Nurturing the nature of innovation: the urban geographies of 'nature-based solutions'

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Abstract

Cities and regions are increasingly recognised as critical environments and change agents in shaping sustainability transitions. Literature on sustainability transitions has so far been dominated by single-case studies, which tend to emphasize the particularities of a place. As such, there is consensus that place-specificity and socio-spatial context matters, but there are little generic insights on how place-specificity – and especially an urban context – matters for transitions. Hence, there is potential to contribute to debates on the urban geographies of transitions by engaging with explanatory rather than descriptive research questions and by mobilising different research strategies. The aim of this paper is to develop such an explanatory perspective, based on a higher aggregate-level analysis, using a database on innovative sustainability interventions. It addresses the question: how and why do urban transition dynamics differ across cities?

The empirical focus of this paper are 'nature-based solutions' (NBS); urban interventions based on natural features that aim to address economic, social and ecological sustainability challenges simultaneously. A database of 967 NBS examples in 100 European cities constructed in the context of the Horizon2020 NATURVATION project provides insights into which of these factors are relevant in explaining urban sustainability innovation dynamics. Building on the geography of transitions literature, we construct a framework to analyse whether localized conditions (e.g. local policies, informal institutions, strategic visions, heterogeneous regional networks or local learning processes) indeed explain the implementation and uptake of sustainable innovation and which of these conditions – if any – are dominant in explaining the emergence of specific types of NBS innovations. The paper discloses the patterns of how socio-spatial conditions influence NBS innovation in European cities and contributes to the literature on the geography of sustainability transitions by developing and testing a conceptual framework that builds upon the state-of-the transitions literature, but moves beyond qualitative single-case study methods.

[preview conclusions]

1. Introduction

Recently, the socio-spatial context of sustainability transitions has gained traction in a so-called spatial 'turn' in transitions literature (Murphy, 2015), with different authors arguing for a more spatially sensitive analysis

of socio-technical transitions (Coenen et al., 2012; Truffer et al., 2015). Although space and scale have often been overlooked as interfering factors in empirical niche analyses, transition scholars increasingly turn to geography to seek insights into variations in niche development pathways and the influences of contextual, place-specific conditions (Coenen et al., 2012; Murphy, 2015; Raven et al., 2012; Truffer et al., 2015).

In this light, the potential role of cities in sustainability transitions is increasingly investigated (Geels, 2011; McCormick et al., 2013; Wolfram, 2015). While urban areas tend to provide fertile grounds for sustainable innovation (McCormick et al., 2013), cities are also the primary locations where unsustainable infrastructures concentrate (Monstadt, 2009). Moreover, cities face a variety of challenges caused by climate change and urbanization that put pressure on urban liveability and social, economic and ecologic sustainability (Hodson & Marvin, 2010).

A key issue of sustainability transitions is the socio-spatial embeddedness of transitions, as differences between locales may be the key to explain the distinct pathways of the innovative interventions, such as NBS, that bring about sustainable transformation (Hodson & Marvin, 2010; Coenen & Truffer, 2012; Truffer et al., 2015). Novel sustainability approaches tend to meet institutional barriers in existing socio-technical regimes, such as technological standards, regulatory requirements, cultural views or market pressures, which are often place-specific (Hansen & Coenen, 2015). Socio-spatial embeddedness relates to the conditions of specific places, such as cities, that influence the potential for their transformation, and that have formed as a result of particular cultures, institutions, political systems, social networks and resources that have developed in these places. Socio-spatial conditions thereby determine the development trajectories of niches and their uptake into and transforming of regimes thereby take part in explaining differences in socio-technical transition pathways (Coenen et al., 2012; Murphy, 2015).

However, geographically-sensitive studies tend to emphasize the particular qualities and characteristics of places in explaining transitions (Hansen & Coenen, 2015). The more systematic ways in which urban, socio-spatial conditions relate to sustainability transition dynamics remain unclear. This research aims to develop an understanding of the patterns in which space and place affect urban sustainability transitions, by engaging with a higher-aggregate analysis. The empirical focus of this paper is on NBS, nature-based interventions aimed at improving urban sustainability and sustainable urban transformation. NBS is an emerging concept that refers to the innovative ‘use’ of nature for addressing societal challenges such as climate change, biodiversity, health and inclusive societies. NBS employ natural elements or systems to enhance urban resilience and regeneration, and aim to address social, economic and ecological sustainability challenges simultaneously. NBS is an umbrella term for a variety of innovative interventions, examples of which are green roofs, waterways or sustainable urban drainage systems. The uptake of NBS as a guiding

principle in the discourse on sustainable cities and the increasing implementation of NBS carry the potential to contribute to the transition towards sustainable cities.

The following section outlines insights on place-specific conditions that drive urban innovation and transition dynamics, and constructs an analytical framework. Section 3 describes our research approach and methodology. Section 4 highlights the key results following from the database analysis, the implications of which are discussed in Section 5. Section 6 concludes and provides potential avenues for further research.

2. Explaining sustainable urban transformation: towards a framework

Nature-based solutions (NBS) are interventions based on nature that offer an alternative to more traditional, 'grey' urban infrastructures and as such form a specific manifestation of the sustainable transformation of the urban environment. From a socio-technical systems perspective, NBS can be conceived of as a 'green niche' (Smith, 2007), an innovative approach that challenges the incumbent urban infrastructure regime, understood here as the "stable urban configurations of institutions, techniques, and artifacts which determine 'normal' sociotechnical developments in a city and thus shape general urban processes and the urban metabolism" (Monstadt, 2009, p. 1937).

