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Understanding transformation patterns in different socio-technical systems – A scheme of analysis

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Johan Miörner [123*], Christian Binz [12], Lea Fuenfschilling [2]

[1] Eawag: Swiss Federal Institute of Aquatic Science and Technology
[2] CIRCLE, Lund University
[3] Department of Human Geography, Lund University

*Corresponding author. E-mail: johan.miorner@eawag.ch

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Understanding transformation patterns in different socio-technical systems – A scheme of analysis

Johan Miörner *[abc], Christian Binz [ab], Lea Fuenfschilling [b]

[a] Eawag: Swiss Federal Institute of Aquatic Science and Technology
[b] CIRCLE, Lund University
[c] Department of Human Geography, Lund University

* Corresponding author. E-mail: johan.miorner@eawag.ch

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Abstract: Transitions literature shows important gaps when it comes to specifying how, and why, transformation processes play out differently in different sectoral contexts. This paper develops a heuristic for analysing a socio-technical system's inherent transformative potential and for comparing transition trajectories in different socio-technical systems with each other. The framework draws on insights from transition studies and organizational institutionalism to specify three features of a socio-technical system which shape its inherent transformative potential and most likely transition trajectories: the degree of institutionalization of socio-technical configurations, their coherence, as well as spatial characteristics of the system as a whole. The contribution of the paper is threefold: 1) it develops a systematic understanding of the basic characteristics of a sector's socio-technical system and how they influence the likelihood, nature, and speed of transition processes; 2) it provides insights to whether and how lessons derived from one sector can be used for understanding transitions in others; 3) it guides the identification of places and spatial scales at which transitions unfold and where leverage points for transformative change lie in different sectors. The framework is illustrated with empirical examples from existing literature on the water- and urban mobility sectors.

Keywords: socio-technical systems; sector transformation; transition potentials; systemness; water; urban mobility

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1 Introduction

Addressing today's most pressing environmental and societal challenges requires deep, transformative changes in sectors as diverse as energy, water, urban planning or healthcare. Yet, achieving transformation in those sectors has proven challenging due to persistent path dependencies that hinder structural change. Among the many perspectives applied to this problem, transition studies provides some of the most sophisticated conceptual frameworks for analysing how, when, where and under which conditions structural change comes about. However, this approach has also attracted some criticism, especially when it comes to analysing and comparing transition patterns across sectors and explaining whether and how path dependencies and transformation patterns systematically differ between them.

Transitions literature understands sector transformation as structural changes in socio-technical systems (STS). STS are configurations of actors, institutions and technologies that fulfil certain societal functions, such as energy provision, water supply, or transport. When studying transitions, scholars often draw system boundaries at the sectoral level, with a sector comprising one or several industries, as e.g. in the 'energy', 'mobility' or 'water' sectors. Theoretical frameworks in the field have characterized transitions as resulting from the interplay of activities at three levels: technological niches, socio-technical regimes, and landscapes (Geels and Schot, 2007). Many studies have focused on characterizing the relationship between these levels or have delved into the specifics of niche dynamics, regime adaptation or landscape pressures, highlighting the role of specific actors, institutions, and practices in structural change processes.

However, the current literature shows important gaps when it comes to analysing a socio-technical system's inherent transformative potential or comparing transition trajectories in different socio-technical systems with each other (Andersen et al., 2020; Alkemade, 2019). Three main knowledge gaps stand out. First, we lack a systematic understanding of the basic characteristics of a sector's socio-technical system and how they influence the likelihood, nature, and speed of transition processes. Second, we lack a comprehensive discussion on whether and how lessons derived from one sector can be used for understanding transitions in others. Finally, and closely related to the former two, we lack a theoretical framework for identifying the places and spatial scales at which transitions unfold and where leverage points for transformative change lie in different sectors.

The implicit assumption of most research based on the Multi-Level Perspective (MLP) (Geels, 2002) is that 'generic' transition trajectories can be identified, which are valid beyond the specificities of sectoral systems (Geels et al., 2016; Geels and Schot, 2007). Yet, recent contributions make compelling arguments that their transformative potential is not uniform and that transition patterns differ systematically between the socio-technical systems in i.e. the energy, water, agro-food or urban mobility sectors (Andersen et al., 2020; Binz and Truffer, 2017; Van Welie et al., 2018; Huenteler et al., 2016; Klerkx et al., 2012; Elzen et al., 2012). In fact, the gradual regime substitution process that is often portrayed for transitions in the energy sector appears to be a rather special case, which does not hold in all countries, sectors, or non-Western contexts (Geels et al., 2016; Van Welie et al., 2018; Runhaar et al., 2020). We thus deem it a crucial contribution to transitions literature to specify more deeply how, and why, transformation processes play out differently in different sectoral contexts.

In this paper, we address this gap in the literature by providing a heuristic for analysing the building blocks of socio-technical systems (actors networks, institutions and technologies) and by describing how their configuration and co-evolution affects the core transition dynamics in different sectors. Our framework, which draws on key insights from transition studies and organizational institutionalism, specifies a socio-technical system's "systemness" through the degree of institutionalization of socio-technical configurations, their coherence, as well as spatial characteristics of the STS as a whole.

The paper is organized as follows: in the next section we outline the basic elements of a socio-technical system (actor networks, institutions, and technologies) and discuss why analysing them in isolation is not sufficient for understanding a system's transformative potential and generic transition patterns. This is followed by a conceptual exploration of the systemness of different STS, outlining a scheme of analysis to assess the degree of institutionalization of socio-technical configurations, the coherence between them, and their spatial characteristics. The conceptual arguments are illustrated with empirical examples from existing literature on the water- and urban mobility sectors throughout the paper. We conclude by identifying possible leverage points for the governance of transitions in different types of sectors and discussing methodological implications of the proposed analytical framework.

2 Socio-technical system elements and transformative potentials

Socio-technical systems have been defined at a most generic level as the "linkages between elements necessary to fulfil societal functions" (Geels, 2004: 900). The main vantage point of this perspective is that essential societal functions like energy, water, food or transport are provided by complex webs of actors, technologies and institutions that co-evolve and get aligned to each other over extended periods of time (Kemp et al., 1998; Geels, 2002; Markard et al. 2012). In this co-evolution, stable patterns of coordination or socio-technical 'configurations that work' get established, which tend to become locked in and resistant to change (Kemp et al., 1998). STS comprise both the supply and demand side of a sector, meaning that they embrace the co-evolution of production and consumption patterns (Geels, 2004). Stability and resistance to change is ascribed to path-dependency and systemic interdependencies stemming from socio-technical regimes. Regimes denote the most deeply institutionalized 'rules of the game' in a system that result out of the historical co-evolution of dominant actors, technologies and institutions (Geels, 2004; Fuenfschilling and Truffer, 2014).

While initially the basic elements of an STS were defined quite broadly, transition studies have increasingly converged in defining them as 1) actors and their networks, 2) technologies and material artefacts, and 3) institutions (Markard et al., 2012; Fuenfschilling, 2019; Sandén and Hillman, 2011). These three elements have proven useful for characterizing regime structures in mature, locked-in sectors, as well as emergent actor networks that push for transformative change in technological innovation systems or socio-technical niches (Geels, 2002; Bergek et al., 2008; Markard and Truffer, 2008).

Actors are usually defined as organizations that are involved in innovation or structural change processes, as well as in the reproduction of existing systems. They include various types of organizations, comprising firms, universities, government agencies, end users, civil society groups or intermediary actors like NGOs, industry associations, or cluster organizations (Rip and Kemp, 1998; Geels, 2002; Bergek et al., 2008; Kanda et al., 2020; Kivimaa et al., 2019; Bergek, 2020). In many cases, the networks that span between those actors are crucial in understanding both where path dependencies stem from and how collective agency may transform locked-in structures (Markard et al., 2016; Heiberg et al., 2022a). Technologies, in turn, denote the "entities, both material and non-material, created by the application of mental and physical effort in order to achieve some value" (Bain, 1937). Material artefacts and technologies often embody dominant knowledge, values, and beliefs and as such contribute to the materialization of institutions and actors and thus the stability of systems (Fuenfschilling, 2019). Institutions, finally, are defined as the regulative, normative and cultural-cognitive structures that guide the behaviour of actors, such as laws, policies, standards, norms, values or cultural expectations (Scott, 2008).

