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Assessing transitions through socio-technical configuration analysis – a methodological framework and a case study in the water sector

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ABSTRACT

Classic accounts of transitions research have predominantly built on reconstructions of historical transition processes and in-depth case studies to identify and conceptualize socio-technical change. While such approaches have substantively improved our understanding of transitions, they often suffer from methodological nationalism and a lack of generalizability beyond spatial and sectoral boundaries. To address this gap, we propose a novel methodology – socio-technical configuration analysis (STCA) – to map and measure socio-technical alignment processes across time and space. STCA provides a configurational and dynamic perspective on how social and technical elements get aligned into "configurations that work", allowing for the identification of differentiated transition trajectories at and across spatial and sectoral contexts. The methodology's value is illustrated with the empirical case of an ongoing shift from centralized to more modular infrastructure configurations in the global water sector. Building on this illustration, we outline potential contributions of STCA to configurational theorizing in transition studies, sketching the contours of what we believe could become a generative epistemological approach for this field.

1. Introduction

Understanding fundamental sector transformations has become a major field of research in innovation studies and related social science disciplines (Smith et al., 2010). In particular, sustainability transition studies have coined key conceptual and analytical frameworks to reconstruct transformation processes in a broad variety of sectors such as energy, water, food, transport or public health (Markard et al., 2012). One of the core tenets of this literature is that sectoral transformations have to be understood as reconfigurations of sociotechnical systems (Geels, 2002). At the core of theorizing lies the alignment of actors, technologies and institutions into socio-technical "configurations that work" (Rip and Kemp, 1998). This implies that if a certain set of actors, institutions and technologies is well-aligned and deeply institutionalized, a sector will evolve along rather narrow trajectories for long periods of time before a deep structural reconfiguration can take place (Markard et al., 2012, Geels, 2004, Markard and Truffer, 2008, Levinthal, 1998).

Due to the complex and systemic nature of socio-technical change processes, the vast majority of transition studies draws on historical or qualitative case studies. These enable a detailed reconstruction of the dynamic realignment processes between technological and institutional elements, and of struggles between proponents and opponents of newly emerging socio-technical configurations (e.g. Geels, 2002). Moreover, even though transition studies have moved beyond historical reconstructions of technology substitution processes and adopted a wide variety of methodological approaches, most studies still remain restricted to in-depth reconstructions of transition processes in specific urban, regional or national contexts (Hansmeier et al., 2021). As a result of this implicit methodological nationalism (Coenen et al., 2012, Hansen and Coenen, 2015, Binz et al., 2020), transition research tends to emphasize context-sensitivity, blurring the fact that many of the relevant alignment and change processes are driven by forces operating at international/transnational levels and in between several places at once (Sengers and Raven, 2015, Binz and Truffer, 2017, Fuenfschilling and Binz, 2018, Bauer and Fuenfschilling, 2019, Heiberg et al., 2020, Miörner and Binz, 2021).

More substantively, over-relying on singular case studies implies that cross-comparisons and generalizations between transition trajectories in different spatial or sectorial contexts remain a challenge. This is likely to

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hamper progress in the future theoretical development of the field (Alkemade, 2019, Andersen et al., 2020). One of the methodological challenges is that evolving configurations - i.e. complex, dynamic relationships between interconnected variables - underpin transition dynamics, rather than a set of independent variables, as assumed in conventional statistical methods and correlational theorizing. A move towards more "configurational theorizing" thus requires methodologies that are able to capture and visualize complex interaction patterns and interdependencies between relevant variables (Weber and Truffer, 2017, Furnari et al., 2020). Hence, we propose a novel, semi-quantitative methodology for mapping shifts of socio-technical configurations over space and time, which we call 'socio-technical configuration analysis' (STCA). The STCA methodology builds on - and substantially extends - a recently established method from the political sciences known as Discourse Network Analysis (DNA) (Leifeld, 2017). We adapt this method in a way that allows to assess (dis-)alignments among actors, institutions and technologies in transition processes.

STCA builds on the coding of network ties among actors and concepts. Concepts may encompass technological solutions, formal rules and regulation, policy measures but also more intangible institutional structures, such as norms, values or logics, which are recorded from any type of textual data. We identify ties between actors and concepts through actor statements recorded in public newspapers and expert magazines in which they relate to technological and institutional concepts. Newspapers and magazines have increasingly been used as sources to capture discursive dynamics in transition studies and economic geography (Geels and Verhees, 2011, Rosenbloom et al., 2016, Meelen et al., 2019, Ozgun and Broekel, 2021). Discourses are defined by the ideas or concepts through which actors ascribe meaning to material or non-material artefacts of the world around them (Hajer, 2006). Recent research has suggested that so-called "critical moments", defined as "events that allow negotiation of meanings, formulation or reformulation of dominant discourses" (Yuana et al., 2020, p. 157), provide contexts in which discursive battles are crucial for understanding transition dynamics. By drawing on documents that capture the evolution of a discourse during critical moments, our approach enables a semi-quantitative reconstruction of the temporal and spatial (dis-) alignments of socio-technical configurations. Mapping different actor statements around institutional and technological concepts as relational structures (networks), we are able to depict the emergence of new, as well as shifts in the dominance of existing socio-technical configurations. The qualitative basis of the data, in turn, enables the identification of key mechanisms and actors that drive these reconfiguration processes.

As an illustrative case, we apply STCA to statements made by actors in national newspapers and global industry magazines about how to respond to challenges in the urban water sector. Conceptually, we follow Fünfschilling and Truffer (2014) in depicting socio-technical transitions as shifts in the most highly institutionalized core of an organizational field (DiMaggio and Powell, 1983, Scott, 1991). Actor statements are interpreted as exemplary voices on how to best solve key challenges in a given field. Coherent combinations of such statements – which we will call "storylines" in the following – can be interpreted as proxy measures for currently existing or future imagined socio-technical configurations. We expect that, during critical moments, the configurations that are compatible with a prevailing regime will be more coherent and voiced by more numerous and more powerful actors than newly emerging configurations. Therefore, socio-technical transitions or reconfiguration processes will be mirrored by shifts in the kinds of storylines that actors mobilize in a field's discourse. During and across critical moments, one might expect to see shifts from one (or several) well-aligned configurations to new one(s), mirroring the de- and re-institutionalization of old and novel regime structures over time.

While STCA can be applied to a wide variety of transition dynamics, we will here limit ourselves to presenting an illustrative case: retracing the multi-scalar discursive dynamics before, during, and after a recent critical moment in the evolution of the urban water management (UWM) sector. This sector has historically developed a highly institutionalized and globalized socio-technical regime, which builds on centralized treatment and bulk transports of water through sewers and water pipes and a state- or market- based governance model dominated by large utilities (Fuenfschilling and Binz, 2018, Larsen et al., 2016). In face of increasing environmental pressures like droughts and flooding in several places around the world, decentralized, modular and community-based solutions have been promoted as a potentially more sustainable alternative (Hoffmann et al., 2020, Larsen et al., 2016). Yet, the uptake of these new socio-technical configurations is still limited in most places and has shown great spatial variation (Heiberg et al., 2020). We will apply STCA to a selection of 576 articles drawn from 70 national and international newspapers during an eight year period from 2011-2018, covering major drought and flood events, which we interpret as critical moments for the UWM sector. This enables the mapping of ongoing (dis-)alignment processes around technological and institutional concepts related to centralized and modular water infrastructures. From this analysis, we identify transition potentials in different countries, derive spatially differentiated development pathways and discuss implications of the approach for policy and industry strategies. Furthermore, by retracing shifts in international expert discourses, we may check whether the national transformations are mirrored by changes in the "global socio-technical regime" (Fuenfschilling and Binz, 2018) or whether they largely remain local/national phenomena.