As an umbrella concept, the NBS niche encompasses several types of innovative approaches to urban infrastructure development. This paper analyses how socio-spatial conditions link to diversity in the development of different types of innovation in the NBS niche, in terms of their nature – i.e. do they include a social innovation, a technical one or both? – their novelty – i.e. do they build on previous ideas or do they represent an entirely new application of the NBS approach? – and their transferability potential – have they been diffused or replicated elsewhere?

Firstly, NBS innovation can be of a social nature, a technical nature, or both, in which case a system innovation takes place. Social innovations encompass significant changes in policies and regulation, governance structures, economic frameworks or cultural paradigms. Technological innovations are new or significantly altered products, production processes or technological infrastructures. If NBS include innovation along both social and technical dimensions and the relations between them, they represent a socio-technical system innovation.

A second aspect to hold to light in determining the relevance of socio-spatial conditions for innovation trajectories is the degree of novelty of these innovations; whether they are copied from other NBS without substantial adaptation, with substantial adaptation, or are entirely new, i.e. with no visible linkage to previous initiatives. The former two can be characterised as incremental innovations, deriving from earlier approaches to NBS, while the latter can be perceived of as a more radical form of innovation.

Thirdly, the transferability of innovations, i.e. whether they have been diffused or replicated elsewhere, determines their potential for upscaling. This represents upscaling in terms of means – the replication, spread or adaptation of techniques, ideas, approaches and concepts – which generally leads to an increase in the ends to which upscaling happens: more impact on socio-economic conditions. The essence of upscaling is thus the growth in scale and scope of socio-economic impact of an intervention (The World Bank, 2003; Van Doren et al., 2016), which can lead to the transformation of regimes (Smith, 2007).

To summarize, three aspects of NBS innovations are of particular relevance to their development:

- the nature of the innovation, i.e. social, technical or system innovation
- the novelty of the innovation, i.e. incremental or radical innovation
- the potential for upscaling, i.e. the occurrence of replication

2.1. The socio-spatial embeddedness of transitions

A central characteristic of niches is that they provide a protective 'space' in which innovations are nurtured and empowered, while being shielded from the competitive selection environments embodied in incumbent socio-technical regimes (Smith & Raven, 2012). Strategic Niche Management, a field of transitions studies concerned with the development and governance of niche creation, identifies three complementary internal processes that are key to niche development: formulating expectations, learning, and network building. The articulation of expectations legitimizes the investment of time and resources in novel approaches or technologies and attracts attention, resources and new actors to the niche. To overcome barriers related to the uncertainty and different perceptions around the introduction of innovations, learning about needs, problems and possibilities of the niche are crucial to its successful development (Kemp et al., 1998). Learning processes are most effective when they include both first-order learning, aimed at gathering facts and data, and second-order learning, where underlying assumptions, values and frames of reference are reflected upon (Naber et al., 2017; Schot & Geels, 2008). The involvement of niche actors in diverse networks supports niche development and upscaling.

Such processes are embedded in local institutional systems and socio-spatial relations (Raven et al., 2012; Smith, 2007). Drawing on geography of sustainability transitions literatures, different socio-spatial conditions can be identified that affect transitions processes. Particularly influential localized conditions for niche development are:

- local and regional visions, policies and plans, in which expectations for niche development are presented
- heterogeneous and multi-scalar governance and stakeholder networks, that drive knowledge exchange, resource pooling and learning processes

- local learning processes
- financial resources and funding structures that are oriented to protecting the niche from market pressures
- informal, localized institutions which, among others, drive collaborative cultures, give direction to legislations and political culture or shape consumer demands
- industrial specialisation, which can be orientated towards or away from sustainable innovation, and is spurred on by agglomeration dynamics like market demand, a specialized labour pool and supporting infrastructures and knowledge institutes
- local natural endowments and resources, particularly relevant when innovations are nature-based, i.e. part of and dependent on local climate and natural environment

Alongside local and regional conditions, conditions at lower or higher scales also play their part in urban transitions, such as human agency or global economic systems. Such conditions are however outside the scope of this paper, as we aim to uncover spatial variety in niche development linked to local, urban conditions.

Local and regional visions and plans are used to articulate expectations and guide learning processes. Such learning processes can be captured in evaluation and monitoring. Niche development benefits from visions that are shared by many actors, supported by tangible evidence from niche experiments, specific in regard to technological, social and economic aspects, and coupled to societal challenges that existing approaches tend not to solve (Kemp et al., 1998).

The articulation of expectations in urban and regional visions and plans is regarded as essential for mobilizing the diversity of local actor groups necessary for the adoption of sustainable alternatives to current urban development practices. The governance of sustainable initiatives requires a collaborative effort to bridge policy areas and stakeholder objectives as well as combine ecological enhancement and economic growth (Hansen & Coenen, 2015), which indicates the importance of **local and regional governance and stakeholder networks**.

Social networks facilitate interaction between stakeholders, the provision of resources, learning processes and the building of support for the innovation (Boschma, 2005; Schot & Geels, 2008). The breadth and depth of networks is important: the more actor types (e.g. private sector, citizens, policy makers, academics) are involved and the better they are able to mobilize commitments and resources within the network, the more supported the niche development is (Naber et al., 2017). Networks are not necessarily (or rather, rarely) purely localized. Network formation is driven by several forms of proximity, of which geographical proximity (e.g. co-location of firms within a city or region) is only one of five (Boschma, 2005). This implies that networks are not confined to or dependent on specific locations, rather, they tend to stretch across different

locations, providing bridges between them. The extent to which niche actors are involved in such networks shapes the chances of niche upscaling. A density and diversity of social networks tends to be associated to urban areas.

