary, for example, construction companies are not mandated to hire a landscape architect for new urban developments, whilst a certified architect is always required. This applies even to new developments that include a pre-set minimum area of greenspace or, in fact, when designing a new urban park. In Sweden, the limited integration of relevant expertise was explained by diverse interpretations of the NBS concept across different disciplines (Fig. 6).

4.3. Barrier #3: Low private sector engagement

NBS often lack profitable business models and tend to generate benefits over a longer period than technical solutions with shorter life spans. Across cases, conditions prevalent in the financial and urban development domains, and to some extent also in the regulatory domain, led to a low willingness among private sector actors to invest. These structural conditions include short-termism (which limits the long-term perspective often needed for NBS to yield benefits and financial returns) and an economic growth-orientation. Furthermore, actors across the urban infrastructure regime, but mostly in the financial and urban development domains, feel uncertain about the costs and performance of NBS and are therefore less willing to engage with and invest in NBS. Moreover, investors generally do not reap the social and ecological benefits of urban NBS, as is illustrated by a German building innovation consultant: *"The question is always 'who is benefiting from that [NBS]?'. If I'm the owner of that building and I need to invest half a million more to have a green façade because my engineers tell me that that mitigates urban heat, I'd say yes but … […] who pays, what's the payback? […] It's again a business model issue."*

In the United Kingdom, Spain and Hungary, perceived low market demand for NBS further dampened private sector interests. In cases where market demand was identified to be high, most prominently so in Sweden, the finance and urban development domains indicated that 'green reputations' are valued and as such provide a reason to engage with NBS implementation.

This barrier was found to interact with other barriers. In Spain, NBS mainstreaming was not thought to be feasible without private sector contributions because of limited public sector capacity (barrier #6). In the United Kingdom (Fig. 7), planning regulation mandating the development of urban NBS is a key condition explaining private investment (finance and urban development domains); however, such regulation is still limited (barrier #5). The German and Dutch cases highlight how a lack of insight in NBS performance and technical quality (barrier #2) resulted in a lack of trust in urban NBS and scepticism, as a Dutch engineering consultant indicates: "*I find green roofs difficult to advise positively about. […] I can see that it contributes much of what our cities have too little of. […] But if I look purely at their advantages for preventing flooding, I consider it a very expensive, nonsensical measure that I don't even trust."*

4.4. Barrier #4: Competition over urban space

NBS proponents tend to compete with other sectors delivering urban functions over land use in dense urban environments. Although NBS can also be integrated into built structures, meaning it is not a zero-sum game, the additional costs associated with implementing and maintaining NBS in this way (e.g. irrigation of a green wall) often makes this cost-prohibitive. In four out of six cases, a difficult to reconcile tension was observed between the need to use urban space for additional housing or urban greening. For example in Hamburg, Germany, an environmental NGO employee explained: *They [the municipality] just have this goal of 10,000 living units per year [..] So they tell the districts, "Find us this many buildings every year," or building sites every year, and that's just it. So the districts have to find areas where they can build new houses."* While Hamburg also has ambitious greening objectives, competition over land use is a key issue. As Fig. 5 shows, the Spain case was slightly different: here urban NBS competed with commercial building development in *peri*-urban areas.

This barrier was exacerbated by the general scarcity of urban vacant space and the density of the built environment in many European cities, along with the policy ambition to further densify urban areas, to align with sustainability objectives. Additionally, we found that national and local governments tend to give high priority to technological sustainability innovations, such as energy or mobility solutions, which sometimes compete with NBS over the sustainable use of urban space. For example, installing solar panels on a roof 'competes' with rooftop greening.

4.5. Barrier #5: Insufficient policy development, implementation and enforcement oriented at NBS

NBS-oriented policy development, enforcement, and monitoring were sometimes reported to be insufficient, and moving from vision to practical implementation can be difficult for the actors involved. In the Netherlands, Hungary and Spain, for example, we observed uncertainty and lack of capacity within local governments to take the lead in sustainability innovations.