The boundaries of STS can be set at different levels of aggregation. In the example of 'urban mobility' or 'construction', societal functions are provided by several interrelated industries with complementary, overlapping and potentially conflicting roles (like i.e. the car, bicycle and tram industries). In the example of 'water', societal functions are in turn fulfilled by only one, relatively coherent core industry. In the Technological Innovation Systems (TIS) literature (Bergek et al., 2008; Hekkert et al., 2007), boundaries are often set more narrowly at the level of specific technological fields or industries like solar photovoltaics, wind power or biogas technologies, which are subsets of the overarching (renewable) energy sector. Given the analytical focus of this paper, we set the boundaries of STS at the level of full sectors that fulfil societal functions – i.e. water, energy, transport, agro-food, etc. – including the corresponding actors, institutions and technologies that have formed around those functions.

For each sector, it is possible to characterise the STS in terms of its foundational elements, i.e. key actors (e.g. type, size, age, ownership structure), institutions (e.g. type, age, coordination mechanisms, performance, infrastructures) and technology (e.g. type, materiality, knowledge base, key natural and human resources). Innovation studies, in particular the Sectoral Innovation Systems (SIS) literature, have expansively explored differences between sectors with regard to the sources of innovation, the actors involved, and how innovative activities are organisationally and geographically structured (Malerba, 2002). The most comprehensive taxonomies to date are drawing on a combination of system perspectives and the writings of Schumpeter (Malerba and Orsenigo, 1996; Breschi et al., 2000; Nelson and Winter, 1982; Schumpeter, 1934), and have proven highly productive in explaining differences in the learning and innovation mechanisms in different sectoral systems.

In this literature's broad exploration of how innovation patterns differ between sectoral systems (Malerba, 2002; Carlsson et al., 2002), Castellacci (2008) developed a sector taxonomy that is most relevant to transition studies, which included both manufacturing- and service industries, and their interrelations. He argues that 'physical infrastructure services' such as water, transport and energy - sectors often explored in transitions research - typically are slow-moving, with particularly low levels of technological opportunity, high cumulativeness, low R&D investment levels, and dominance by large firms (Castellacci, 2008). SIS studies furthermore show that sectors dominated by large incumbents (e.g. steel, shipbuilding) are innovating in a slower, more incremental pattern than sectors with populations of smaller firms (e.g. biotech, IT services) that enter and exit the sector in a dynamic pattern of creative destruction (Malerba, 2002; Dicken, 2007; Schumpeter, 1942). Vertically integrated lead firms are also more likely to create monopoly or oligopoly conditions that pose strong entrance barriers for newcomers, thus relegating the innovation pattern to a slow-moving, path dependent trajectory (Malerba, 2002; Castellacci, 2008). Finally, also state ownership of key assets and firms is often associated with slow-moving and risk-averse innovation patterns (Castellacci, 2008).

At the same time, however, the sectoral systems literature has remained focused on the supply-side of innovation, that is, technological regimes and knowledge bases that enable the development and manufacturing of new products and services (Geels, 2004). Yet, deriving ever more fine-grained knowledge-based indicators is not sufficient to understand transformation patterns, which arguably also necessitate a thorough understanding of the institutional, material or demand-side elements that hinder the unfolding of structural change processes (Geels, 2004; Coenen and Díaz López, 2010; Binz and Truffer, 2017). The findings for innovation patterns do thus not directly translate to sectoral transformation processes. For example, the sectoral systems literature assumes that sectors dominated by large, incumbent firms innovate in a slower, more path dependent pattern than sectors with populations of smaller firms. Yet, regarding transformative potentials, one may also argue in the reverse direction, stating that in sectors with large firms only a few key players fundamentally changing their development trajectory will have ripple effects throughout the global sector structure (Fuenfschilling and Binz, 2018).

Consequently, we agree with transition scholars that the transformative potential and generic transition patterns of a sector cannot be fully understood by analysing the characteristics of its basic STS elements (actors, institutions, technologies) alone or by relying on traditional knowledge indicators from sectoral systems literature. One must rather adopt a configurational perspective, which emphasizes the alignment, institutionalization and spatial arrangement of specific configurations of STS elements, both at the supply and demand side (Furnari et al., 2020; Heiberg et al., 2020; Heiberg et al., 2022b). A basic idea underpinning this argument is that sectoral preconditions do not ‘reveal themselves’; the existence of a certain structural configuration does not guarantee change, and the same configuration of basic elements may lead to fundamentally different transformation trajectories in different STS. Applying a configurational perspective then allows one to understand how the basic system elements relate to each other, and how they have co-evolved over time, giving rise to qualitatively different ‘grammars’ in different STSs.

In other words, exploring a sector’s socio-technical ‘systemness’, i.e. the nature of its underlying socio-technical configuration, allows grasping its ideal-type transition dynamics. In the remainder of this paper, we will draw on and expand on recent work in transition studies that conceptualizes the nature of socio-technical systems through the degree of institutionalization and coherence of system elements over time and space (Fuenfschilling, 2019; Runhaar et al., 2020; Fuenfschilling and Binz, 2018). Throughout our conceptual exploration, we will connect and illustrate our arguments with empirical insights from two sectors that are discussed widely in transitions literature, namely the water and urban mobility sectors. Urban mobility refers to the socio-technical system that provides mobility in cities. The sector faces severe sustainability challenges, such as pollution, greenhouse gas emissions, congestion, fatalities, injuries and reduced quality of life among urban populations (Moradi and Vagnoni, 2018; Da Silva et al., 2008). As a result, Moradi and Vagnoni (2018) recently alluded that sustainability, defined broadly, has become the most important concern for this sector.

The water sector, in turn, refers to the socio-technical system that provides water and sanitation services. Albeit given considerably less attention in transitions literature, the sector is also facing immense sustainability challenges related to rapid urbanization, urban sprawl, climate change, water scarcity, and demographic shifts (Hoffmann et al., 2020; Larsen et al., 2016; De Haan et al., 2015; Brown et al., 2009). In high- and middle-income countries, this sector relies on extended pipe networks, which are characterized by strong technological and institutional path dependencies. Transitioning towards alternative s-t configurations, such as on-site water reuse, conservation and various forms of nature-based solutions, would provide crucial benefits to meeting current and future water challenges, but the respective solutions have so far been only moderately successful in a select number of contexts around the world (Hoffmann et al., 2020; Larsen et al., 2021).

3 Systemness: Alignment, institutionalization, and coherence of socio-technical configurations over time and space

Building on recent contributions that have combined transition studies with insights from organizational institutionalism (Fuenfschilling, 2019; Fuenfschilling and Binz, 2018; Baumgartinger-Seiringer et al., 2021) and human geography (Hansen and Coenen, 2015; Binz et al., 2020; Miörner and Binz, 2021), we will now introduce the following three essential features to describe the systemness of an STS: 1) the degree to which s-t configurations are institutionalized, 2) the degree of coherence between different s-t configurations, and 3) the spatial configuration of the overall STS.

First, the *degree of institutionalization* addresses the question how institutionalized specific *socio-technical configuration(s)* are in a STS, i.e. whether or not a given combination of technologies, institutions and actors has become deeply aligned, legitimized and taken-for-granted. The idea that the level of structuration plays a crucial role in transition dynamics has been central already in the foundations of the MLP (e.g. Geels, 2002). The concepts of niche and regime correspond to different levels of structuration that socio-technical configurations exert, implying that niches, i.e. novel, loosely coupled, and weakly institutionalized socio-technical configurations, are less stable and exerting less power over actors than the historically grown, highly institutionalized s-t configuration(s) associated with the regime. The strength and impact of a specific socio-technical configuration then directly depends on its degree of institutionalization (Fuenfschilling and Truffer, 2014). Institutionalization can be understood both as a process and a variable. The process is one of social construction and co-evolution, with varying degrees of agency involved (Fuenfschilling and Truffer, 2016; Berger and Luckmann, 1966; Latour, 1996). Socio-technical configurations may initially be loosely coupled, unstable and impermanent connections that form and dissolve around emerging technological or social innovations (typically early niches). It often takes time for a configuration to align and develop: actor roles, technological classifications and uses, corresponding regulations, values, standards, norms and cultural beliefs all need to develop and align into a ‘configuration that works’. Once a configuration like fossil energy systems or centralized water infrastructures has become highly institutionalized, it forms part of the regime and exhibits locked-in and path-dependent development trajectories.