To overcome barriers related to the uncertainty and different perceptions around the introduction of innovations, **learning processes** about needs, problems and possibilities of the niche are crucial to its successful development (Kemp et al., 1998). In urban sustainability innovations, performing experiments in a real-life urban setting is a main method to acquire knowledge and experience. Learning processes benefit from the existence of social networks, which can provide a platform for knowledge co-creation and exchange. Especially when it comes to second order learning, a wider social context of communities, organisations and institutions can be of influence. Local learning processes can be captured in evaluation and monitoring activities.

The uncertainties that go with bringing innovative innovations to market shape economic decision-making. The creation of protective 'spaces' for innovation is enhanced by regulatory measures or financial assistance aimed at providing a buffer against market pressures (Kemp et al., 1998). Besides regulatory measures, protection comes in the form of **financial resources and (alternative) funding structures**. The availability of financial resources for sustainable initiatives is strongly dependent on local governance structures and municipal revenues (Droste et al., 2017).

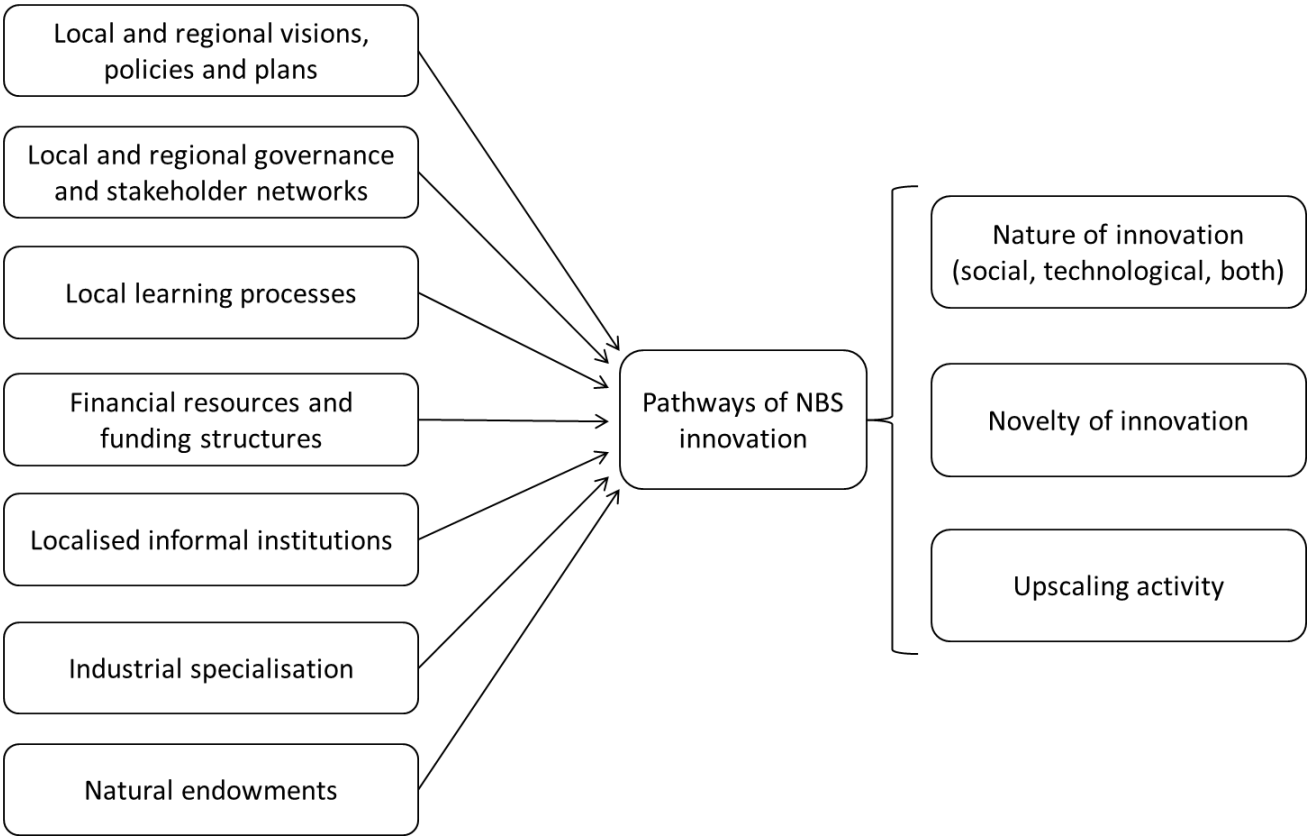
An institutional perspective on innovation highlights the important role of **informal localised institutions**, defined here as "*territorially bound norms, values and practices*" (Hansen & Coenen, 2015, p. 97), as a source of geographical differences between the development of niches. Localized institutions affect the development of innovative sustainable interventions in a number of ways, for instance through shaping norms and values around consumption or collaborative cultures and the extent to which cooperative networks around environmental objectives are formed. Brought about by activism, information provision or disturbing events, discourses on sustainability such as 'green city' or 'eco-city' influence norms for actions and future visions, and thereby can create momentum for the uptake of sustainable alternatives to urban development (Rohracher & Späth, 2014; Young, 2011).

However, in any territory a heterogeneity of norms and institutional cultures can exist; although institutions are localised, they are not necessarily pervasive across any particular space. A clash between different institutional norms can hinder the uptake of innovations (Hansen & Coenen, 2015). Moreover, as the transferability and diffusion of an initiative also depends strongly on its ability to adapt to or fit in with mainstream practices elsewhere, a too strong dependence on localised institutions may counteract the further upscaling of innovations (Smith, 2007).