The paper is organized as follows. Section 2 outlines the conceptualization of transitions as spatially and temporally differentiated (dis-) alignments of alternative socio-technical configurations, and elaborates how discourses can be used for retracing the corresponding dynamics. Section 3 introduces the STCA methodology and illustrates how it can be used for retracing socio-technical reconfigurations over time and space. Section 4 illustrates the application of STCA to our empirical case in the UWM sector. Section 5 discusses the implications of our findings and outlines the contours of a broader research agenda leveraging the full potential of the STCA methodology.

2. Mapping and measuring the (dis-)alignment of socio-technical configurations through a discursive lens

In transition studies, the structural transformation of sectors is essentially conceptualized as the "destabilization or de-institutionalization of existing socio-technical configurations and the creation and diffusion, hence institutionalization, of new ones" (Fuenfschilling, 2019: 2). Transitions occur when well-aligned and stable socio-technical configurations - the combination of technologies, actor networks, and institutions that have co-evolved and stabilized over long periods of time - start to get supplanted by one or several alternative configuration(s) with new core values and technologies. The electricity sector, for example, faces a transition from centralized fossil and nuclear power generation and long-distance power grids towards decentralized smart-grid connected renewable energy technologies. Typically, these transformations are accompanied by major shifts in the underlying rule sets – also called the 'regime', 'grammar' or 'deep structure', which guide the practices of actors in a field (Geels, 2002). To understand a transition, one has to explain how regime shifts come about, i.e. how certain institutional and technical elements get re-aligned or displaced by new ones to converge into new socio-technical configurations that work. This contribution aims at formulating a new methodological approach for mapping and measuring such reconfiguration processes. To do so, we first have to elaborate on how to conceptualize the relevant dynamics.

2.1. Socio-technical configurations as alignments of actors, technologies and institutions in organizational fields

As a conceptual starting point, we adopt a neo-institutional perspective on socio-technical transitions, which understands

transitions as reconfigurations in organizational fields (Fuenfschilling, 2019). Fuenfschilling and Truffer (2014), building on Thornton and Ocasio (1999) and DiMaggio and Powell (1983), argued that this perspective enables conceptualizing socio-technical change processes in a less categorical and rigid way than the conventional distinction of regime, niche and landscape structures (Hoogma et al., 2002, Geels, 2002, Rip and Kemp, 1998). Organizational fields are defined as the aggregate of organizations that define "a recognized area of institutional life", as for example an economic sector with competing companies, users, consumers and regulators (DiMaggio and Powell, 1983, p.148). More recently, this definition has been extended to an understanding of fields as relational spaces in which various organizations interact in collective sense making processes around organizational and field level processes (Wooten and Hoffman, 2016). In this context, socio-technical regimes can be understood as the most highly institutionalized elements in an organizational field (Fuenfschilling and Truffer, 2014). Transitions can accordingly be understood as emerging socio-technical configurations, whose social and technical elements get more aligned and institutionalized as they mature and start to reshape previously dominant configurations in the field. Structural change may take a wide variety of forms, from a linear substitution of established regime structures by an upcoming niche configuration (as presented in much of transitions literature), but also all sorts of hybridization dynamics, such as those which Smith and Raven (2012) called stretch-and-transform or fit-and-conform patterns. Our argument thus resonates with recent calls for developing more multi-dimensional and configurational theorizations of transition trajectories (such as Fuenfschilling, 2014, Geels et al., 2016, van Welie et al., 2018).

The institutional view on transitions, furthermore, enables the qualification of regime structures as more or less strongly institutionalized socio-technical alignments at any moment in time (Fuenfschilling and Truffer, 2014, van Welie et al., 2018). Fünfschilling and Truffer (2014) argued that the strength of a regime in guiding actor strategies is, among others, dependent on the number of competing field logics present in the corresponding organizational field. Field logics constitute coherent bundles of institutional logics which are defined as the "socially constructed (…) values, beliefs, and rules by which individuals produce and reproduce their material subsistence, organize time and space, and provide meaning to their social reality" (Thornton and Ocasio, 1999, p. 804). A strong regime is characterized by a strongly aligned and deeply institutionalized socio-technical configuration, which responds to a single and largely uncontested prevailing field logic. A weak regime, instead, would be characterized by (several) poorly aligned socio-technical configurations, which have to accommodate several competing field logics (Fuenfschilling and Truffer, 2014). The organizational field as a whole will, in general, hold a variety of more or less strongly aligned and institutionalized socio-technical configurations composed of technological and institutional concepts that get promoted by diverse actor coalitions. The conventional view of a transition playing out between a single dominant regime, getting challenged and ultimately overthrown by a single niche, therefore, represents only one (and arguably a rather special) case among many potentially relevant transition trajectories (van Welie et al., 2018, Geels et al., 2016).

2.2. Mapping and measuring re-configuration dynamics through discourses

The empirical assessment of change in socio-technical configurations requires a detailed capturing of the dynamics that lead to the (dis-) alignment of actors, institutions and technologies. In most transition studies so far, socio-technical alignments were identified by tracing reconfiguration processes through in-depth historical and qualitative case studies (Hansmeier et al., 2021). This approach provided deep insights into core mechanisms that drive specific transition processes, but made it rather difficult to generalize findings across different technologies, sectors, time periods or spatial units (Svensson and Nikoleris, 2018, Sorrell, 2018). One of the reasons for the prevalence of this methodological approach is that compared to other realms of innovation studies, – e.g. those focusing on knowledge dynamics, which can be measured (partially) through global patent and publication databases – there are no comparable systematic and extensive stocks of data that would enable to map socio-technical (dis-)alignment dynamics with quantitative methods.

In order to overcome these limitations, we here propose a methodological approach, which builds on textual recordings of discourses. Hajer (2006, p.67) defines discourse as the "*ensemble[s] of ideas, concepts and categories through which meaning is given to social and physical phenomena, and which is produced and reproduced through an identifiable set of practices*". Discourses serve as a suitable lens to reconstruct changing configurations because they reflect different actors' arguments for or against the need for change in a given field. Especially in critical moments, actors will be compelled to publicly voice their opinions in order to control for problem definitions, the assumed nature of future challenges, or influence how contradicting values will be considered in future development pathways (Seo and Creed, 2002, Wooten and Hoffman, 2016, Yuana et al., 2020).

Discursive approaches have already been applied to various problems in socio-technical transition studies. They have been used to analyze strategies of transition proponents (Raven et al., 2015, Smith et al., 2014, Smith and Raven, 2012), the building and maintenance of legitimacy for specific technologies (Geels and Verhees, 2011), the semi-coherence of socio-technical regimes (Fuenfschilling and Truffer, 2014), and the formation of socio-technical storylines, e.g. through the translation of landscape pressures in proponents' and opponents' framing activities of different socio-technical concepts (Rosenbloom et al., 2016, Yuana et al., 2020).

Discourses thus provide useful proxy measures for identifying patterns, dynamics and strategies through which socio-technical configurations may develop, align, stabilize or get challenged. We interpret alignments in these configurations as follows: If during a critical moment, a specific concept, say a technology or value, is used in congruence with a large number of other concepts in the larger discourse, we would argue that it has a higher potential to become a highly institutionalized part of the regime. Its congruence with many other concepts indicates compatibility and hence easier alignment with regime structures than more peripheral concepts that are only used in an isolated fashion causing friction with taken-for-granted beliefs. A cluster of closely aligned concepts, may thus be interpreted as a (socio-technical) "configuration that works" (Rip and Kemp, 1998), while loosely connected clusters may be attributed to less mature socio-technical configurations. The more coherently concepts are co-framed positively (or negatively) in actor's statements, the more strongly aligned the configuration will be.