Second, we argue that the assessment of changing levels of structuration (arguably the hallmark of transition studies), has to be complemented with an analysis of the degree of coherence between different s-t configurations. The degree of *coherence* addresses the *constellation of competing socio-technical configurations* that exist in a given STS. Semi-coherence has been identified as a potentially important source for transitions (Fuenfschilling, 2019; Runhaar et al., 2020). The argument here follows research in organizational institutionalism that has studied how the availability of different institutional rationalities in a system, i.e. the presence of institutional complexity, affects organizational behaviour. Scholars have found that institutional complexity can open opportunities for structural change because it provides actors with different behavioural scripts that increase the scope for legitimate actions (Greenwood et al., 2011; Raynard, 2016; Vermeulen et al., 2016; Zietsma et al., 2017). At the same time, it can also serve as a key challenge for the actors pushing for change, as they have to navigate conflicting cultural demands in ‘hot’ phases of a transition (Yuana et al., 2020; Hacker and Binz, 2021). Assessing how many alternative s-t configurations exist in a given STS and whether they evolve in a stable settlement or a conflictual/competitive constellation is thus of key importance.

The third feature of systemness refers to the overall spatial constellation and forms of interaction between socio-technical configurations that are evolving in territorial subsystems and the ‘global’ STS (Miörner and Binz, 2021; Fuenfschilling and Binz, 2018). We here follow recent contributions in human geography, which argue that the forms of spatial variation and multi-scalarity in STS have important implications for a sector’s transformative potentials (Coenen et al. 2012; Murphy, 2015; Binz et al. 2020). The main argument is that variance in the degree of institutionalization and coherence of s-t configurations between different countries, regions, cities, etc. constitutes an important source of friction, and innovation. For instance, actors may mobilize success stories from places far away when trying to institutionalize a novel s-t configuration in a local context that is locked-in to the incumbent regime configuration (Heiberg et al. 2021; Späth and Rohracher, 2012). Or failures of one s-t configuration in one place may delegitimize the same idea in other contexts, with very different initial conditions. Another key question is whether an actor structure exists in a sector, which is active at a global level and able to translate and diffuse a dominant s-t configuration between territorial contexts (Fuenfschilling and Binz, 2018). The existence of a strong ‘global regime’ structure arguably lowers the transformative potential in the respective sector (ibid.).

In the next section, we will conceptualize the degree of institutionalization, coherence and spatial characteristics in more depth and discuss how each of them can be empirically assessed.

3.1 Assessing the degree of institutionalization of socio-technical configurations

Drawing further on institutional lines of thinking, we can identify a set of dimensions that indicate an increase in the degree of institutionalization of a given socio-technical configuration. In general terms, the process of institutionalization is tightly connected to an increase in legitimacy and taken-for-grantedness (Colyvas and Powell, 2006). Breaking this down further, we suggest the following five dimensions to be of particular relevance:

One of the most common indicators is ***time***. Already in the seminal work by Selznick (1957) and Berger and Luckmann (1966) institutionalization is understood as a process that takes time and goes through various stages. The latter described this process in three stages: habitualization, objectification and sedimentation, each stage representing an increase in taken-for-grantedness of a given practice in a certain environment. Many later contributions in organizational institutionalism have built on this idea that institutions need to be understood as a product of a historical process and that the degree of institutionalization alters its impact on the environment (Zucker, 1977; Tolbert and Zucker, 1983; Meyer and Rowan, 1977). It is generally assumed that the degree of institutionalization increases with time, i.e. the longer a certain element or s-t configuration has been building up and survived, the higher it will be institutionalized.

Another important dimension of institutionalization concerns the ***materialization and translation*** of discursive and informal aspects of elements into more material and formal components within a socio-technical configuration (Hajer, 1995; Scott, 1995). This usually refers to the translation of cultural-cognitive and normative institutions, such as expectations, beliefs, best practices, or values into more formal institutions like standards, regulations and laws that come with different enforcement mechanisms. In addition, material objects and technologies are known to incorporate, reproduce and sediment cultural beliefs and values, as has often been pointed out in science and technology studies (Latour, 1990; Pinch, 2008). Once materialized in objects, overarching institutional rationalities become harder to change, which is one of the foundations of the path-dependency argument in evolutionary economics, and the reason that socio-technical configurations are assumed to be more stable than their elements in their own capacity (c.f. David, 1985).

Another important dimension is the ***scope of diffusion*** of a particular element or s-t configuration. A configuration can be legitimate and impactful in a very small setting in one location, such as a specific way of managing energy provision on a remote island, or it can have diffused to several sectors (water, energy, transport, etc.). Examples thereof are certain business models, activities by consultancy companies and international non-governmental organizations, general purpose technologies, or financial funding structures. Some elements or s-t configurations are thus not unique to one system only but are rooted in several sectoral systems and can be regarded as having legitimacy and impact on a macro-level, which increases their degree of institutionalization (Kanger and Schot, 2019). The result of the diffusion of certain configurations will be noticed by an increase in isomorphism between actors and structures across sectors (Meyer and Rowan, 1977; DiMaggio and Powell, 1983). De-stabilizing and transforming such socio-technical configurations is arguably more difficult than changing configurations that are anchored in one sector only (Schot and Kanger, 2018).

Another indication for a high degree of institutionalization is ***invulnerability to intervention***, i.e. a strong resistance to change and resilience to reproduce the same structures despite social interventions like policies, regulations, standardization, criticism, shaming or social exclusion (e.g. Colyvas and Powell, 2006). Finally, in a similar vein, ***starkness*** is also indicative of institutionalization. If many actors are completely convinced of the legitimacy of a configuration, the degree of institutionalization is most likely high. This usually shows through the lack of - or low levels of - dissent or controversy. Starkness is similar, but not the same as taken-for-grantedness, since the latter is often very implicit and unconscious, while the former can be explicit and intentional as well.

Table 1 presents an overview of the above-mentioned dimensions. It should be noted that no dimension alone will determine the degree of institutionalization of a given element or configuration, but rather that they interrelate and reinforce each other. At a most aggregate level, we may argue, though, that the more dimensions fulfil the criteria for high institutionalization, the more likely it is that a configuration is strongly institutionalized and that its potential for fast transformation is low.

Table 1: Dimensions of institutionalization

Dimensions	Degree of institutionalization Low		High
Timespan	Short (months of years)	⟺	Long (several decades or generations)
Materialization	Low materialization/ translation	⟺	High materialization/ translation
Scope of diffusion	Low (relevant in only one sector)	⟺	High (relevant in several sectors)
Invulnerability to intervention	Vulnerable	⟺	Invulnerable
Starkness	High dissent and controversy	⟺	Low dissent and controversy

Source: own elaboration based on a summary of the literature.

Applying these ideas to the water sector reveals a dominant s-t configuration with a very high degree of institutionalization, scoring high on most dimensions in table 1, maybe with the exception of scope of diffusion. Many of the key technologies, actors and institutions, as well as the dominant regime configuration have remained unchanged for 50, sometimes even more than 100 years in this sector (Sedlak, 2014). The dominant 'hydraulic' rationality, has materialized in highly sturdy, centralized water-based infrastructures, which are implemented with investment horizons of 80-100 years and very hard to change ex-post (Kiparsky et al., 2013). While this dominant regime rationality has not diffused heavily into other sectors, it has materialized in very diverse cultural, socio-political and economic contexts, which makes it a de facto standard in many places even before any water infrastructure has been built up (Fuenfschilling and Binz, 2018; Nilsson, 2016). Finally, despite many local attempts of developing alternative, small-scale and water-sensitive, solutions (Wong and Brown, 2009; Lüthi and Narayan, 2018), the water sector's core s-t configuration has proven astoundingly invulnerable to interventions and faces only limited controversy in most places (high degree of starkness).