A relevant underlying condition observed across the national cases as well as domains is that the local government has a strong influence on urban NBS uptake through their dominant role in urban planning. We observed regional differences in policies relevant to urban NBS and sustainability, which creates challenges for nationally and internationally operating companies (mainly in the finance and urban development domain) around the need for adopting a place-specific approach.

This barrier manifested differently in each case, which can be traced back to differing structural conditions. For instance, in the Netherlands and Germany, the main barrier observed was a gap between policy design and implementation. Relevant structural conditions underpinning this barrier, reported in the Netherlands and Germany, include policy silos and a lack of coherence in urban greening goals. Elsewhere, the underlying issue was limited enforcement. For example, a planner at a Hungarian local government indicated: "*I think these [directives such as the Environmental Law, Environmental Protection Act or the landscape strategy] are just rules that can be bent, [… they] cannot really be enforced*". This was explained by the limited organisational capacity within municipalities resulting in a project-based (rather than policy-driven) approach to urban greening.

4.6. Barrier #6: Insufficient public resources

NBS implementation, maintenance, and mainstreaming often suffer from a lack of public funding, which limits municipal capacity to engage with NBS implementation and management. This is especially problematic given that NBS are 'living' and growing interventions, which implies they rely on a different maintenance and management approach than grey urban infrastructure solutions.

The lack of municipal resources for urban NBS implementation, maintenance and management sometimes resulted from austerity measures at the national level (United Kingdom and Hungary). As a contact person within the UK regulatory domain noted: *"The whole agenda around green infrastructure, it really came to the fore in terms of a policy framework just at the time where at a national level we embraced austerity, which is really unfortunate. Because although there are lots of ways to engage private sector funding for green infrastructure, at the end of the day, largely because it's still all about providing public goods, you still need quite a lot of public sector investment in green infrastructure to really make it work. […] There's lots of willingness and interest from particularly local authorities, but they are very limited in what they can do because they're under such severe*

financial constraints at the moment".

Differences in public funding availability can also be tied to differences in local residential and property tax revenue, which in some cases contributed directly to the funding budget for urban greening. Lastly, funding for urban NBS tended to be project-based rather than of a structural nature, which impedes scaling and maintenance of successful projects. While EU funding for urban greening is theoretically accessible for all European countries and therefore a shared structural condition, we found that their importance and the ability to compensate for this resource gap seems to vary between countries and cities.

4.7. Barrier #7: Challenges around citizen engagement

In order to function well, NBS need to be brought into alignment with local environmental, physical and social contexts, which requires a level of citizen engagement. However, this is often experienced as difficult, contested, or insufficiently prioritised. The case study visualisations (Appendix) reveal how different underlying conditions lead to different outcomes for this particular barrier. The Hungary and Spain cases (Figs. 3 and 5 respectively) are characterised by relatively limited experience with citizen engagement as part of urban NBS development, although variations between cities and city districts were observed. One of the explanations for this in Spain is lack of environmental awareness leading to unrealistic expectations. A greenspace officer at Barcelona City Council expressed this in the following way: "*When people talk about renaturing, they think that Barcelona's parks are going to look like German or English parks; they're going to be green, full of grass and people are going to be able to walk, cycle, take the dog and picnic everywhere […]. And when you point out that it actually has a different latitude, different soil and different hydric regime, people get angry, they don't understand, 'you're being difficult, why can't we do it?*'". Moreover, urbanisation and the development of new grey infrastructure are still often regarded as better indicators of societal progress than NBS. One of the explanations provided for limited citizen engagement in Hungary is the limited funding availability to support these processes, which leads to a lack of efforts to reach out to citizens, limited incentives for the public to participate and few assurances that doing so will lead to tangible results. In the Netherlands and Germany (Figs. 4 and 2), citizens were generally engaged to a higher extent but not always in ways conducive to NBS development. Some exhibited 'NIMBYism' ('not in my backyard'): residents desired the benefits, but not the disbenefits, e.g. plant sap or leaf litter on their cars or homes.