One key advantage of this methodological approach is that extensive textual databases exist, through which statements about socio-technical concepts can be empirically assessed. Potential databases comprise a wide array of secondary textual media, such as newspapers, conference proceedings, government protocols, online blogs, social media platforms or industry magazines, but also primary data like interview transcripts. Textual data sources that cover different spatial and/or temporal contexts furthermore enable researchers to analyze developments over time and to compare between geographical or sectoral contexts in a systematic way. STCA, in particular, improves our ability to retrace the geography of socio-technical transition processes, since it allows to empirically assess how transition proponents and opponents voice their opinions differently in different arenas or layers of the socio-technical system (Smith et al., 2014, Miörner and Binz, 2021). As an example, we can distinguish conceptually between expert discourses that are forming in the globalized professional expert circles of a sector (i.e. the global regime), and public policy discourses that are carried out by actors embedded in specific national/regional/urban spatial subsystems (Miörner and Binz, 2021). In the global regime layer, internationally

operating companies, NGOs, consultants or investors will divergently evaluate certain technical approaches and engage in battles around the directionality of their field at international conferences, trade fairs, as well as in professional industry magazines, blogs, etc. In territorially embedded layers, in contrast, discursive battles will be fought in the context of national, regional or even urban policy arenas. The relevant statements might in turn be staged in local/regional/national newspapers as well as in parliamentary debates, roundtables, policy fora, and the like.

3. Socio-technical configuration analysis (STCA)

Based on the above conceptual framing, we will now elaborate the STCA methodology in more detail. We depart from an established method in political sciences, Discourse Network Analysis (DNA, Leifeld, 2009, Leifeld and Haunss, 2012, Leifeld, 2017), which was originally developed to analyze policy debates. The core idea of DNA rests on generating relational data structures that connect actors with different beliefs, arguments or policy stances (Leifeld, 2009, Leifeld, 2017). Based on these relations, DNA can on the one hand be used to study "advocacy coalitions" (Sabatier, 1988), which are operationalized through actor congruence networks, where links between actors are established based on their similar (congruent) statements around a given concept. On the other hand, the same approach can also be used to analyze prevalent "storylines" in a policy discourse. Here, concepts are aggregated into so-called concept congruence networks. If two concepts are uttered in tandem by the same actor(s), this implies some degree of ideological and intrinsic compatibility between them. Congruent supportive or obstructive statements around several concepts can then be interpreted as coherent storylines (for such an operationalization see also Leifeld and Haunss, 2012). The content of these relational data may then either be represented in so-called affiliation or two-mode networks, or in one-mode projections as actor or concept congruence networks.

DNA has already been applied in socio-technical transition studies, mostly to analyze political advocacy coalitions and public policy debates related to sustainability transitions (Schmidt et al., 2019, Schmid et al., 2020). STCA builds on the intuition of these approaches but expands far beyond the realm of policy debates. Rather, similar to Geels and Verhees (2011) and Konrad et al. (2012), it perceives societal, political and professional discourses as a relevant proxy measure that mirrors prevailing socio-technical configurations.

As Geels and Verhees (2011) have shown, the proponents and opponents of a given technological solution do not only evaluate its performance, but also consider its meanings in broader social, political, economic, ecological, or spatial contexts. Hence, STCA captures how individual organizations evaluate technologies, infrastructures, policies, regulations or sectoral paradigms and norms. Drafting actor congruence networks then enables us to map actor coalitions that share certain rules, norms, interests, visions and beliefs about appropriate solutions for a prevalent problem. Concept congruence networks, in turn, enable us to assess how closely different concepts are aligned with each other. The visual inspection of these networks can be complemented with network statistics, which enable to infer the degree of institutionalization of specific concepts and configurations as well as the tracing and comparison of reconfiguration patterns across time and space.

As a prerequisite for such an analysis, the textual data from which the analysis is derived, needs to be a representative sample of the respective socio-technical field's discourse. It is therefore important to make sure that, for example, newspaper articles cover the full diversity of diverging views (and editorial stances) on a certain topic, or that interviewees represent a broad range of perspectives in a specific field. Oftentimes, in socio-technical discourses, researchers will have an expectation regarding important actors and positions. If these do not appear in the data, then the data sources may need to be improved or extended or initial assumptions revised until theoretical saturation is reached (i.e. adding additional data sources does not change the overarching storylines anymore).

In the remainder, we will mostly elaborate on how to interpret concept congruence networks, since they are most useful for analyzing shifting socio-technical configurations. In figure 1, three ideal-type constellations are presented, which might be interpreted as shifting socio-technical configurations in an organizational field. At a most basic level, socio-technical configurations are identifiable as sub-networks of technological and institutional concepts, which are more strongly interlinked among themselves than with other concepts. The width of the links between concepts reflects the strength of their mutual alignment. Furthermore, we differentiate shapes and colors of symbols in order to denote attributes of the concepts. Following Fuenfschilling and Truffer (2014), we position concepts in a 'radar plot' in order to differentiate between 'central' and more 'peripheral' concepts.

Radar plot I depicts a configuration with strongly aligned technologies and institutional concepts (solid filled nodes), which can be interpreted as representing a socio-technical regime. The pattern-filled, more peripheral cluster of nodes represents a competing socio-technical configuration of technologies and institutional concepts that is less aligned with the majority of other concepts and supported by fewer and more peripheral actors. In plot II, concepts of the peripheral configuration are getting partly integrated into the regime structure, which thus becomes hybridized. Plot III, then, shows a reconfigured regime constellation, that resulted from a merger of the formerly distinct configurations.

Eq**u**ipped with this conceptual intuition, we may now further operationalize the framework with network indicators that allow for a deeper characterization of configurations in concept congruence networks. First, we propose two measures for assessing the **degree of institutionalization** of a given concept: Its degree centrality and the frequency of its use. *Degree centrality* measures the number of other concepts that a concept is linked to in the discourse. In actor networks, a person with a high degree centrality can be interpreted as "a major channel of relational information, […] occupying a central location" (Wasserman and Faust, 1994, p. 179). In concept congruence networks, degree centrality reflects the number of other concepts that have been co-mentioned in a congruent way. A central concept is therefore one, which is used congruently with many other concepts. Visually, a concept's degree centrality score may be represented by its position in a radial centrality layout (Baur, 2008). Concepts in the core of the radar plot thus denote the 'core' of a discourse in a given point in time.

The degree of institutionalization of a certain concept can, however, not solely be read from the position on the radar plot. It also depends on the number of actors who have endorsed it in a given period. The more different actors have used a concept in their statements, the more prevalent that particular concept is. Especially in critical moments, one can assume that concepts that are more prevalent in the discourse also have a higher degree of institutionalization. Visually, the number of actors using a concept is captured by the size of each node.

A given concept's degree of institutionalization can thus be inferred from a combined view on both measures. I.e. a large node (concept used by many different actors) with a high degree centrality (positioned close to the core of the radar plot) arguably has a high degree of institutionalization. A small node (few actors using the concept) with low degree centrality (positioned at the fringe of the radar plot) represents a rather peripheral concept in the overall discourse with a lower degree of institutionalization.