The urban mobility sector provides an interesting contrasting case. On the one hand, the car-based regime configuration has been remarkably stable for half a century, and new actors have entered the scene and challenged core technologies (i.e. combustion engines, manual driving) only relatively recently (Bardal et al., 2020; Miörner and Trippl, 2019). The core rationalities underpinning the 'personal car mobility' configuration have diffused to - and are highly legitimate in - many other sectors of the economy (e.g. agro-food, manufacturing, tourism, etc.), and have materialized into a dedicated set of laws, technologies, standards and physical infrastructures (not the least 'roads' as multi-purpose auxiliary infrastructures). On the other hand, neither has the dominance of the 'personal car mobility' configuration been eternal, nor does it stand uncontested in the STS at large. The sector has structurally transformed at least twice in the last century (from horses to public transport in the beginning of the 20th century, and from public transport to cars in the 1950s) (Geels, 2005). In most contexts, the personal car mobility configuration furthermore co-exists with a number of alternative s-t configurations, several of which are also highly institutionalized. For example, a majority of citizens in Kolkata rely on public transportation and the city's diverse rail-, bicycle- and water-based transport options are arguably all institutionalized to a higher degree than the personal car-based mobility regime (Ghosh and Schot, 2019). Also rail-based systems like trams and subways have remained a deeply institutionalized configuration in many cities around the world. (Turnheim and Geels, 2019).

3.2 Degree of coherence between socio-technical configurations

The second feature of systemness relates to the coherence of a given STS and can be assessed by identifying the ***number of socio-technical configurations*** that co-exist in the system and that exhibit distinct institutional rationalities, i.e. that can be delineated as ideal-typically different from each other. A system with one sole configuration providing a societal function on the basis of a set of unified technologies and rationalities (i.e. the water sector) is arguably more coherent than a system with several s-t configurations providing the same societal function based on strongly diverging technologies and institutional rationalities (i.e urban mobility). STS can thus exhibit different degrees and types of institutional complexity, depending on how many s-t configurations co-exist and how well they are aligned with each other.

On the one hand, different s-t configurations can be compatible to the point that they re-enforce each other, which gives rise to mutual dependence and a symbiotic relationship between them, which increases stability. Systems can also operate in a state of ***settled alignment***, meaning that more than one incompatible, deeply institutionalized configuration is present, but that they co-exist without major contestation because they 1) have jurisdiction over different parts of the system (e.g. management and the medical profession in health care (Denis et al., 2001)), or 2) one configuration is clearly prioritized over others (Greenwood et al., 2011).

On the other hand, institutional complexity can also bring about tensions and lead to ***unsettled alignment*** between configurations. For instance, two s-t configurations may follow different underlying rationalities in the same jurisdiction without any well-established prioritization. This leads to contestation, with actors from one dominant configuration fending off transformation pressure coming from competing alternatives. Different combinations of overlap or incompatibility between s-t configurations will force the actors in the system to find suitable organizational responses and structural adaptations (Greenwood et al., 2011; Raynard, 2016; Aldrich and Fiol, 1994).

Coming back to our empirical illustrations, it is possible to observe substantial differences in coherence in the water and urban mobility sectors. The water sector in most countries is dominated by one, clearly prioritized s-t configuration (centralized water infrastructure). Only in a few contexts, complementary s-t configurations dominate in small, clearly delineated parts of the system (such as informal settlements in some low-income economies, or on-site water systems the remote rural areas of the US, Japan or France). In most cases, those alternative configurations co-exist with the dominant regime in a state of settled alignment, thus without causing strong contestation. Countries with two highly institutionalized configurations that compete in an unsettled, conflictual constellation also exist (see the example of India discussed below), but they remain exceptions, rather than the norm. Urban mobility services, in contrast, are typically provided by different complementary configurations (cars, rail based transport, buses, bicycles, pedestrianism etc.) that co-exist in more or less settled constellations (van Welie et al. 2016). For example, the alignment between rail based public transport and personal car mobility is in most contexts clearly defined by the distinct infrastructural preconditions for the two mobility modes (car users cannot drive on railroad tracks and vice versa) and serves different types of urban mobility needs in a largely complementary manner. The introduction of e-scooters, on contrast, has in many urban areas led to a conflicting relationship with other users, especially in relation to the competition for road- and sidewalk space (Tuncer et al., 2020).

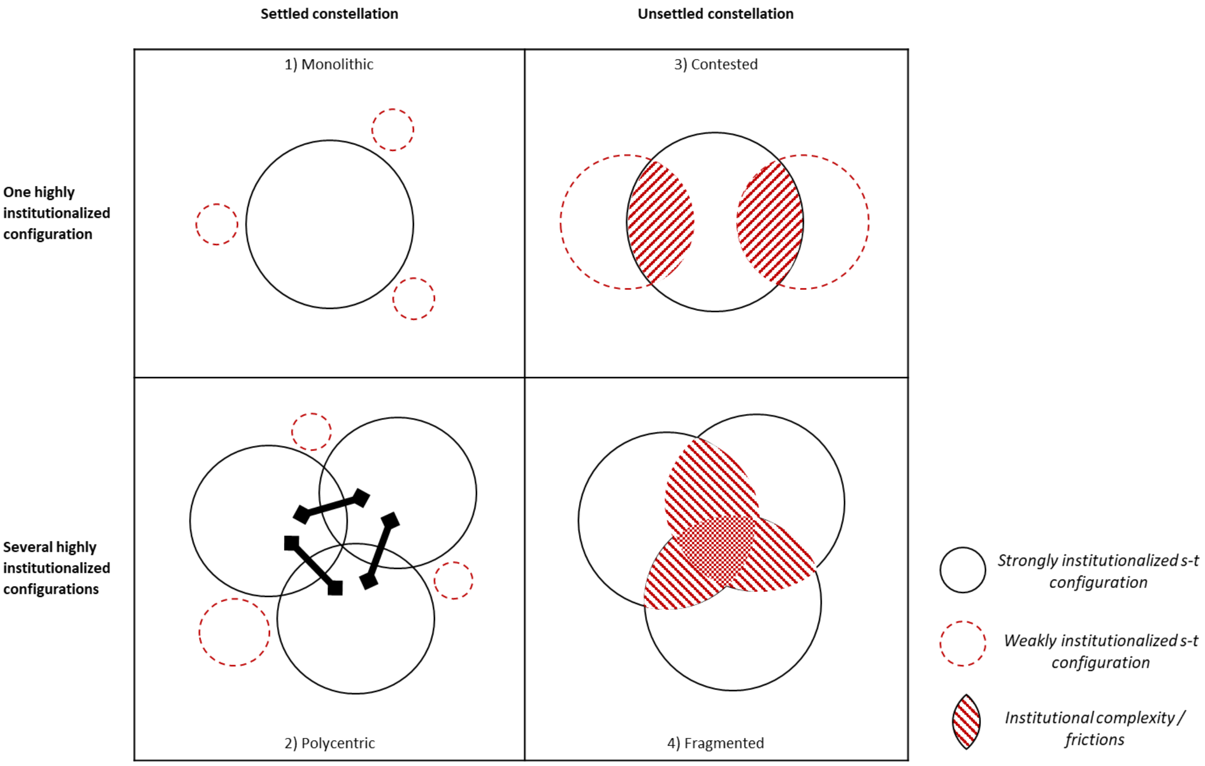

Figure 1: Different forms of coherence in socio-technical systems. Own figure.

Inspired by Van Welie et al. (2018), Fig. 1 summarizes four ideal-typical combinations of the number of socio-technical configurations in a system, and their overall relationship with each other in terms of settled or unsettled constellations. In general, transformative potential is higher in systems with unsettled constellations, and increases with the number of competing configurations. In systems with a **monolithic** constellation (quadrant 1 in Fig. 1), one socio-technical configuration dominates. Even though some alternatives exist, their degree of institutionalization is low and poses no threat to the dominance of the dominant regime. The water sector is an illustrative example of a socio-technical system with a monolithic constellation, which strongly limits transformative potentials.

In sectors with a **polycentric** constellation, like the urban mobility sector in European cities, several highly institutionalized configurations co-exist in a relatively stable system-level settlement. The relationships between different configurations are complementary, meaning that even if their technologies and guiding rationalities are not compatible, they are still well-aligned to each other and serve to perform different roles in providing the overall societal function of urban mobility. One pattern that can be observed in many places is that the personal car mobility configuration stands out as the ‘prioritized’ option for mobility, with e.g. public transport and human-powered mobility being subservient complements for specific mobility needs (i.e. shorter/longer trips, leisure trips, or cost-efficient transport). The mutual dependency implies that none of the configurations can be fully overthrown or substituted by another one, thus limiting the system's overall transformability. At the same time, the existence of different guiding rationalities in the same sector also implies that more opportunities for divergent action or a re-configuration of the overall constellation exist than in a monolithic constellation like in the water sector.