Evolutionary economics and relational perspectives on the role of space and place in innovation highlight the economies of agglomeration offered by urban environments as mediating factors in the successful development of niches, such as **industrial specialisation**; the geographical concentration of related firms is beneficial to the innovation dynamics necessary for sustainability transitions (Hansen & Coenen, 2015). Specialized clusters benefit from agglomeration economies, such as a skilled labour pool, shared infrastructure and a dense network of supporting institutions and intermediaries and opportunities for knowledge exchange between science and industry (Hendricks & Calkins, 2006). In addition, the presence of consumers and local market formation play a role in the formation and development of innovative sustainable practices. For instance, the proximity of engaged end-users drives the further development of innovative niches by enabling fast feedback loops (Hansen & Coenen, 2015).

The importance of **local natural endowments** is highlighted in several studies, yet not often explicitly theorized (Hansen & Coenen, 2015). Several mediating factors are at play here, such as the accessibility of natural resources or symbolic or social attachment to them (e.g. in the case of placing wind turbines). Resource scarcity of traditional resources (e.g. fossil fuels) can factor in as an enabler for investing in sustainable alternatives. In addition, environmental events or pressures such as natural disasters, sea-level rise or decreasing air quality can spur on alternative approaches to urban development (Munoz-Erickson et al., 2016).

Figure 1. Analytical framework: local urban conditions influencing pathways of NBS innovations



3. Methodology

The research aims to uncover spatial variety in niche development linked to local, urban conditions based on an iterative process that was empirically and theoretically informed. This section outlines the contents of the database and the process of analysis.

3.1. The NBS database

This paper builds upon efforts to construct an extensive database on European NBS initiatives in the context of the NATURVATION project (https://naturvation.eu). The database was constructed between June-August 2017 and holds data on 976 NBS initiatives from 100 cities across Europe (NATURVATION project, 2017). Cities were selected to represent various urban conditions regarding economic development, green space, and climate vulnerability. Up to 10 projects per city were collected based on diversity across ecological domains, sustainability challenges, or governance arrangements (Almassy et al., 2017). Information in the database was based on desk research of verifiable data and was complemented by interviews in case data was insufficiently available.

Most of the initiatives in the database were ongoing at the time of data collection (368 initiatives; 50 unknowns). Parks and (semi)natural urban green areas formed the largest segment of NBS initiatives, representing 53% of all social innovations, 42% of technological innovations, and 60% of system innovations. Urban green space connected to grey infrastructure were the next biggest segment, including 38% of social innovations, 34% of technological innovations and 46% of system innovations. Water bodies were included in 30% of all NBS, and 23% of all social innovations, 35% of all technological innovations and 33% of all system innovations.

In terms of ecosystem services provided, almost all projects provide cultural services (87%), with a focus on recreation and aesthetic appreciation. Regulating services were more common in technological (80%) and system innovations (70%) than social ones (55%). Habitat services were common across all types of innovation (65%), albeit somewhat more common in system innovations (68%). Provisioning services were least common (31%), mostly as a result of their relative absence from technological innovations (21% in technological versus 40 resp. 37% in social and system innovations).

Information of 57 variables was collected in the database. The variables related to innovation were selected based on insights from the emerging field of 'geography of transitions' and were expected to have a relevance for innovating with nature in cities. Information included e.g. starting date, completion, state of implementation, goals and NBS challenges addressed, ecological domains, services provided, governance, drivers, financing, innovativeness, monitoring, and replicability.

3.2. Proxies for localized conditions for NBS innovation

An iterative process between theory and empirical data resulted in the identification of variables in the database that could function as proxies for variables that were considered relevant based on theoretical insights from the geography of sustainability transitions.

Table 1: Database variables that serve as proxies for the localized conditions identified in theory

Conditions	**Variables**[1]
Local and regional visions and plans	Intervention is mandatory, as a result of…
	Intervention is voluntary, as a result of…
	Mandatory intervention
	Mandatory/voluntary
	NBS intervention implemented in response to a local regulation/strategy/plan
	NBS intervention implemented in response to a national regulations/strategy/plan
	NBS intervention implemented in response to an EU Directive/Strategy
	Presence of GI/NBS research project mentioned in connection to the project
	Presence of specific city-level GI/NBS section/part in a more general plan mentioned in connection to the project
	Presence of specific city-level GI/NBS vision/strategy/plan mentioned in connection to the project
	Voluntary intervention
Governance and stakeholder networks	Citizens involvement in assessment/evaluation of the NBS intervention
	Initiating organization of the NBS
	Mode(s) of citizen involvement in evaluation/assessment of the NBS intervention
	Non-government actors involved if the initiative is led by co/hybrid governance or by non-government actors
	Participatory methods/forms of community involvement used
	Power distribution within the initiative
	Presence of city network or regional partnerships focused on NBS mentioned in connection to the project
	Primary beneficiaries identified by the project
	Spatial scale

[1] In this representation, the database variables are thematically grouped to make the table more manageable. A more detailed overview of variables and proxies can be found in the Appendices A – C.

	Type of stakeholders involved
Local learning processes	Availability of a web-based monitoring tool
	Citizens involvement in the analysis of the assessment/evaluation
	Follow-up to the evaluation/assessment
	Presence of monitoring/evaluation reports
	Presence of formal monitoring system
	Presence of indicators used in reporting
	Use of GIS in mapping impacts
Financial resources and funding structures	Non-financial contribution
	Source of funding
	Subsidies/investment for GI/NBS in the city mentioned in connection to the project
	Total costs
	Type of financing instruments used for the NBS intervention
	Type of non-financial contribution

3.3. Database analysis

The database analysis comprised two elements. Subsection 3.3.1 outlines our approach to identify variables that are linked to novelty level and replicability of NBS initiatives. Subsection 3.3.2 describes the analysis of the cities with the highest levels of novelty and replicability in NBS innovation.