As a second analytical step, we turn the focus to identifying congruent storylines - i.e. clusters of technological and institutional concepts that are strongly aligned with each other, thus representing a coherent socio-technical configuration. The **alignment between concepts** can be operationalized by a normalized edge weight that considers the similarity of two concepts in terms of the organizations that have used them congruently. To this end, we calculate each concept pair's jaccard similarity (Gower and Legendre, 1986). Jaccard similarity (s) is expressed as:

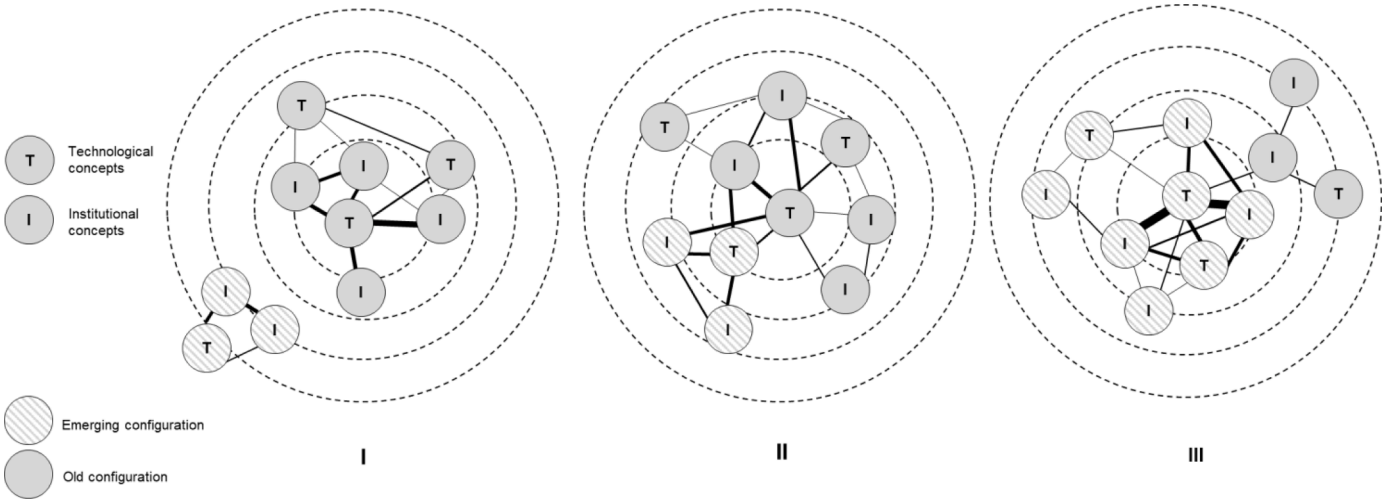

Fig. 1. Socio-technical configurations as alignments of technological and institutional concepts. Own illustration.

$$s = \frac{a}{(a+b+c)},$$

where $n11 = a$, $n10 = b$, $n01 = c$ *and* $n00 = d$

Where a represents the number of organizations that have used both concepts congruently (n11). The sum of a, b and c represents the number of organizations that have referred to both *and* either one *or* the other of the two concepts (n11 + n10 + n01). d represents the case of no joint referral (n00). If s turns 1, then numerator and denominator are the same, meaning that two concepts are always used in congruence, as no organization uses one without also using the other. An s close to 0, instead, indicates two concepts that are only rarely used congruently. Accordingly, a jaccard index of 1 or close to 1 indicates a more coherent storyline than an index value close to 0. We visualize the alignment between concepts accordingly by setting the shading and the width of an edge according to its jaccard index value. This way concept clusters, and hence coherent storylines, may be detected through the visual inspection of the graph. Clustering techniques could further be applied for the quantitative detection of coherent socio-technical configurations.

As a last analytical step, one may turn to the **overall composition of the concept congruence network**, which indicates whether and how strongly different socio-technical configurations in a field are aligned with each other. In some cases, different configurations will be largely isolated from each other, thus hinting at a fragmented or splintered regime structure. In other cases, different configurations may show strong overlaps, hinting to a hybridized polycentric or even monolithic regime structure. We use a combination of aggregate network indicators here. First, *network density* is calculated to assess the proportion of actual links compared to the maximally possible links among all concepts in the network (Wasserman and Faust, 1994). The higher the density, the more connected are the concepts in a graph, hence, the more aligned are the core storylines presented in the discourse during a certain period of time. Second, *average degree* and the *average number of actors per concept* reflect the average alignment of concepts with each other, and the average amount of actors behind concepts. In future research, these measures may be enriched with additional indicators for overall network composition, as e.g. global clustering or cohesion coefficients. As an illustration inspired by our empirical case, figure 2 presents a hypothetical concept congruence network in the UWM sector. The blue dots represent a well-aligned socio-technical configuration that connects (here randomly chosen) concepts like key technologies (T), regulations

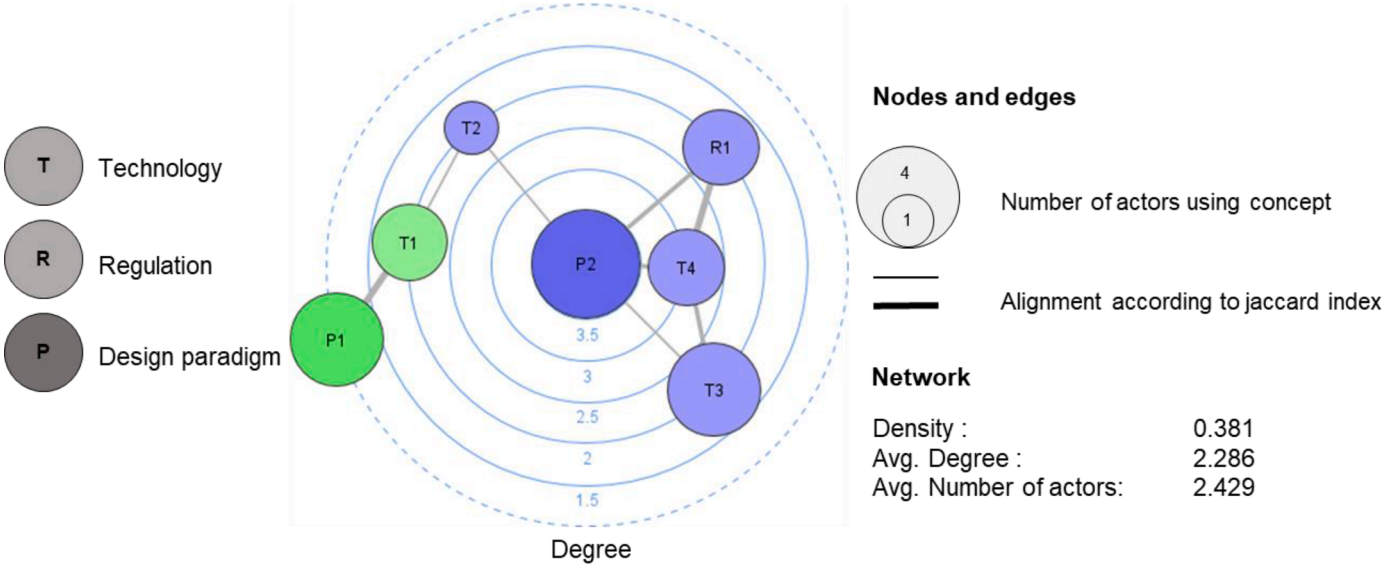

Fig. 2. Hypothetical, illustrative concept congruence network in the UWM sector. Colors reflect concepts associated with centralized (blue), or decentralized (green) water infrastructures. Own figure.

(R), and infrastructure paradigms (P) around centralized water infrastructures. Green dots in turn represent a more emerging configuration around modular water infrastructures. We may now characterize this network in more detail, based on the analytical procedure outlined above.

Infrastructure paradigm P2 (centralized treatment) constitutes the most deeply institutionalized, core concept of the discourse. It is compatible with four other concepts, resulting in a degree of 4, which is clearly above the average degree of the full network (2.286). Its relatively large node size furthermore indicates that a high number of actors have congruently used the concept. Both indicators thus suggest a high degree of institutionalization for P2. When turning to the identification of coherent storylines, the jaccard normalized edge weights indicate strong alignment between concepts related to centralized water infrastructures, especially P2, T4, R1 and T3. The closed triplets P2-T4-T3 and P2-T4-R1 furthermore indicate that a coherent storyline exists among the blue dots. The overall pattern thus indicates that a deeply institutionalized (regime) configuration exists around centralized water infrastructure. Also the overall density of the network (0.381) indicates that over one third of possible connections between nodes are present, hinting to a rather well-connected overall network structure, which is here driven by the core configuration around centralized infrastructures. The P1-T1 configuration around modular water infrastructure, in turn, is less deeply institutionalized and more peripheral to the overall discourse. Even though a strong alignment exists between P1 and T1, the storyline is only loosely connected to the core storyline in the field. In the remainder, we will apply this methodology to the analysis of socio-technical reconfiguration dynamics during a critical moment in the global UWM sector's recent evolution.