Third, systems can also be characterised by a **contested** relationship between a dominant socio-technical configuration and one or several less institutionalized, although quickly emerging, alternatives, which follow an incompatible institutional rationality. Quadrant 3 in Fig. 1 illustrates a situation where the dominant regime configuration is under strong pressure from the (de-)institutionalization activities driven by actors promoting diverging technologies and guiding rationalities. The emblematic example of this situation is the energy sector, whose incumbent regime configuration (fossil fuels) is under increasing pressure from renewable alternatives (wind power, bio-energy, solar PV, etc.) that quickly scale up and are progressively institutionalizing an alternative regime rationality in the STS that will ultimately substitute and de-legitimize the incumbent regime (Markard, 2018; McMeekin et al., 2019).

Finally, **fragmented** system constellations are conceivable, in which several highly institutionalized socio-technical configurations co-exist and compete with each other in an unsettled pattern (van Welie et al., 2016). This is arguably the most complex constellation, since several deeply institutionalized, yet incompatible, configurations fight for dominance in the same jurisdictional space, without being mutually dependent. On the one hand, one may expect the highest transformative potential in this constellation, since multiple routes of legitimate action exist. On the other hand, the strong (and volatile) complexity might also be a hindrance to strategic action, as any intervention might get overthrown in a rather chaotic overall transformation trajectory (Hacker and Binz, 2021). The study by van Welie et al. (2016) provides an emblematic illustration of this situation with competing service regimes for sanitation in informal settlements. Another recent example is the ascent of platform economies in sectors as diverse as retail, tourism, or transport. IT firms have entered these different sectors with disruptive business models, which have taken many cities by surprise and triggered organized opposition in various parts of the world (Pelzer et al., 2019; Yuana et al., 2020). This has led to a complex pattern, where transformative s-t configurations are quickly diffusing, but resistance is also building up in parallel, which leaves the faith of the respective transitions trajectories rather controversial and open-ended (Frenken et al., 2020; Frenken and Fuenfschilling, 2021).

3.3 Assessing spatial characteristics

As a third key feature of systemness in our framework, we propose to disentangle the spatial characteristics of the STS in focus. In the analytical steps outlined above, some conceptual tension exists between the rather abstract, aggregate view on the socio-technical system as a whole in a (global) sector perspective vs. the more concrete, territorially embedded transition dynamics that occur in various places around the world. In fact, the degree of institutionalization of the same s-t configuration may vary strongly between different cities, regions or countries around the world. I.e. wind power may be a deeply institutionalized, dominant form of energy generation in Denmark, providing more than 70% of domestic energy demand, while it is barely legitimate in Saudi Arabia. This differential in degrees of institutionalization between places constitutes an important potential source of friction and transformative pressure. On the other side of the same coin, the degree of institutionalization and coherence between s-t configurations observed in specific cities, regions or countries cannot be aggregated directly to a global sector level, since in some cases, the 'global sector' may follow a guiding rationality that draws quite selectively on solutions from some particular regions, while ignoring s-t configurations that prevail in many other places (Miörner and Binz, 2021).

To understand a sector's overall transformative potentials and most plausible transition trajectories, one thus needs to read across and between territorially embedded and more globalized STS structures and try to 1) understand what competing, more or less deeply institutionalized s-t configurations exist in different countries/regions/cities and how they compete for dominance in concrete territorial contexts; 2) understand whether competing configurations are co-existing in more or less coherent and institutionally complex or settled constellations; and 3) aggregate the insights on degrees of institutionalization and coherence from different territorial contexts into a global picture of whether and how structural change happening in specific territorial contexts relate to each other in the STS as a whole. To embrace this spatial and scalar complexity, we propose to analyse an STS' spatial characteristics along three main dimensions, namely spatial diffusion; spatial variation and adaptation; and the degree to which the STS exhibits a global regime structure.

First, sectors may differ in terms of the ***spatial diffusion*** of their socio-technical configurations. As outlined above, in some STS, s-t configurations have diffused widely in space and into very diverse spatial contexts with varying geo-physical and cultural context conditions. The wider a certain configuration has diffused in space, the more broadly its structural elements are taken-for-granted, and thus the more difficult it becomes for actors to fundamentally challenge or change them. This is very visible in the water sector, where centralized infrastructure solutions are implemented in all continents and throughout developed, emerging and developing economy contexts. This global diffusion by now strongly limits local actor's agency in framing credible alternative to the dominant regime solution. In urban mobility, in turn, certain configurations like buses, bicycles or personal cars have also diffused globally, yet with much stronger variation in terms of their reach, real-world implementation 'on the ground' and combinations with complementary transport solutions, thus leaving more room for constructing and diffusing novel 'success models'.

Second, sectors may exhibit differences in terms of the ***spatial variation and adaptation*** of s-t configurations to place-specific conditions. In some sectors, a standardized 'one-size-fits-all' solution (or bundle of solutions) exists that is diffused worldwide, with very minor adaptation to local context conditions. For instance, the same smartphone applications or computer software are used globally to organize businesses and social interactions. In other sectors, s-t configurations have to be strongly adapted to local circumstances. Low spatial variation and adaptation can be associated with rather low transformative potential, as the sector as a whole experiences only limited needs for variation within the dominant regime configuration. Here again, the regime solution in the water sector represents a generic infrastructure paradigm that is reproduced in various parts of the world without much adaptation to local circumstances, while urban transport infrastructure looks very different in different cities (think about, for example, the transport infrastructure in Venice vs. New York City vs. La Paz).

Third, sectors differ in terms of the degree to which certain s-t configurations have been institutionalized at the level of a ***global regime.*** Some sectors are characterised by a strong global regime structure, referring to a socio-technical configuration and guiding rationality with a high degree of institutionalization at the global level, which is reproduced by a set of dominant actors, technologies and institutions that evolve analytically somewhat distinct from territorially embedded subsystems of the STS (Fuenfschilling and Binz, 2018). Through various translation processes that mediate between the global and (sub-)national levels of the STS (Miörner and Binz, 2021), the global regime has a structuring effect that influences the degree of institutionalization and coherence of national and sub-national manifestations of the same STS. In sectors with a strong global regime, a global actor structure typically exists that is able to cross-connect the implementation of (incumbent) solutions in various territorial subsystems at once. A strong hierarchical relationship between different spatial scales in these actor networks (i.e. hierarchical value chain governance modes) will in most cases serve to reinforce a prevailing regime rationality.

3.4 Overarching conceptual framework and operationalization

Fig. 2 summarizes the discussion above in a stylized visual representation of the STS in a given sector. For illustrative purposes, we base this on our understanding of STS in the water sector and define subsystems at the level of three different countries. However, they could also be defined at other geographical scales, such as cities, regions or supranational entities like the EU.

Subsystems I and II in this illustration denote relatively coherent STS configurations, where one deeply institutionalized regime configuration (bolded configuration A, centralized infrastructure) co-evolves with various less deeply institutionalized alternative 'niche' configurations (dotted configurations B, C and D, various water-sensitive solutions) in a settled relationship, with clear priority given to the regime solution and alternatives causing frictions only at the very fringes of the regime (striped overlap between A/C in subsystem II). Subsystem III, in contrast, depicts a constellation in which two deeply institutionalized configuration (A and B, centralized and on-site water treatment) co-exist and overlap with each other in the same jurisdiction, thus causing institutional friction (stripped overlap between both configurations). The presence of two incompatible solutions in an unsettled constellation lowers that subsystem's internal coherence, and challenges local actors to reconcile incompatible institutional demands. At the same time, the presence of two deeply institutionalized s-t configurations also equips them with two routes of legitimate action, which increases the overall transformative potentials in this particular context.

When referring to spatial characteristics, Fig. 2 contains spatial variation mostly when comparing subsystems I and II with III. In subsystems I and II, configuration A is clearly dominant, while in subsystem III it is challenged by an equally deeply institutionalized alternative configuration. Subsystem III thus holds the highest potential for transformative change in the STS toward configuration B. When taking a full system view, one however also sees that configuration (A) is deeply institutionalized in all subsystems and that on average the constellation of s-t configurations in various subsystems looks quite similar. This is hinting at the existence of a 'global regime', which exerts influence beyond any territorially defined subsystem, and which transposes mimetic pressures in space, thus limiting the overall scope of variation in the STS (Fuenfschilling and Binz, 2018). Overall, when assessing institutionalization, coherence, and spatial characteristics in such a holistic manner, it thus becomes clear that this STS possesses a relatively low degree of transformative potential.