Novelty and replicability analysis

The approach to analysing novelty and replicability of NBS innovation followed a similar structure. First, characteristics were identified that are important for all types of innovation. Second, differences between NBS innovations based on level of novelty and replicability were identified.

To do so, NBS initiatives were distinguished as technological innovations (product, process or infrastructural), social innovations (policy, economic, governance or cultural) or system innovations (social and technological innovation combined); and grouped based on novelty and replicability. Projects were compared based on their scores on other variables in the database and categorized according to the proxies of the categories Table 1). First, to mark variables that were important for all types of innovations, variables that were present in over 50% of the occasions were identified (Appendix A). Subsequently, the novelty and replicability analyses were conducted.

The novelty analysis is based on the distinction between new initiatives and initiatives copied or derived from previous initiatives with or without substantial adaptation. The former were classified as radical

innovations and the latter as incremental. Whether or not the radical and incremental initiatives differed significantly was determined with a (two-tailed) difference of proportion test. Differences with a z-level larger than [-]1.96 were considered significant, corresponding to a position outside the 95% confidence interval. This allowed for the identification of key variables for radical and incremental innovation.

This analysis was repeated for the replicability of NBS projects. Social, technological and system innovations were grouped based on the distinction between initiatives transferred to later initiatives with or without substantial adaptation, and those not transferred to other initiatives. This allowed for the identification of proxies with relevance for learning and scaling of innovation and hence for the potential development of the NBS niche.

City analysis for clusters of novelty and replicability

As a further step in the analysis, the key localized conditions for the emergence of radical innovation were identified. Cities with three or more radical NBS innovations were marked as 'innovative cities'. NBS projects in these cities were compared with projects in other cities, to assess whether a noticeable effect of city innovativeness exists. The basic methodology is similar to the aforementioned novelty and replicability analyses. The analysis is conducted in three steps: first, radical and incremental innovations within 'innovative cities' are compared. Second, radical NBS innovations in innovative cities were compared with radical innovations of the other cities in the database. Third, incremental NBS innovations in these cities were compared with incremental NBS innovations in the other cities. These analyses served to assess whether there are indications for an 'innovative-city' environment.

4. Results

Section 4.1 outlines the findings from the novelty analysis. Section 4.2 focuses on niche development by identifying the significant variables correlating with the replication of NBS innovation. Section 4.3 describes the innovation characteristics of cities.

4.1. Radical and incremental innovation

Out of 976 NBS projects in the database, 520 projects included characteristics regarding the type of innovation and status of novelty (i.e. radical or incremental)[2] (see Table 1). This section provides an analysis of novelty characteristics based on the NBS database. The underlying data is appended (Appendix B).

Table 2: Database contents based on innovation type and novelty

Type of innovation	**Radical**	**Incremental**	**Total**

[2] For the remaining 456 initiatives there was at least one omission of such data. These innovations were excluded from this part of the analysis.

Social	32 (17,7%)	149 (82,3%)	181
Technological	81 (37,9%)	133 (62,1%)	214
System	44 (35,2%).	81 (64,8%)	125
Total	157	363	520

Subsequently, the database is analysed in relation to the theoretical framework outlined in Section 2. For each condition, the results are first described based on presence (quantity), and then on significant differences between incremental and radical innovations. The former provides insights on crucial variables for NBS innovation in general, while the latter provides specific insights on important variables of radical innovations vis-à-vis incremental innovations.

Local and regional visions, policy, and plans

NBS innovation tends to be linked to local and regional vision, policy and plans. Indicators for this variable are present in well over 50% of all project types (only for radical social and radical technological innovations, the values are slightly lower [respectively 41% and 49%])(L268)[3]. System innovations are often embedded in a more general plan (L288). With little variation across innovation types, NBS were more frequently voluntary (60%) than mandatory (36%) (L271; L272).

However, this linkage with local and regional policy does not hold for all types of innovation. Radical social innovation less frequently occur as an explicit response to local and regional policy (L268; L285). In contrast, radical system innovation occurs less often when local visions and plans are absent (L269).

There is also a relatively large number of projects that have unclear (unknown) connections to regional and local policies (L264; L267; L287; L296). For these variables there is no positive correlation to novelty status of NBS innovations.

Taken together, this indicates that all types of NBS innovations are generally connected to local and regional policies and visions – yet often implemented on a voluntary basis. However, using local policies to set the direction may hamper radical social innovation.

Governance and stakeholder networks

Governance arrangements varied strongly between projects. In 77% of NBS innovations, municipalities had some form of involvement (L239). The local government is also often the initiating actor, except for radical social and system innovations (L224). The private sector was involved in 60% of technological and system innovations, versus 31% of social innovations (L243). Citizen or community groups were involved in 76% of system and social innovations, and 48% of technological innovations (L2047). Co-planning (i.e. the direct

[3] The L value refers to the Valnr. column in the appendices. This number forms a reference to a specific value.

involvement of and cooperation between different stakeholder groups in the planning/development process of the intervention) was much more common in social (51%) and system innovations (42%) than in technological ones (16%) (L250). City networks or regional partnerships are particularly often present in social innovation and system innovation (L291).

In almost all projects (91%), citizens or community groups were primary beneficiaries (L205). The local government or municipality are also frequently mentioned as main beneficiary for all types of innovations (L200).