4. Analyzing and mapping recent transition dynamics in urban water management with STCA

The UWM sector constitutes a well-suited empirical case for illustrating the STCA approach, as it is facing strong transformation pressures globally and boasts a complex global actor structure that can be expected to exhibit relevant activities in different locations and at different spatial scales. With an estimated annual investment volume of 500 billion US dollars in 2014, the sector is dominated by private or public water utilities, as well as large multinational equipment suppliers, engineering consultants and service providers like Suez, GE, Dow, Veolia or Thames Water (Lieberherr and Fuenfschilling, 2016, OECD, 2019, OECD, 2018). Next to public investments, also international development banks, and private investors play an increasingly important role (OECD, 2019).

Scholars and practitioners alike are increasingly highlighting the importance of making UWM practices more sustainable, resilient, and fit-for-purpose (Larsen et al., 2016, Hoffmann et al., 2020). Modular, decentralized treatment technologies combined with community-based values play a key role in the storylines by actors pushing for radical change in UWM. Proponents of this alternative socio-technical configuration typically argue that diffusing the conventional, large-scale infrastructure paradigm to the whole world will be difficult to finance, and socially/ecologically damaging (Sadoff et al., 2015, UN-WWAP, 2015, Eggimann et al., 2018, Larsen et al., 2021). The promise of modularized and decentralized technologies, in turn, rests on the hope that they can benefit from "economies of unit numbers" rather than economies of scale at the level of the treatment unit, making them cheaper, more flexible, and more efficient in closing local resource cycles (Wilson et al., 2020, Dahlgren et al., 2013, Larsen et al., 2016).

In contrast to conventional, centralized UWM solutions, modular and decentralized socio-technical configurations are still nascent in many parts of the world. They are pushed by relatively few industrial actors, and with funding and support mostly originating from philanthropy (especially the Bill and Melinda Gates Foundation – BMGF), NGOs, or research and development agencies (OECD, 2019). Yet, based on the continuing transformation pressures in the water sector, we would expect them to be increasingly raised in discourses during critical moments, such as droughts or floods, as viable alternative to the incumbent regime solutions. Incumbents may in turn be expected to react to these storylines by defending the existing regime or promoting solutions that are more compatible with the status quo (here e.g. seawater desalination or large-scale wastewater recycling schemes) (Fuenfschilling and Truffer, 2016, Williams, 2018, Fuenfschilling and Binz, 2018). Thus, empirically, we expect controversial (and potentially shifting) debates around the best-suited technologies, infrastructure paradigms, policies, regulations, and guiding values for dealing with water challenges that revolve around centralized vs. modular configurations.

4.1. Database and methods

Our illustrative application of STCA is based on discursive information collected from global newspaper repositories. We first screened the global repository Nexis Uni for outlets and articles dealing with water problems in various English speaking countries and in international industry magazines during 2011-2018. This period was chosen because it covers critical moments related to severe drought or flooding events in various parts of the world. Well-known examples include the droughts in the South-Western USA between 2011-2017, a major drought crisis in South Africa since 2015, as well as ongoing regional drought and flooding pressures in India (Spinoni et al., 2019, and see A5). A set of 191 outlets classified as quality newspapers and industry magazines by Nexis Uni, plus newspapers from India, South Africa, and Singapore, was filtered with a search query focusing on centralized or modular water technologies. The newspapers and industry magazines were selected in order to cover public discourses in different major cities within the countries analyzed, as well as global sectorial expert discourses in water treatment related sectors such as mining, oil and gas and the chemical industries(for details, see A1). As outlined in A1, our database intentionally covers media outlets with diverging editorial stances (i.e. New York Times, Washington Post, and Christian Science Monitor in the US discourse).

The search query was iteratively built based on the review of secondary literature and interviews with leading technology experts at the authors' home institution, using both general and specific technology terms, to account for potentially changing terms and definitions of configurations used across time and space (for details, see A2). Of initially around 800 articles, 576 articles stemming from 70 outlets were deemed relevant and subsequently coded by two coders with help of DNA-software (Leifeld, 2018). The first author developed and tested a coding scheme (A3) before teaching a second coder in consistently applying it, involving feedback rounds and inter-coder reliability checks. The coding differentiates several innovative water technologies both within the centralized and modular paradigms. Further, we distinguished individual concepts for the centralized vs. modular infrastructure paradigm, and for different types of governance and regulative approaches (i.e. hierarchical utility-based vs. distributed/community-based forms of governance) that actors would mobilize in the context of their statements.

Wherever applicable, direct and indirectly quoted statements by organizations were coded. For each code, an agreement variable specifies if a paradigm, technology, policy etc. was being referred to positively (supportive) or negatively (obstructive). Congruence among concepts may then either emerge from two concepts that have jointly been evaluated positively *or* negatively, as both instances indicate ideological compatibility between the concepts. For example, statements about large-scale desalination and large-scale wastewater reuse might indicate congruence either if they are conjointly rejected by many actors, or if they are conjointly supported by many actors. Eventually, for each code, we captured the dominant spatial scale of the activity of the organization referring to a concept, (i.e. global for multinational companies, (sub-) national for governments or local utilities, etc.), based

on separate desk research. Further, we captured the spatial reach of the newspaper/magazine, in which a statement relating to a concept was published (i.e. global for industry magazines, regional/national for newspaper articles, also see A1). Figure 3 illustrates how we moved from textual data to coding concept-actor affiliations and finally to the projection of concept congruence networks.

The code-co-occurrence matrices created with DNA software were later filtered with the help of R to calculate jaccard normalized concept congruence networks based on the statements of globally and nationally embedded actors. The networks were divided into three time-slices, reflecting shifts in average global drought patterns around the world: 2011-2013 a dry period, however with precipitation slowly returning to average levels, 2014-2016 accelerating droughts globally, and 2017-2018 a continuation of the droughts (A5). The US, South Africa and India stood out in terms of discursive activity (A4; A5). All three countries experienced particularly severe drought in the observed period, which spurred extensive coverage by public media.

The relevant concept congruence networks were analyzed with the above described network measures and were visualized with the software package *visone* (Baur, 2008). The underlying relational datasets of these socio-technical alignment dynamics were further analyzed with help of descriptive statistics regarding key actors and actor types. To this end, we identified the organizations behind all *favorable* statements around the modular or the central paradigm (green or blue in our coding scheme). By favorable, we mean the sum of all supportive or positive statements around concepts associated with one paradigm (e.g. modularization), and all obstructive or negative statements around concepts associated with the respective opposite paradigm (e.g. centralization).

In the remainder, we will present the results for socio-technical reconfiguration processes by global professional experts, and by actors from the three contrasting country cases. These three countries, taken together, account for half of all statements captured from over 30 countries (see App.4).

4.2. Comparing socio-technical reconfiguration dynamics in the global regime for UWM and select national subsystems

The results presented in figures 4-7 enable to systematically cross-compare transition dynamics in different layers of the socio-technical system[1]. The results reveal particularly interesting differences between statements made by global experts, as well as US, South African and Indian actors. We will start out by characterizing each of these cases along the suggested measures of degree of institutionalization and configurational alignments. We will then move to a discussion of observed differences by drawing on insights from the qualitative content analysis and the contextual information on critical moments that is contained in the analyzed newspaper articles.