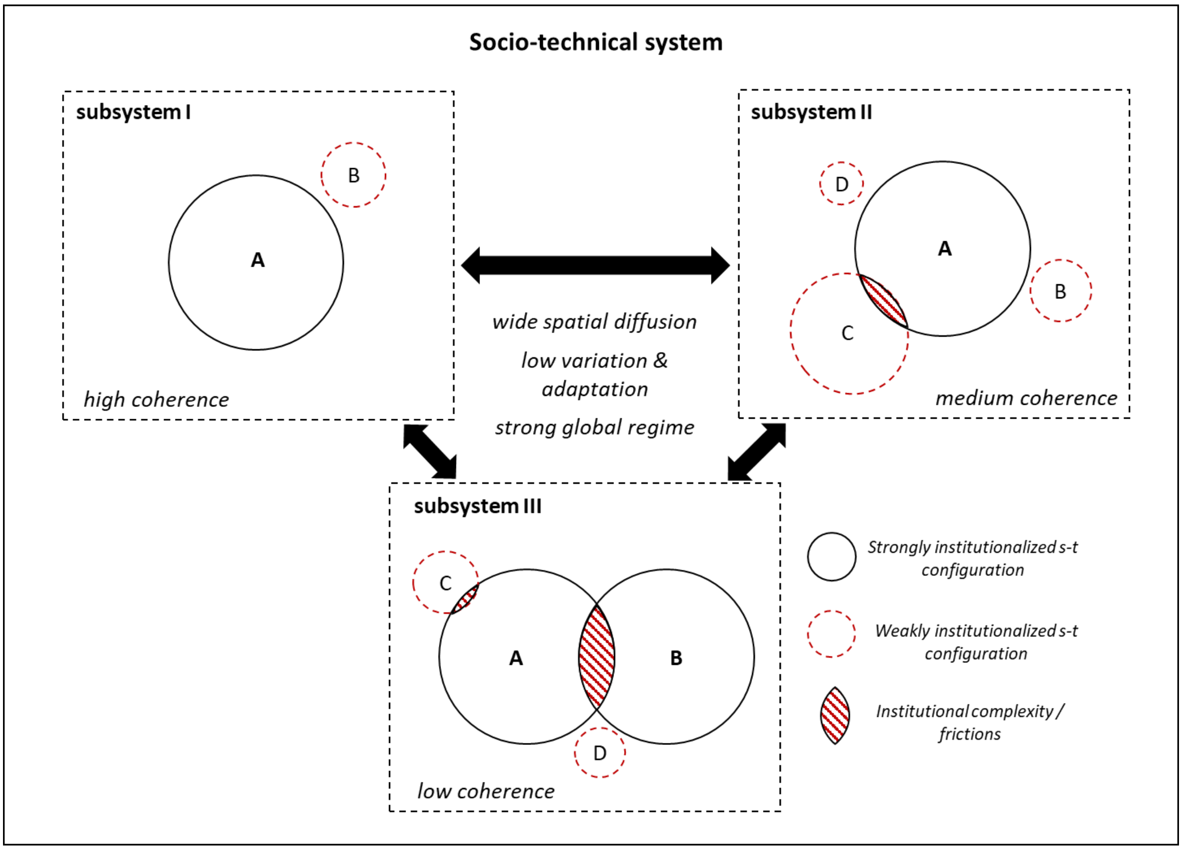

Figure 2: Conceptual framework: illustrative example. Own figure.

A second key question relates to how one would measure each dimension of our framework with suitable indicators, going beyond the perfunctory analyses outlined so far. Table 2 provides a summary and overview of our key analytical dimensions and the corresponding indicators as a first step towards an operationalization of our framework. The systemness of a sector's STS can obviously take various forms, depending on how the three features are developed and how they interact with each other, thereby fostering windows of opportunity for innovation and change or, to the contrary, contributing to the system's maintenance and regime reproduction. While a thorough characterization of all possible permutations lies below the scope of this paper, we will use our two illustrative empirical examples of the water and urban mobility sectors to showcase some key differences in their overall STS configurations and the resulting effects on transformative potentials.

Table 2: Overview of dimensions and indicators.

Features of systemness	Dimension	Potential operationalisation
Institutionalization	**Timespan**	Identify the duration of existence of system elements (actors, technologies, institutions) and their configurations: When did the current actors, technologies, institutions emerge; how long have they existed separately and/or in a specific configuration?
	Scope of diffusion	Identify the reach of the system elements (actors, institutions, technologies) and map how many of those are present/dominant in multiple sectors. How similar are actors, institutions, and technologies within and across systems, i.e. what is the degree of isomorphism (high/low)?
	Invulnerability to intervention	Identify resistance to change: Can elements or configurations be changed by small interventions? Do they withstand strong social interventions? Is the configuration able to reproduce despite interventions?
	Starkness	Identify the level of discursive activity: Is there a lot of discourse and discussion? Are actors questioning system elements? Is there an ongoing controversy?

	Materialization	Identify if informal and intangible system elements (values, beliefs, expectations, norms, etc.) and s-t configurations have been materialized and translated into tangible and material elements, such as technologies, infrastructure, laws and regulations, policies, financial commitments, professional standards, official classifications, specific organizations, etc.
Coherence	**Number of institutionalized configurations**	Identify the number of configurations offering different ways of providing the same societal function: what are the core technologies in the sector? Who are the main actors and how do their networks look like? How can different configurations be distinguished from each other (on the basis of underlying rationalities, core technologies, actor-networks, etc.). What concepts are used to frame certain combinations of actors, institutions, and technologies?
	Alignment	Identify the relationship between different competing or complementary s-t configurations: How do they differ from each other? How are different configurations connected to concrete actor networks and/or advocacy coalitions? What are the underlying rationalities and to what extent do they compete with / complement alternative configurations?
Spatial characteristics	**Spatial diffusion**	Identify the degree of spatial diffusion of core s-t configurations: have core technologies, actors and institutions diffused into many different places (countries, regions, cities)? Are there unified ways of providing the societal function that looks similar across different territorial contexts?
	Variation and adaptation	Identify the degree of variation of s-t configurations in different territorial subsystems: is the configuration of actors, institutions, and technologies similar across contexts? Are there place-specific conditions that influence how societal functions are provided? Does the combination of different s-t configurations look similar or different across contexts? Are there national, sub-national or even intra-urban differences?
	Global regime	Identify the degree to which dominating s-t configurations and their alignment have been institutionalized at the global level: map the existence of global standards, norms and 'ways of doing things' in the sector. Are there actors (or actor-networks) with a hegemonic position, global reach or definitional power in the sector's value chain or production network?

Source: own elaboration.

Further summarizing our prior discussion of the two illustrative cases based on the indicators above (also see Figure 3) can serve to distil their inherent transformative potential in more depth. The STS in the water sector largely depends on one *deeply institutionalized* s-t configuration that has existed for *several decades if not centuries* (Sedlak, 2014). The regime configuration has proven highly *invulnerable to policy intervention*, is taken for granted in various cultural and geographic settings and has *materialized into physical infrastructure*, as well as (global) *standards and regulations* that are very hard to change. The STS furthermore features a *monolithic* regime structure that gets challenged by alternative s-t configurations only on the fringes. The STS overall shows *low spatial variation* with *limited adaptation* to place-specific conditions, and is strongly influenced by a *hierarchically organized global regime* structure providing water and sanitation solutions. Almost all of these elements point to a comparably low overall transformative potential and a transition trajectory that deviates from conventional niche upscaling models (see section 4.1).

The urban mobility sector, in contrast, is characterised by many features that indicate a higher (though arguably not the most extreme) transformative potential (Fig. 3). While the s-t configuration of personal car mobility is *highly institutionalized* with supporting infrastructure, regulations, standards and taken-for-granted practices, there are several other institutionalized and *highly legitimate alternative s-t configurations* competing for dominance in the sector. As such, the urban mobility sector features significantly *lower coherence* than the water sector, with *polycentric* patchworks of different s-t configurations that are all highly institutionalized and *competing with and/or complementing each other* in the provision of urban mobility. Furthermore, the STS exhibits regime configurations that are considerably less globalized than in the water sector, with constellations of different s-t configurations coming in a range of 'local flavours' with solutions being *strongly adapted* to a city's particular geo-physical and cultural particularities. The lower overall coherence and *stronger* *spatial variation* thus clearly point to a relatively higher degree of overall transformative potential and a transition trajectory that is deeply embedded in specific places (see section 4.1).