When comparing differences in radical and incremental innovations, radical social innovations are often initiated by the EU or the national government (L221; L222). Governance of this particular type of innovation is mostly done by non-government actors (L211). Co-governance between government and non-government actors negatively correlates to radical social innovations (L210). Radical technological innovations appear to benefit from co-governance by government and non-government actors (L210), e.g. the community (L216) or a public sector body (such as a school or a hospital) (L212). Participatory methods through co-planning with the community, a task force, and joint management also tend to be included more often in radical technological innovation (L250; L252; L256). Radical system innovations are frequently co-governed by research institutes (L215).

In summary, NBS initiatives are characterised by the involvement of a variety of stakeholders, yet they are aimed almost universally at benefitting citizens. Findings may also indicate that while radical social innovations are stimulated by the EU and national governments, it may not be beneficial for those more novel innovations to be guided by these bodies. Radical technological innovations do tend to include co-governance models and participatory methods.

Local learning processes

Citizens tend to be involved in the evaluation and assessment of incremental social and system innovation (L291; L386). The involvement of citizens in monitoring is relatively scarce for radical system innovation (L395; L391). However, relatively often, data availability was limited (L373; L376; L379; L392; L385; L397; L400).

When comparing differences between radical and incremental innovation, radical social innovation is less likely to be monitored (L371) and to have indicators for its reporting (L374). Radical technological innovation is negatively correlated to the involvement of citizens in the assessment or evaluation (L386). This also holds for system innovation, and then particularly when citizens are involved in the analysis of the evaluation (L395).

There are only significant negative correlations present in the database. A lack of positive correlations with monitoring indicates that monitoring, as a way of formalizing learning processes, does not seem to stimulate radical innovations.

Financial resources and funding structures

Half of all projects (53%) received financial support in connection to the project – most commonly out of the local authority's budget – in the form of earmarked public budget or subsidies. Social and technological innovation are less frequently funded by local governments, but still around 50% of such innovations are financially supported by local government budgets (L297; L311). Compared to technological and system innovation, social innovations (both radical and incremental) also frequently receive non-financial contributions, such as services or labour (L329; L334). For technological innovation, it is relatively often unknown whether non-financial contributions have been received (L331).

Comparing radical and incremental innovations reveals that radical social innovations generally receive less funding, and may have difficulties attracting funding. Radical social innovations correlate with the absence of city level subsidies (L298), as well as with the lowest category of funding (L300). Due to the database structure, this category includes all initiatives up to 50.000 Euro. Arguably, this is still a large amount of money for such initiatives. However, as radical social innovation also tends to be linked to a funding structure of loans (L320), this supports the premise that there may be difficulty in finding funding. At the same time, radical social innovation correlates positively to economic development and decent employment (L361) and may contribute to increased wellbeing and welfare.

For radical technological innovations holds that these are positively linked to equity funding (L321) and also to the provision of goods (L333). Radical system innovation is less likely to be supported by crowd-sourcing as a means for funding (L315). This indicates that this may not be the best funding structure for novel and complex innovations.

In brief, local authorities are primary funders of NBS innovation. Social innovations are more likely to receive non-financial support. However, findings suggest that more radical forms of social NBS innovations also experience difficulty in attaining funding, and are generally less costly, even though they tend to benefit economic development.

4.2. Replication of innovation

Out of 976 NBS projects, 327 initiatives included an innovation type and a replicability status. This implied that 649 initiatives were excluded from this part of the analysis based on unknown data. This is a larger proportion than in the analysis of innovation characteristics. This also implied that for the replication analysis, a different set of projects was analysed compared to the novelty analysis.

However, the composition of initiatives included in this replicability analysis largely corresponds to the selection used for the innovation analysis, with a few exceptions. There are remarkably fewer projects with private sector involvement (23% of technological and 16% of system innovations). Technological innovations in the replication analysis had more citizen involvement (63%, approaching the average of 69%). While social innovations reported in this analysis received non-financial contributions more often (62% versus 44%), the system innovations group contained fewer projects with non-financial contributions (45% versus 60%).

Table 3: Database contents based on innovation type and novelty

Type of innovation	*Replicated*	*Not replicated*	*Total*
Social	63	60	123
Technological	52	90	142
System	34	28	62
Total	149	178	327

This section provides an analysis of replication characteristics based on the NBS database. Appendix C provides the underlying data.

Local and regional visions, policy, and plans

There is a relatively high number of unknowns in this section of the database (L264; L267; L287; L290; L293). It is likely that in a number of these cases, no connection to policy exists, as it is more easy to confirm the existence of a connection than it is to confirm its absence. In none of the cases do these unknowns result in a significant relation to replicability.

Replicability of social innovations appears to benefit from the absence of local policy related to NBS implementation. This is visible both in a negative correlation between social innovation and local policy and a positive correlation with the absence of such policy (L268; L269). However, when the social innovation is linked to a more general plan, there is a positive correlation with replicability (L288). Social innovations are also more likely to emerge in response to mandatory or voluntary regulation (L291; L276; L282). Voluntary implementation in the absence of regulation strongly relates to the absence of replicability (L284).

For technological innovation, there are few significant scores related to replicability. Exceptions are formed by a positive relation when the NBS is connected to a research project (L294) and as a response to voluntary environmental standards (L282).

Concerning system innovation, it appears that some local guidance and embedding in wider plans are beneficial to replicability. The implementation of system innovation that does not occur as a response to

national policy positively relates to replicability (L266). However, some guidance appears beneficial as the absence of more general city level plans negatively relates to system innovation (L289).

Taken together, the difference analysis indicates that the replicability of particularly social and system innovations appear to benefit from general local policies and visions, but are hampered by too narrowly formulated policy. These insights hint towards the identification of two strategies for enhancing the replicability of particularly social innovation. On the one hand, it could emerge in response to regulations. The other strategy is to allow space for social innovation to emerge. This could occur through voluntary regulations, or by designing more general policy plans.