Reconfigurations in global-scale actor statements

Our data reveals considerable stability in the socio-technical configurations derived from statements of experts in multinational organizations, among which we would expect to find many proponents of the existing global regime (Fuenfschilling and Binz, 2018). Overall stability is reflected by the combined evaluation of the configurations in the depicted networks, and the density score, which remains stable at around 0.22 across all three periods. In terms of degree of institutionalization, it is striking that large-scale wastewater recycling usually appears at the core of the radar plot, having a high degree centrality, which indicates a strong compatibility with many related concepts. Larger node sizes of the most compatible blue nodes further indicate that conventional, centralized concepts have been congruently used by more actors than the modular ones. The 2011-2013 period shows an almost complete separation between centralized and modularized concepts. During 2014-2016, linkages between these two competing configurations become more evident. As node sizes show, the centralized paradigm remains referred to by more actors than other concepts, but the differences among centralized and modular concepts get less pronounced. In the latest phase, water reuse-oriented concepts show the strongest alignment across modular and centralized concepts. Also the number of actors using each concept is similar across the two configurations. The descriptive statistics also show that favorable statements around modular concepts become much more prevalent after the 2014 period. An increasing average degree and overall increasing numbers of statements from the 2014-2016 period onwards, indicate that modular concepts are increasingly being promoted at the global regime level. Additionally, statements around modular technologies become more prevalent and alignments across modular and centralized concepts increase. Yet, apart from the increasing institutionalization of water reuse, we see no strong configurational shifts in this layer, even during critical moments in various places around the world. These external shocks seem to only indirectly affect the discourse in the global professional expert circles, by creating growing compatibilities among modular and centralized concepts in the global regime over time.

To further interpret these patterns, we use the qualitative data from the coded newspaper articles and the actor coalitions underlying each configuration (Figure 5c). The global expert discourse in our dataset is populated with statements made by the largest multi-national water technology companies in the world (Dow, GE, Veolia, Kemira, Grundfos, BASF, LG, Lanxess, Hyflux), as well as several larger engineering consultants, international associations like International Water Association, International Desalination Association, and intergovernmental organizations (UN, World Bank, WEF, WarterAid among others). Looking at the dominant global actor types contributing to the discourse (Figure 5c), we can see that the incumbent regime configuration is dominantly maintained by multi-national companies, whereas the emerging modular configuration(s) depend on international NGOs and charities promoting it. Interestingly, aside from International Organizations and NGOs, also incumbent players like Dow (in 2011), Veolia (2016), and GE and BASF (in the latest period) are promoting modular technologies explicitly in their statements. While the evidence is still spurious, this development may indicate an emerging shift in global regime discourse for the period after 2018. The BMGF appears as an important and stable proponent of modular and decentralized UWM approaches from around 2014 onwards, which coincides with the launch of their global "Reinvent the toilet challenge" and other related global lobbying activities (Eckhoff and Wood, 2011, Miörner and Binz, 2021).

Concept reconfigurations based on statements from US actors

Whereas the global expert discourses suggest a pattern of stability and path-dependency, statements by US actors indicate more dynamic reconfigurations. Figure 5 illustrates a strong increase in statements during the 2014-2016 period. This coincides with the major drought in California and other South-Western States (NIDIS, 2018, Spinoni et al., 2019, A5), which found strong resonance in US media. Overall, network density is rather stable between 2.3 and 2.1, showing more separated concept configurations in the earliest phase, reflected by individual solutions proposed by individual actors. This gradually shifts towards more complex configurations in the latest phase. Both in terms of degree centralities and numbers of actors, the centralized paradigm is most institutionalized in the first phase. This changes drastically during the drought period, when alternative, modular concepts gain salience. While concepts related to the centralized paradigm like desalination and large-scale wastewater reuse remain very prevalent, we see a more strongly aligned new configuration around packaged-treatment plants, onsite energy-water systems and rainwater harvesting, which puts the modular paradigm to the center of the discourse. A configuration of various new concepts starts to challenge the dominant configuration around centralized technologies. The modular configuration then

[1] Note that edge width and color are calculated individually for each radar plot. Thus, a specific edge width and shading might not reflect the exact same Jaccard value comparing across phases and cases.

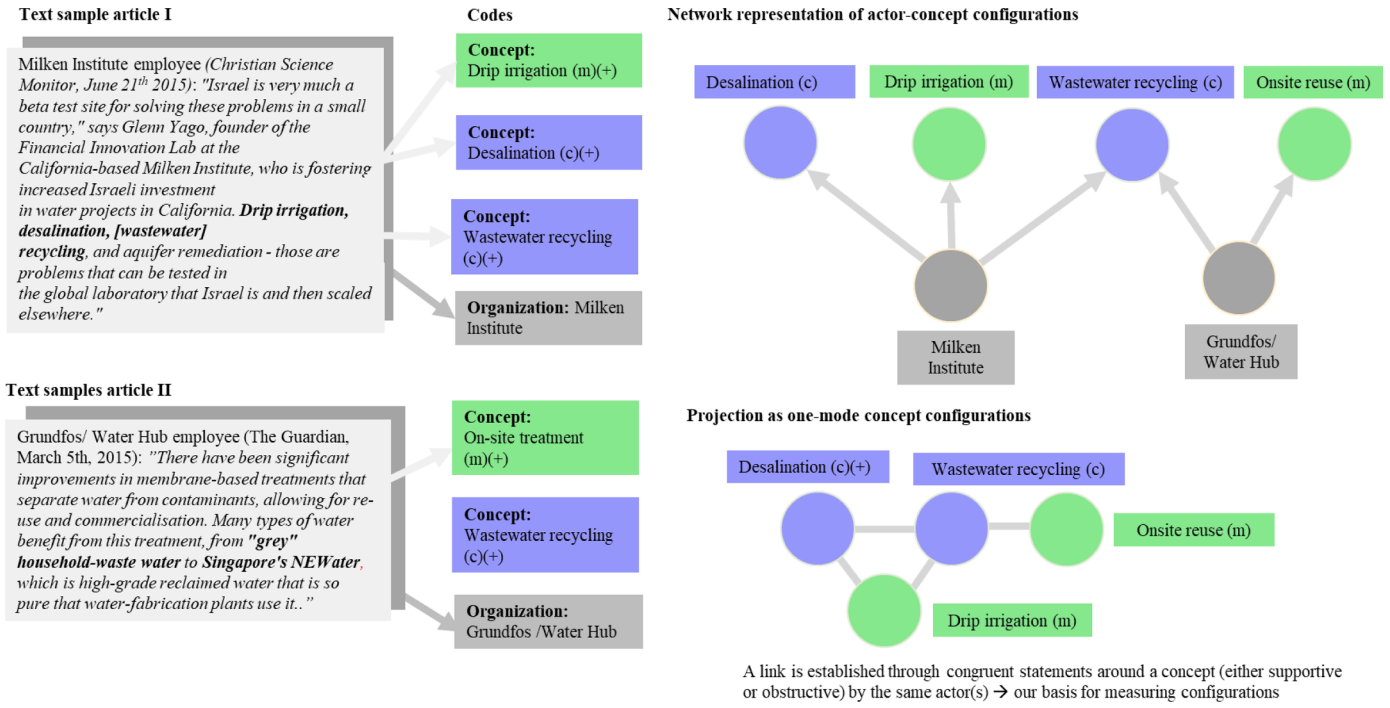

Fig. 3. From statements to actor-concept affiliations and further to concept configurations. Own figure