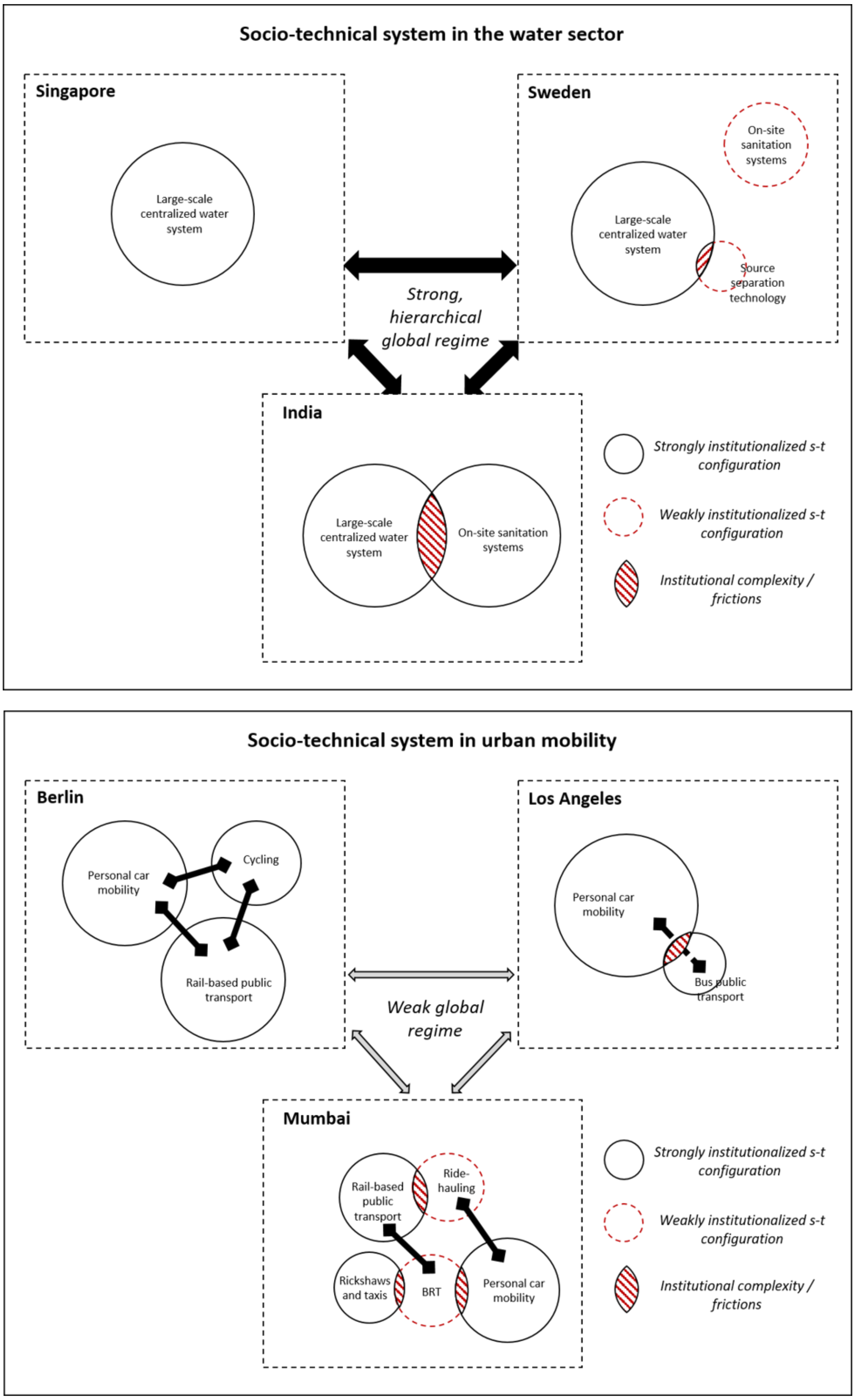

Figure 3: Comparison of the socio-technical system in water and mobility. Own figure.

4 Governance and methodological implications and contours of a future research agenda

The framework outlined above should be understood as a novel heuristic for analyzing and cross-comparing transition trajectories in different sectors. As such, its full explanatory potential will only be mobilized once it has been applied to a systematic comparison of transition trajectories in various sectors. This notwithstanding, we would like to highlight two areas, where future scholarly work appears most promising. One is related to governance implications, the other to methodological implications.

4.1 Leverage points for transformative change in different STS

A first contribution of our framework lies in its ability to derive potential leverage points for governance interventions to foster sustainability transitions in different sectors. On the one hand, the three features of systemness have direct implications regarding the type of intervention that is most likely to be effective. On the other hand, the aggregate configuration of a sector's STS also points to different spatial scales at which interventions appear more or less promising.

In sectors with a monolithic and highly globalized STS, such as the water sector, the strongest leverage points for transformative change arguably lie in the disruption of its global regime structure. Global regimes can most effectively be influenced with 'top-down' interventions by actors that own the resources, network positionality or credibility to influence the institutional environment of powerful corporate and government interests (Verbeek and Mah, 2020; Tilsted and Bauer, 2021; Fuenfschilling and Binz, 2018; Miörner and Binz, 2021). The high degree of institutionalization and coherence of the sector's regime configuration will furthermore typically necessitate interventions in the regulatory domain, altering broad incentive structures through bans, changes in standards, taxation and/or subsidies, with the potential to disrupt deeply locked-in cognitive and industrial structures.

Transitions governance accordingly requires strategic multi-scalar regime disruption rather than only geographically contained (niche) experimentation (see also Miörner and Binz, 2021). While experimenting with place-specific, innovative solutions may be important for developing new technologies or to solve place-specific challenges, it will in most cases not suffice to achieve sector-wide transformation. To become transformative, bottom-up experimentation needs to be actively and strategically translated into storylines that gain salience in global expert communities and corporate networks and subsequently re-direct multinational actor's investment streams, knowledge systems and dominant business models. In some cases, global expert discourses and standards may even be transformed without any (or very limited) real-world demonstration in the first place (Miörner and Binz, 2021). Prior work has also identified 'generalized others' like international NGOs, leading universities, environmental activists or large donors as particularly relevant in transforming this type of sector (see e.g. Miörner and Binz, 2021; Fuenfschilling and Binz, 2018).

In this STS type, one can furthermore not expect full regime substitution, in which the current regime is fully replaced by an alternative solution (as, for example, in the ongoing energy transition). Transitions are more likely to take the shape of a gradual hybridization of the dominant regime. This can happen through layering of alternative rationalities, moving towards a more polycentric regime structure where conventional, centralized and several alternative on-site/modular configurations co-exist in a settled alignment (Hacker and Binz, 2021). Indeed, in the water sector, change agents increasingly mobilize the model of 'city-wide inclusive sanitation' (Gambrill et al., 2020), which propagates that densely populated central business districts continue to be served by centralized sewers, while residential sub-urban areas and informal settlements are served by a variety of on-site systems. In this model, centralized infrastructures and the 'hydraulic' rationality are not fully substituted, but rather complemented or 'hybridized' by alternative solutions which are introduced in parallel to the dominant regime with limited jurisdictional overlaps between competing s-t configurations (Hacker and Binz, 2021; Van Welie et al., 2018; Hoffmann et al., 2020).

Transition governance in this type of STS could accordingly be concerned with identifying territorial contexts where the degree of coherence is particularly low. Such situations are often a consequence of place-specific conditions that come with inherent challenges for the globally dominant solution (Miörner et al., 2021). A case in point is the case of Indian cities, where staggering rates of urbanization make centralized sewage solutions practically infeasible, which opens space for alternative configurations (Heiberg et al., 2020; Reymond et al., 2020). Another example is the emergence of on-site potable and non-potable reuse technology in some cities in California, triggered by increasing landscape pressures like droughts and severe water scarcity (Hacker and Binz, 2021). Finally, transformation would most likely have to be fostered by globally visible 'lighthouse projects' that give rise to socio-technical templates that can change global expert discourses and be translated into other places (Hoffmann et al. 2020; Turnheim and Geels 2018).