Governance and stakeholder networks

The local community is the main beneficiary of all types of NBS innovation (L205). Local governments are also a primary beneficiary for replicated system innovation (L200) and are often involved in replicated social innovation (56%), non-replicated technological innovation (62%), and equally for replicated and non-replicated system innovation (50%) (L224).

When zooming in on differences between replicated and non-replicated innovations, the replicability of social innovations tends to be higher when the innovation is implemented at the district or the neighbourhood scale (L197). Moreover, when the main beneficiaries are the municipality, NGOs, or civil society actors, replicability occurs more often (L200; L202). However, the involvement of the municipality as a main actor negatively relates to the replicability of social innovation (L239), as does initiation by a public sector institution (e.g. school or a hospital) (L217). Co-governance by government and non-government actors also reduces the replicability of social innovation (L217). Replicability of social innovation occurs more often when the community is involved by way of education or dissemination of information (L253). The use of a task force for community engagement has a similar correlation (L252).

The replicability of technological innovation is positively related to community involvement (L255) and joint implementation (L255).

The replicability of system innovation is positively related to having the municipality as its main beneficiary (L200). The involvement of NGOs has a similar relation (L241). Also, the existence of regional partnerships links up with the replicability of system innovation (L291). In addition, when participatory methods of community involvement are unknown, this negatively relates to the replicability of social and system innovation (L293).

It must also be taken into account that it is likely that not all innovations were developed with the intention to be scaled up. Some innovations are designed to solve a local issue without the ambition to solve similar

issues elsewhere. This could be an explanation for the negative correlation between replicability of social innovation and initiation by a school or hospital (L217).

Most of the significant scores appear in relation to the replicability of social innovation. This hints towards a call for the conscious incorporation of social innovation, and innovation in general, to stimulate learning and assess the potential for continuation.

It appears that the strong embedding in the local community on the scale of a district or a neighbourhood positively impacts replicability (L197), except when it is narrowly confined to a specific institution such the implementation of an NBS in a school or a hospital (L217). Replicability also relates to participatory forms of community engagement (L255;L252).

Generally, the involvement of the community in participatory methods tends to positively impact replicability. The positive correlation between the involvement of NGO's and local community and the replicability of more complex innovation (system innovation) is a strong call for including these groups (L241; L226).

Local learning processes

The data on local learning processes was often 'unknown' (L373; L376; L379; L382; L385; L397; L400). When focusing on the remaining data in the comparative analysis, a clear pattern emerges: monitoring, in different forms (e.g., citizen engagement, use of web-based tools, use of geographic information systems (GIS)), coincides with the replicability of different types of innovation (L380,383,384,392,398,386). This appears to be the case more frequently for system and technological innovations than for social innovation. NBS initiatives that have been marked as 'unknown' often show the exact opposite with regard to technological and system innovation (L385,388). This pattern could indicate that monitoring is more ingrained in the process of system and technological innovations and may be a necessary step for the replication elsewhere. This calls for a more explicit inclusion of such local learning processes to promote the replicability of innovations.

On a more detailed level concerning monitoring approaches, the use of web-based tools for monitoring seem to correlate with technological innovation (L380). Replicability of system innovation positively relates to citizen involvement in the follow up to an assessment or an evaluation (L398). However, in absolute numbers, monitoring by way of involving citizens is scarce. This could be a cautious call to increase such monitoring and to include attention for social innovations.

Financial resources and funding structures

NBS initiatives tend to receive city level funding for at least part of the initiative (L297; L311)[4]. This is often through direct funding or subsidies (L319).

When focusing on the difference between replicated and not replicated innovation, replication of social innovation occurs more often when funded through crowd-sourcing or through regional budgets (L310; L315).

Technological innovation is less often replicated when funded by the local authority (L311) or through crowd-funding (L251).

Replicated system innovation often receives non-financial contributions and investments by NGOs (L313; L329; L334). Such initiatives also frequently receive direct funding and funding through national budgets. There is a negative correlation with funding by the local authority (L311).

In summary, it seems that hybrid funding structures, including non-financial contributions, positively relate to the replicability of initiatives. Local funding is often present, but does not appear to be a stimuli for replication per se. This may indicate that there is little attention to continuity of innovation on the local level, or that the innovations on a local level address specific local contextual issues and have little potential for, or interest in, upscaling.

4.3. Innovative-city environments

This last part of the analysis zooms in on projects in innovative cities. Cities with three or more radical innovations were considered 'innovative' cities. The radical projects in these innovative cities were compared with radical projects of the remaining (less-innovative) cities, and this was repeated for incremental innovations. Table 4 outlines the quantities and the structure of the analysis. This section will first depict the 'most innovative' cities from the NBS database, followed by the comparative city analyses. These analyses served to assess whether there are indications for an 'innovative-city' environment.

Table 4: structure of comparative city analysis

Novelty	**Top 22 cities**	**Remaining 78 cities**	**Total**
Radical	87	70	157
Incremental	70	293	363
Total	157	363	

[4] Only for technological replicated innovations this is less than 50% (= 35%) (L297). However, precisely for this type of innovation, it is frequently unknown whether there is municipal funding (L299).