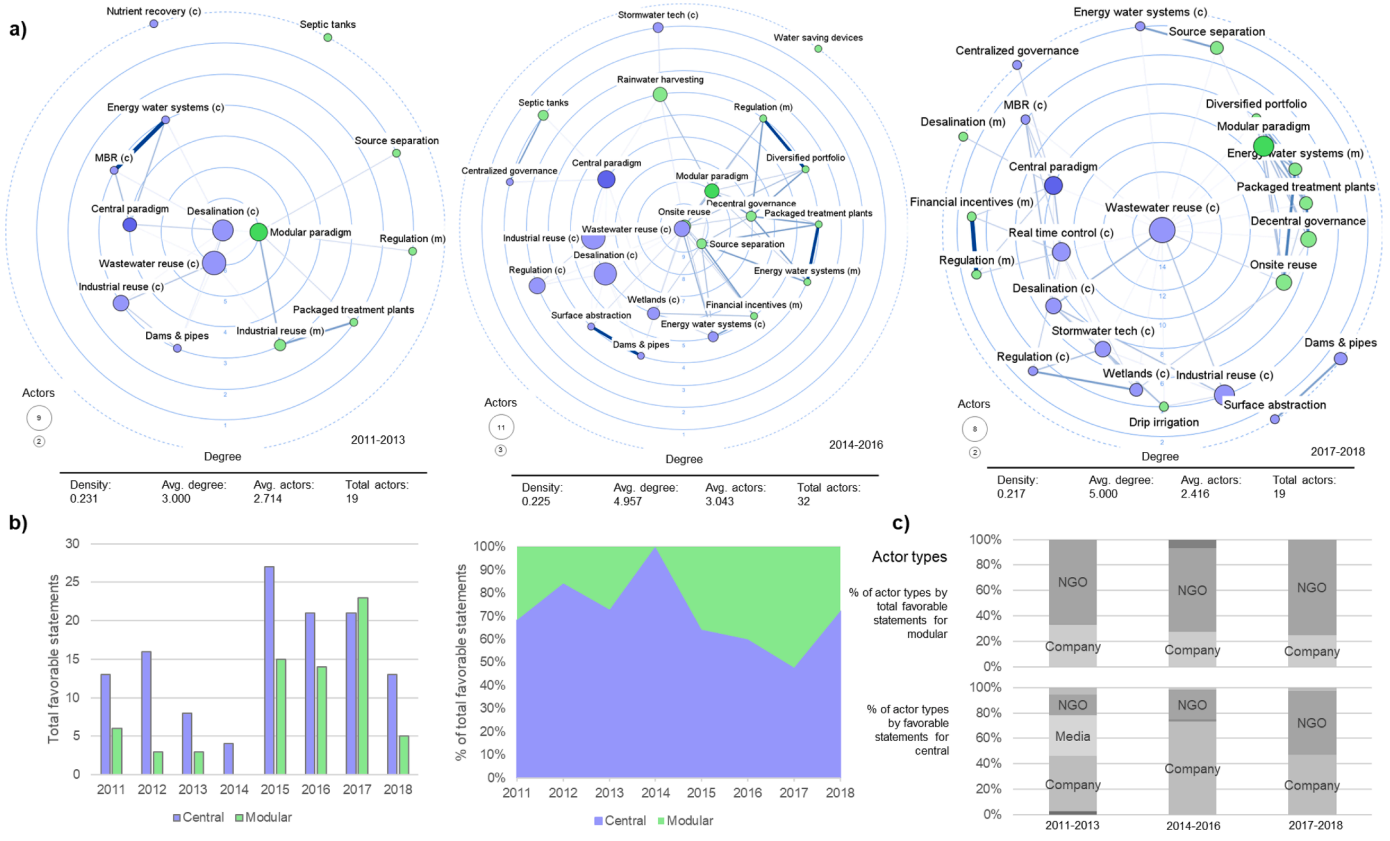

Fig. 4. a) Dynamics in socio-technical configurations based on global actors' statements, three phases. Blue: Conventional, centralized water systems, Green: Emerging, modular water systems. **b)** Total and % of annual favorable statements for centralized (blue) and modular (green) elements. **c)** Dominant actor types as % of favorable statements, three phases.

remains prevalent and visible also in the latest phase, which indicates that its overall institutionalization has increased in the period of interest. Overall, our data thus suggest a configurational shift away from centralized technologies towards modular approaches in the US.

A look at the actor type distribution (Figure 6c), and the qualitative data in the articles confirms this picture. Whereas the actor coalition

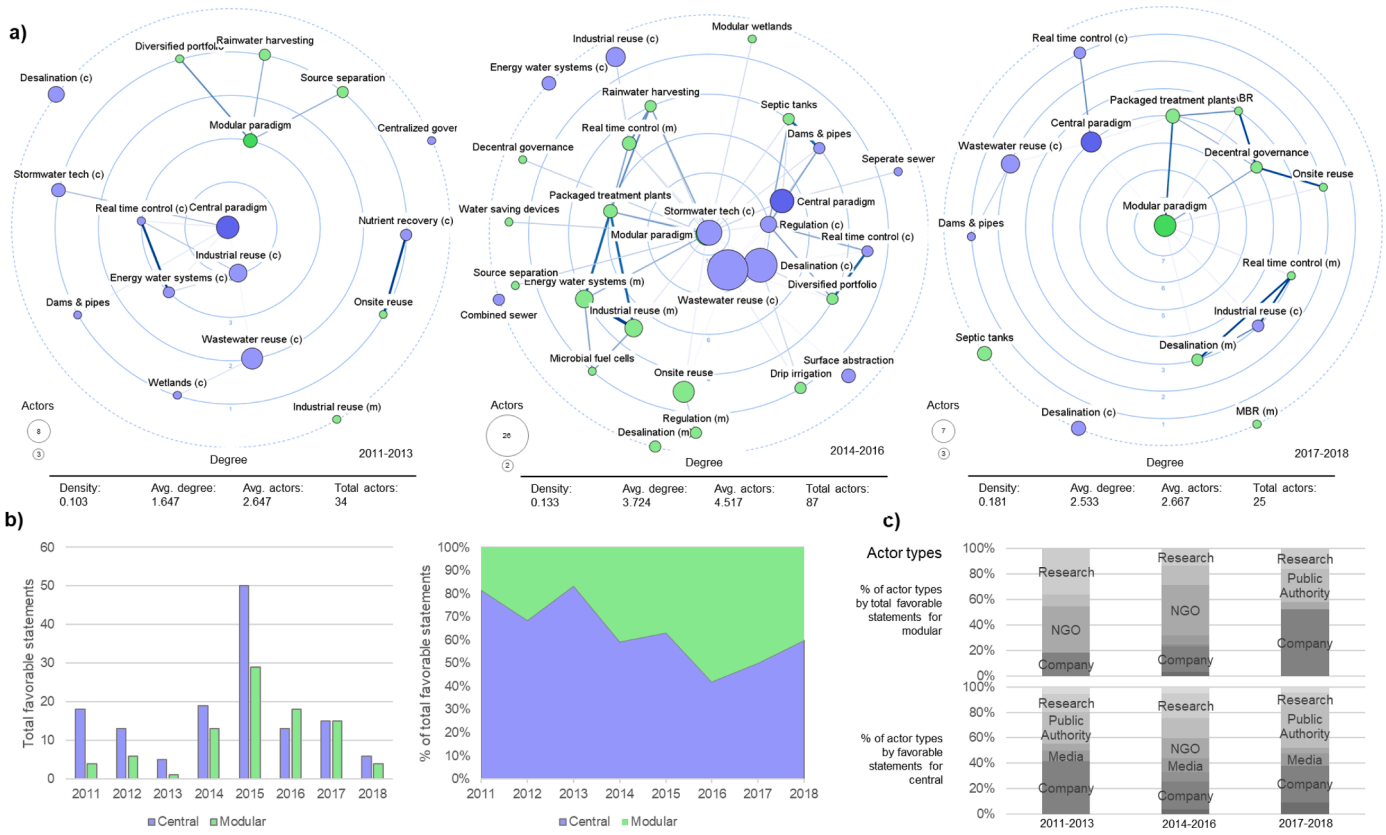

Fig. 5. a) Socio-technical configurations based on US actors' statementstatements, three phases. Blue: Conventional, centralized water systems, Green: Emerging, modular water systems. **b)** Total and % of annual favorable statements for centralized (blue) and modular (green) elements. **c)** Dominant actor types as % of favorable statements, three phases.