5. Discussion

The urban infrastructure regime framework allows for a systemic and integrated understanding of the structural conditions that shape the barriers to NBS mainstreaming. By considering the heterogeneity of urban infrastructure regimes, our findings show a broad set of structural conditions that directly and indirectly, and often conjointly, generate a range of barriers that hamper the mainstreaming of urban NBS, as visualised in the country case diagrams (Appendix). Moreover, these conditions can vary between countries, implying that the same barrier could have different underlying conditions depending on its context. This study goes beyond previous studies on barriers to the uptake and implementation of urban NBS and specific examples of this (e.g., Sarabi et al., 2019; Wamsler et al., 2020a), which did not explicitly consider the role of structural conditions.

5.1. Key insights

The urban infrastructure regime approach taken in this study illuminates why barriers to urban NBS mainstreaming persist. The structural conditions of regimes reinforce the status quo and, wherever mainstreaming of NBS would require innovative knowledge, practices, or technologies, barriers arise that prevent its integration into conventional urban development practices. Our findings show that some structural conditions appear more fundamental to regime functioning than others, influencing multiple barriers as well as other conditions. For example, in several cases we found that trust in 'engineering' practices provided an important regime rationality. This affected the functionality of the entire system in multiple ways: it exacerbated stakeholder silos, it promoted the development of codes, standards, and knowledge paradigms eschewing 'soft' NBS benefits and performance, and it incentivised innovation in engineering-heavy technologies.

Barriers to urban NBS mainstreaming also persist because structural conditions are interdependent. A regime perspective on structural conditions improves our ability to see interrelationships and interdependencies between heterogeneous structural conditions and, by extension, between barriers. For example, the barrier of low private sector engagement is reinforced by barriers and conditions relating to: (1) limited public resources, resulting in a dependency on private sector (and citizen) contributions to green space implementation and maintenance; (2) limited policy implementation and guidance on NBS to steer private sector activities regarding urban development; and (3) limited knowledge on NBS performance, which hampers the development of business cases for urban NBS as well as collaborative governance with and between private actors. Actions aimed at overcoming barriers to mainstreaming NBS may prove inefficient if the structural root causes for these barriers, and the causal interdependencies between these structural conditions, are not understood. Although previous articles have also described interlinkages between individual barriers (e.g. low citizen engagement) and underlying conditions (e.g. insufficient public resources or policy development) (Sarabi et al., 2020; Wamsler et al., 2020b), we are not aware of studies mapping relationships between barriers to urban NBS and structural conditions taking into account the dynamics in the finance and urban development domains. Sarabi et al's (2020) conclusion based on a review that "political barriers are identified as the underlying critical factors affecting all the other barriers" (p. 8) is suggestive of a bias towards the regulatory domain in the available research on NBS.

Our findings also offer key insights into how to overcome barriers. First, targeting more fundamental conditions could have more systemic impact. Structural conditions that underpin multiple barriers and influence other structural conditions might be leverage points for shifting the obdurate system of urban development (Abson et al. 2017). Interventions vary in their ability to change a system. Any intervention in a system is transformational in proportion to the extent to which the particular aspect it acts upon can drive wider shifts (Abson et al., 2017; Meadows, 1999). Our application of a comprehensive regime analysis shows one way to identify such leverage points. A second insight is that multiple structural conditions might need to be tackled at once to address barriers given observed interdependencies between them (Eisenack et al., 2014). Barriers to NBS mainstreaming tend to be underpinned by structural conditions transcending functional domains.

Our application of the urban infrastructure regime concept to urban NBS analysis based on multiple domains and dimensions (i.e. structural conditions) showed how the concept of regime heterogeneity (Geels, 2004; Næss & Vogel, 2012; Fuenfschilling & Truffer, 2014) can be applied to analyse the influence of complex urban infrastructure regimes on urban innovation. Our parallel analysis of three functional domains within the urban infrastructure regime reveals differences in prevalent structural conditions between domains, yet also shows mutual dependencies and alignments in the way barriers for NBS mainstreaming are formed. The barrier of limited collaborative governance is a case in point: each domain experiences fragmentation of stakeholder landscape and silos in organisational forms, whether it is policy and budgeting silos in the regulatory domain or investment and project management silos in the urban development and finance domains.