In sectors featuring a polycentric STS and a high degree of spatial variation and adaptation, such as the urban mobility sector, transitions are in turn much more likely driven by a reconfiguration of place-specific constellations of already legitimate s-t configurations, such as changes in modal splits, than the introduction and upscaling of entirely new mobility solutions (such as e-scooters or flying taxis). The strongest leverage points for transformative change thus exist at both global and local levels, but while processes of (de-)institutionalization at the global level may still be important, greater emphasis should be put on the development of best-practices through local experimentation, and the 'flat' diffusion of these across different territorial sub-systems (Sengers and Raven, 2015).

Transition governance in this sector type can thus utilize regional and tailored interventions incentivizing combinations of s-t configurations with lower environmental or social impact, rather than one-size-fits-all solutions that are propagated globally. This implies the need for an inclusive and participatory approach for governing transition process. In the urban mobility sector and other comparable STS, transitions may be the result of recombination processes in urban centres that reduce the relative importance of unsustainable solutions vis-à-vis sustainable ones. Furthermore, scholars have argued that the focus on radical regime-shifts reflects a western bias in transition studies, and an 'infrastructure ideal' (Graham and Marvin, 2002) that may be hampering the adoption and optimisation of existing sustainable alternatives (Ghosh and Schot, 2019). This point to the importance of involving not only high-profile niche-actors in the transition process, but also actors of established s-t configurations. A case in point is how public actors in the Indian city of Kolkata are heavily invested in expanding and modernising the existing public transport system, representing a transition trajectory with great sustainability potential which does not involve niche innovation or regime substitution (Ghosh and Schot, 2019). Similar arguments have been made in relation to the urban waste management sector, in terms of targeting the relative importance of waste incineration and different forms of established recycling solutions (Madsen et al., 2021). A potential key factor to enable such recombinatory transition trajectories may be the existence of well-designed support structures that receive extra-regional resources and are linked up to global innovation systems, but are tailored to local needs (Binz and Truffer, 2017).

Finally, when it comes to the emergence of niches and more radical alternatives to the established s-t configurations, the key challenge in the polycentric STS of the urban mobility sector calls for innovation at the interface of different established (and emerging) configurations (Sareen et al., 2021). For example, bridging concepts such as "multi-modal" urban mobility may connect and change the relative importance of different s-t configurations, and utilize the potential of emerging innovations such as e-scooters and ride-hailing in transitions, reaping potential benefits despite the fact that their upscaling alone may never suffice to trigger a transition in the sector. In other words, the relationship between different established and emerging s-t configurations may be challenged by innovations that explicitly target to optimize their relative importance for achieving more a more sustainable provision of the overall societal function.

4.2 Methodological implications

A second contribution lies in the potential of operationalizing and adopting this framework in empirical analyses, which offers plentiful inroads for methodological innovation. In this section, we briefly reflect on what type of research is most suited to advance this line of study and advocate for more cross-comparative case studies that make use of mixed methods, qualitative and quantitative data, as well as improved ways of data visualization.

Assessing degrees of institutionalization and coherence of STS is a challenging and time consuming task that is in principle open to several methodologies. One approach is conducting deep contextual qualitative case studies in various STS and associated subsystems in order to identify s-t configurations, their institutionalization as well as their mutual alignment. This is often done via qualitative methods and data, such as expert interviews, participant observations, and/or content analysis of secondary data or surveys. Yet, this approach, which still widely dominates transition research (Hansmeier et al., 2021), also shows limitations in terms of comparability and generalizability of single case studies. We thus think that a more promising approach is to instead make use of semi-quantitative approaches like qualitative comparative analysis (QCA), social network analysis, machine-learning based procedures or topic modelling, as well as socio-technical configuration analysis (STCA). The latter approach combines qualitative coding of global textual databases with social network analysis to analyse, visualize and map the overlaps between competing socio-technical configurations in a given subsystem or an STS as a whole (for an in-depth discussion see Heiberg et al., 2022b). These new approaches allow us to map s-t configurations and their evolution over time and space and also provide insight into 'transitions-in-the-making'.

Another way to conduct (semi-)quantitative mapping exercises that decode s-t configurations is making better use of global databases. For instance, many professional associations in water, energy, food or chemical sectors compile very comprehensive databases which provide insights on the global distribution of technologies and companies. Similar data bases exist for company ownership structures, e.g. the Orbis (Bureau van Dijk) database (see e.g. Verbeek and Mah, 2020). These types of databases and mapping methods allow us to re-think how to visualize our data in order to see relevant patterns. Visualization is key when working with complex and large data sets. Software that helps to generate timelines, network diagrams, graphs, plots, treemaps, etc. that use specific colours and forms are essential tools that need to be developed further in order to properly describe and analyse system structures (for an interesting example see e.g. Howard, 2016; Howard et al., 2021). The potential of utilizing existing global databases when studying sector-level configurations also lies in the possibility of mapping spatial characteristics and multi-scalarity of a STS, a topic that has been largely neglected so far, not unlikely due to methodological limitations. Recent and ongoing studies are demonstrating how network methodologies allows for the analysis of previously blackboxed features of STS, such as ownership interlocks (Tilsted and Bauer, 2021) and subsidiary-networks (Lesch, 2021).

5 Conclusions

In this paper, we set out to develop a more sophisticated understanding of how characteristic features of the STS in different sectors influence the likelihood, nature and speed of transition processes. Drawing on insights from transition studies and organizational institutionalism, we have elaborated a framework to study the effects of different types of systemness in the STS of various sectors. We show that a sector's inherent transformative potential cannot be fully understood by only analyzing the core elements of its underlying socio-technical system (actors, institutions and technologies) but has to rely on a configurational analysis emphasizing the alignment, coherence and spatial arrangement of these elements.

The key contribution of our framework is that it offers a novel inroad for analyzing, systematizing and cross-comparing transition potentials and the dynamics of structural change in different sectors. While many conceptual frameworks exist for analyzing innovation and 'niche' dynamics, how to systematically assess 'regimes' or socio-technical systems in their aggregate has interestingly remained an under-addressed question. We here complement existing typologies of sectoral innovation and transformation patterns with a more comprehensive view of the relevant institutional and spatial dynamics that influence whether, how and where a locked-in system may be pushed toward transformative change. These lessons are also highly relevant for policy makers, who might adapt their concrete instruments, policy mixes and the targeted spatial scales to the systemness of a given sector.

It goes without saying that our approach also needs further specification in various respects. First, we did not fully operationalize our analytical framework, but only outlined key analytical dimensions and potential ways of assessing them in empirical research. Considerable conceptual and methodological innovation will be needed when developing concrete, cross-comparative research designs based on our framework. Conducting in-depth qualitative case studies will not suffice as a methodological approach for assessing alignment, coherence and spatial variation in complex STS. We thus rather encourage future analysts to combine case studies with novel semi-quantitative approaches that combine qualitative coding of textual databases with quantitative assessment of key alignment and institutionalization processes. Qualitative comparative analysis (QCA), socio-technical configuration analysis (STCA), or various types of network and discourse analysis techniques are highly relevant methodological approaches for the type of configurational theorizing that is envisioned in our framework.

A second, more conceptual, challenge revolves around the ways in which the dimensions of our framework interrelate and mutually reinforce or block each other. Dynamics in one dimension may co-constitute and reinforce dynamics in the other. A more dynamic assessment of potential patterns of cumulative causation between alignment, coherence and spatial dynamics in a transition process were beyond the focus here but should certainly be emphasized in future applications of our framework. Given the intricacy of our framework, we encourage the development of a long-term research agenda as a collective endeavor for transition scholars and researchers in related fields.

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Environmental Social Sciences
Eawag - Swiss Federal Institute of Aquatic Science and Technology
Contact person: Johan Miörner
Überlandstrasse 133, 8600 Dübendorf, Switzerland
Tel.: +41-587-656493
E-Mail: johan.miorner@eawag.ch
https://www.eawag.ch/en/department/ess/

Department of Geography and Regional Research
University of Vienna
Contact person: Michaela Trippl
Universitätsstraße 7/5/A0528, 1010 Vienna, Austria
Tel.: +43-1-4277-48720
E-Mail: Michaela.trippl@univie.ac.at
https://humangeo.univie.ac.at/