Table 4: Overview of the most innovative cities in the NBS database including characteristics[5]

City	Innov. Projecs	Human resources in science and technology (HRST) by NUTS 2 regions (2015)	Area (km2) 2015	Population density (per km2) (2015)	Aggregate potential impact to climate change (2010)	University present
Antwerpen	7	49,6	1000	1079,5	0,58	Yes
The Hague	6	50,2	286	3353,5	0,63	Yes
Utrecht	6	57,8	1449	917,9	0,54	Yes
Iaşi	6	15,1	n.a	n.a	0,37	Yes
Greater Manchester	5	50,8	n.a	n.a	0,10	Yes
Craiova	5	22,9	7414	89,4	0,58	Yes
Porto	4	28,5	n.a	n.a	-0,05	Yes
Wirral	4	47,3	256	2048	0,09	Yes
Wuppertal	4	44,9	n.a	n.a	0,29	Yes
Hannover	4	45,6	2291	496	0,05	Yes
Palermo	3	27,7	5009	254,3	0,35	Yes
Bari	3	26,4	3863	327,5	0,32	Yes
Genova	3	36	1834	467,9	n.a	Yes
Málaga	3	33,8	7309	225,5	0,21	Yes
Bilbao	3	54,5	n.a	n.a	0,04	Yes
Liverpool	3	47,3	134	4249,7	0,15	Yes
Coventry	3	45,6	99	3464,6	0,01	Yes
Greater Nottingham	3	49,7	75	4228,8	0,01	Yes
Liège	3	45,7	797	791,4	0,16	Yes
Amsterdam	3	54	n.a	n.a	0,79	Yes
Hamburg	3	55	755	2351,1	0,14	Yes
Kraków	3	n.a	327	2348,2	0,10	Yes

To provide some context on the most innovative cities in the NBS database, Table 5 comprises basic information on these cities. The NBS database information is supplemented with information from the Eurostat database and the ESPON database. It appears that all of these innovative cities are university cities and have a relatively high population density (compared to the less-innovative cities). The further analysis is based on the information derived from the NATURVATION database. The key results from the comparative

analysis are schematically outlined in Appendix D. When these analyses are taken together, the following insights are derived.

First, when focusing on differences between radical and incremental innovation in innovative cities, it appears that incremental social innovations more frequently receive financial support, either from the municipality of from private foundations. Municipal involvement is also higher in these projects. Public sector and research/university are more frequently involved in radical social innovation.

Second, from the comparison between radical innovations in both groups of cities (most innovative and less-innovative cities) follow apparent differences in funding structures as well as connection to policy. Radical innovations in innovative cities were more likely to be voluntary interventions, both in terms of planning guidance and environmental standards. The presence of a city-level vision/strategy/plan (both specific and general) occurred more frequently in relation to projects in less-innovative cities. Projects in innovative cities were more likely to receive contributions in the form of donations, goods, and services and labour. This implies that voluntariness and development independent from existing local plans facilitate a favourable innovative habitat in innovative cities. In less innovative cities, the habitat may be such that development in the absence of policy is not sufficiently supported. There, radical innovations may need to become connected to existing plans in order to receive sufficient legitimacy to develop.

A third phase of analysis focuses specifically on incremental innovations and compares those between innovative and less innovative cities. Although this analysis focuses on *incremental* innovations in comparison between cities with *radical* innovations, this analysis shows the strongest distinctions[6]. Incremental social and system innovations receive 40% percent more financial support in innovative cities than in cities with fewer radical innovations. National government, local governments, and private foundations were more likely to be involved in incremental social projects in 'innovative' cities than in those projects in other cities. Projects in these cities also reported more subsidies, and from diverse sources (EU, local governments, private foundations, NGO's).

5. Discussion

This paper provides insights into the conditions that form important elements for novelty of innovation, replicability, and the occurrence of innovative-city environments. Before reaching a discussion and a conclusion we will first reflect on our methodological approach. First of all, we aimed to gain insights in common denominators of innovation characteristics in the early stages of a transition, i.e. in niche development. While this research certainly set the stage for these insights, and included a large dataset, its

[6] The differences of all observations can be found in Appendix D.

limitation is that it solely focuses on NBS innovations. Further research on other early-stage transitions can elaborate on these insights.

Second, considering the database, the unknown data makes some of the insights somewhat exploratory. Detailed qualitative studies and quantitative research that is based on specifically the insights from this study are needed to verify the insights from this database analysis. Combined quantitative and qualitative research can provide insights in connections and causalities beyond the presence and correlation this research focused on. For replicability, data may particularly be limited as many initiatives are still ongoing and have a change of future replicability. Additionally, it is likely that replication is not always registered; the property of replicability can be argued to be primarily a characteristic of the follow-up initiative rather than of the initial project. However, the advantage of using this database is that it allows for comparing replicated and not-replicated initiatives without a preselection on replication, which makes the data more neutral.

The innovative-city environment analysis provides some additional information by complementing the NATURVATION database with additional external databases. Additional and systemic coupling can create additional insights in key variables impacting the developments in the early stages of transitions. Such coupling with additional databases could also offer solutions to address the fact that the NBS database did not include variables that could serve as proxies for some of the localized conditions that emerged from geography of transitions literature, such as informal localized institutions, or natural endowments.

Regarding the more general patterns that emerge from the analysis, we reflect in particular on the 'local connection' that many NBS initiatives seem to share, and the relative weight of policies and governance structures in this respect. In addition, radical social innovation seems to be an outlier in respect to its behaviour under various localized conditions. Lastly, the relatively strong influence of local governance and policy is reflected upon in relation to a city's innovativeness.

[to be completed]

- Several conditions strengthen the link between NBS innovations and their urban environments
- The influences of policies and plans are relatively strong, but can have adverse effects
- Radical social innovation does not 'behave' like other types of innovations: how to nurture it
- Effects of city-innovativeness

6. Conclusion

[answers the question: how and why do urban transition dynamics differ across cities? What are the patterns in which space and place affect urban sustainability transitions]

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