Our findings also contribute to the urban greening literature by demonstrating how an urban infrastructure approach accommodates analysis of system dynamics as well as context-specific conditions. The

comparison of national cases reveals heterogeneity in structural conditions between countries, and the potential of seemingly similar barriers being underpinned by different configurations of structural conditions. For instance, whereas NBS compete with other land uses for scarce urban space in all cases, we encountered variable configurations of underlying conditions such as strong demand for housing development, urban densification trends, competition with other sustainability solutions for urban space, knowledge limitations, and lack of funding for urban NBS. This implies that while using a generic regime framework is valuable to refocus attention from 'surface-level' barriers experienced at the level of individual NBS projects to regime-level structural conditions, context-specificity should not be overlooked. Structural conditions vary between nations and even regions, calling for further research that can unveil place-specific approaches and recommendations for NBS implementation (Albert et al., 2020; Dorst et al., 2019; van der Jagt et al., 2020).

Although not our main objective, another key output is a comprehensive overview of barriers to urban NBS mainstreaming based on research across multiple countries and functional domains. Overall, the barriers reported in this study largely confirm previous overviews that draw on smaller scale datasets (e.g. NBS project, city or region). The barrier *limited collaborative governance* confirms constraints such as 'sectoral silos' (Kabisch et al., 2016; Wamsler et al., 2020a), 'silo mentality' (Sarabi et al., 2020), 'lack of coordination' (Egusquiza et al., 2019) and 'interagency fragmentation' (Deely et al., 2020). The barrier *knowledge, data and awareness challenges* corresponds with the category of knowledge barriers including limited access to information, lack of technologies and uncertainty about NBS operations and performance reported by Egusquiza et al. (2019). Uncertainty is also covered by Kabisch et al. (2016) and Sarabi et al. (2020), while Deely et al. (2020) and Wamsler et al. (2020a) stress the importance of human capital and capacity. *Lack of private sector engagement* is less clearly covered as part of existing overviews of barriers to NBS uptake, but Wamsler et al. (2020a), refer to the need for private sector collaboration. 'Space constraints' described by Sarabi et al. (2020) and Deely et al. (2020) overlap with our barrier *competition over urban space* but do not explicitly address competition with engineered sustainability measures. The challenges around *insufficient policy development* and *public resources* feature prominently in the literature on NBS as legal/policy and economic/funding barriers, respectively. Finally, the *citizen engagement challenges* barrier is compatible with 'lack of citizen interest' (Wamsler et al., 2020a), 'lack of participation' (Egusquiza et al., 2019) and 'limited opportunities for community empowerment' (Deely et al., 2020) reported elsewhere.

Beyond providing a comprehensive overview of barriers for the mainstreaming of urban NBS, the main contribution of our study is the development of an improved, systematic framework for conceptually distinguishing barriers from underlying structural conditions. We observe that existing studies usually intermix barriers with structural conditions. For example, Sarabi et al. (2019) describe *uncertainty about NBS effectiveness* as a barrier, which we consider to be a structural condition related to the dominance of engineering expertise, underpinning multiple barriers. Similarly, Deely et al. (2020) identify, among others, *design and construction challenges;* we treat this as a structural condition emerging in the 'physical infrastructures and technologies' dimension. Furthermore, Egusquiza et al. (2019) and Kabisch et al. (2016) include as barrier *the tendency for decision-making to be based on short-term goals*, which we consider a structural condition related to the way political systems are organized and the tendency for policy to be reactive to current technologies and existing problems rather than proactive (Dorst, van der Jagt, Runhaar, & Raven, 2021).

5.2. Methodological reflections and further research

The analysis demonstrated that the same barriers often relate to different structural conditions across different cases. However, linking barriers to conditions was to some extent dependent on researcher interpretation. Follow-up research could take place in the form of longitudinal analysis, inquiring into temporal shifts in structural conditions and how this impacts on barriers, to make our findings more robust.

Our framework is based on a choice of three dominant domains in the development of the urban built environment and infrastructures. Yet we do not claim that these domains are the only ones that bear relevance to urban development. Future research is needed to determine whether other functional domains should be identified (e.g., knowledge or cultural). In addition, while this study analysed NBS as a general category of interventions, it is conceivable that barriers and conditions for mainstreaming vary across NBS types (Kiss et al., 2019) and this could be subject to further study.

Moreover, further research could determine if our conceptual model of urban infrastructure regimes can be extrapolated as an integrative approach to other innovations for urban sustainability. By emphasising and visualising urban complexity, this framework offers a perspective that goes beyond the sectoral boundaries traditionally set in regime analyses. It thereby reveals interdependencies between the structural conditions prevalent in different urban functional domains, which offers insights into relevant leverage points and possible transition pathways that can be carved out for other urban sustainability innovations. Lastly, it is worthwhile to explore the approach in different geographies. This study has focussed on European countries, which – at the time of research - were are part of the European Union, which arguably will have already led to transnational alignment across the urban development, policy and finance domains, at least more so than in other geographies, whether in developed geographies like the EU, or in rapidly developing economies and the Global South.

6. Conclusion

This empirical study offers an overview of barriers to the mainstreaming of urban NBS in six European country cases and an improved, context-sensitive understanding of why such barriers persist. A second contribution of this study is an understanding of socio-technical regimes as complex, heterogeneous systems, made up of different functional domains (regulatory, financial and urban development) that shape the mainstreaming of sustainability innovations. As such, it provides a comprehensive analysis of why urban NBS mainstreaming is difficult to achieve or generalise: it depends on a complex web of highly contextual structural conditions.

We identify seven key barriers to the mainstreaming of urban NBS: limited collaborative governance, knowledge, data and awareness challenges, low private sector engagement, competition over urban space, insufficient policy development, implementation and enforcement, insufficient public resources and challenging citizen engagement. Importantly, a country case comparison showed that any particular barrier to urban NBS mainstreaming may have different underlying structural conditions, depending on their geographical context. This warrants a context-sensitive approach to the mainstreaming of NBS. The approach of taking into account the multi-domain nature of urban infrastructure regimes supported a more comprehensive overview of relevant structural conditions for NBS mainstreaming in an urban context. Follow-up research could more explicitly identify alignment – or lack thereof – between regime domains, to identify potential transition pathways in a more detailed way. Particularly for more complex, multi-domain regime constellations in the urban context it is still less clear how regime alignments and interdependencies affect opportunities and challenges for implementing sustainable innovations (Holtz et al. 2008; McPhearson et al. 2016).

This study contributes to the literature on urban NBS by providing deeper insight into the complex system-level structures that influence their mainstreaming. Thereby it provides an outlook on where to intervene when addressing barriers to NBS mainstreaming: interventions have to take place at the level of (underlying) structural conditions rather than at the level of the (resulting) barriers. Yet, the

paper only indicated the possible presence of more fundamental system nodes. Insights into opportunities for NBS implementation could benefit from further research that focuses specifically on identifying such leverage points. This should also take into account that leverage points could be place-specific. By explicitly considering the heterogeneity of these structural conditions, their interlinkages and how they lead to barriers to NBS mainstreaming, we arrive at more nuanced, granular and holistic understandings of the complex challenges for accelerating urban sustainability. Finally, the study contributes to the literature on (urban) sustainability transitions, and particularly in response to calls for future research to better conceptualise and investigate transitions as unfolding through interactions across multiple (urban) systems and scales (Hölscher and Frantzeskaki, 2021; Wolfram et al., 2016; (Papachristos et al., 2013) Raven, 2007).

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Appendix. System visualisations of urban infrastructure regimes per case

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.landurbplan.2021.104335.

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