advocating classic regime concepts (large firms, public authorities, research institutes) remains stable throughout the whole period (only with some smaller deviation during the drought), the actor coalition supporting modular UWM technologies has structurally changed its composition. While in the beginning, NGOs and research institutes dominated the discourse, public authorities and companies gain prominence in later phases. We would interpret this pattern as an increasing maturation of the innovation system around modular water technologies in the US. The qualitative data reveals that while in the beginning the modular configuration is promoted by smaller charities and larger universities (CalTec, Harvard, and Stanford), after 2014 new actors enter the discourse. Especially Californian actors contribute to a big surge in supportive statements around 2015 and 2016 (Figure 6a). This is particularly driven by NGOs and research institutes such as the Arid Lands Institute, the Pacific Institute, or Greywater Action, as well as UC Berkeley and Stanford University, who are combining emerging and core configurational concepts in their storylines. At the same time, also political stakeholders, especially from the city of San Francisco, appear as new supporters of modular greywater systems at the building scale (onsite non-potable reuse). Large-scale desalination, a typical regime concept pushed in 2011-2013, gets highly disputed in California during 2014-2016. At the federal level, NGOs like WateReuse or the US Water Alliance, as well as a larger producer of packaged treatment systems (Cambrian Innovation) also gain prominence in the discourse.

Concept reconfigurations based on statements from South African actors

Similar to the US, South Africa was hit by a major drought during 2015 and 2016 (Spinoni et al., 2019, A5), which is similarly reflected by an increasing number of statements coded after 2015. The South African data, however, suggest different reconfiguration dynamics. First of all, overall alignment of the proposed concepts is consistently higher than among US actors and global experts. Density varies strongly but ranges consistently above 0.3, implying that configurations proposed by South African actors are overall slightly more aligned than in the US. During 2011-2013 the network reveals two well-aligned configurations around the centralized paradigm and large-scale reuse and around desalination and industrial reuse. Modular technologies are rarely proposed and if so, then mostly in relation to the two dominant configurations. With increasing drought pressures from 2014 onwards, this pattern gets slightly more blurred. The most institutionalized concepts now revolve around the centralized UWM paradigm but also include modular technologies such as rainwater harvesting and energy-water systems. In the latest phase however, this pattern is reversed, as a more divided regime configuration emerges, in which modular and centralized technologies are not conjointly mentioned anymore. In fact, our alignment measures and node-sizes indicate that modular concepts are only proposed by a very small number of actors whereas the majority of actors continues to support centralized solutions. Thus, unlike US actors and global experts, an increasing institutionalization of modular configurations cannot be observed in South Africa. Our analysis rather suggests that the South African discourse realigns with the dominant global regime configuration.

Prominent proponents of modular concepts in South Africa comprise the Government based in Pretoria, the City of Durban, its local University of KwaZulu Natal and a company with expertise in industrial water treatment. The Government turned towards modular technologies, and especially rainwater harvesting during the 2015-2016 drought, while otherwise heavily investing in large-scale desalination in Cape Town and other places. It fits into the picture that modular rainwater harvesting technologies are most strongly promoted. They require relatively little adjustment of the existing socio-technical regime, since they are relatively low-tech, cheap solutions and are already part of the UWM system in some South African cities (Mwenge Kahinda and Taigbenu,

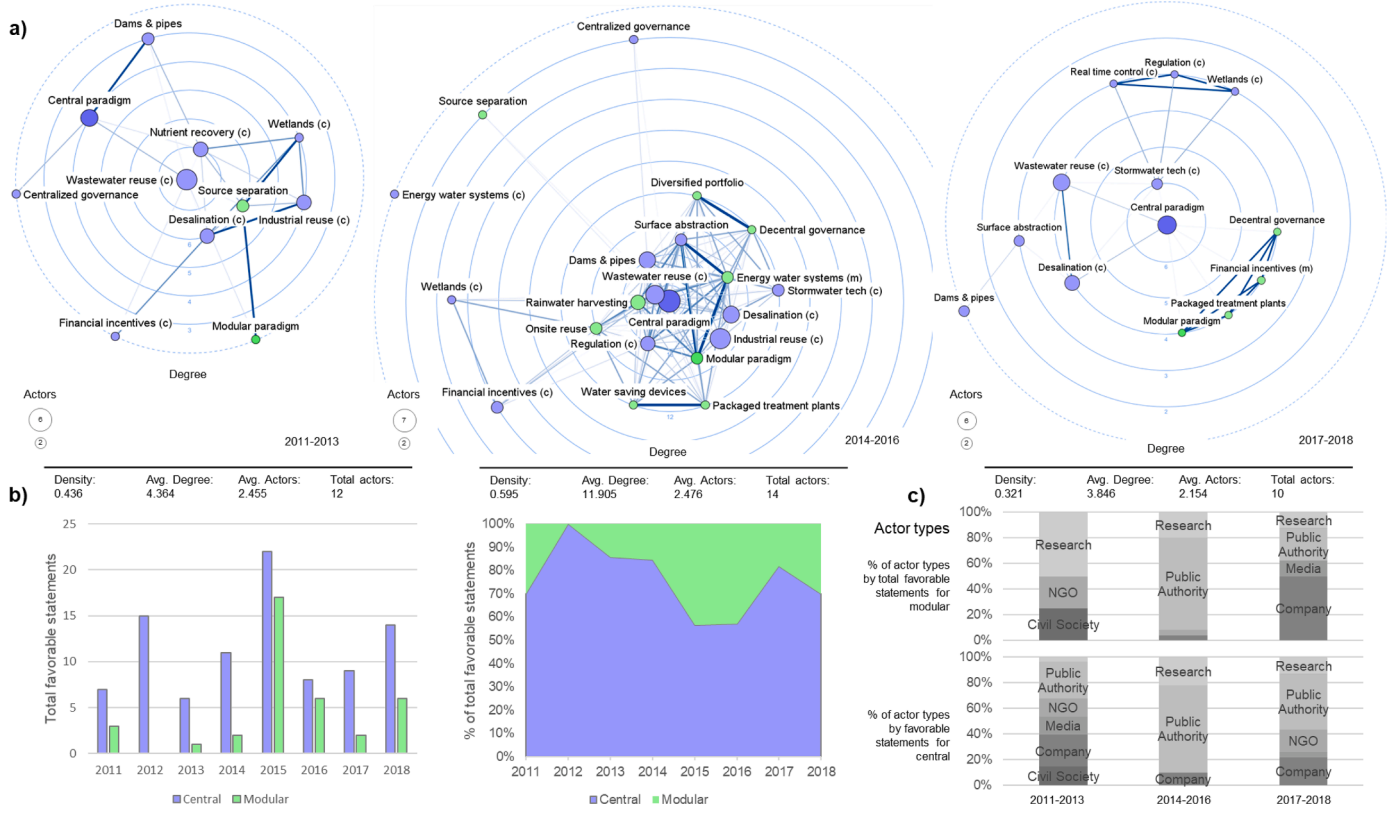

Fig. 6. **a)** Socio-technical configurations based on South African actors' statements, three phases. Blue: Conventional, centralized water systems, Green: Emerging, modular water systems. **b)** Total and % of annual favorable statements for centralized (blue) and modular (green) elements. **c)** Dominant actor types as % of favorable statements, three phases.

2011, Hacker and Binz, 2021). The city of Durban and the University of KwaZulu Natal are experimenting with more radical on-site urine diversion technologies, strongly driven by international funding through the BMGF (see also Sutherland et al., 2015).

Concept reconfigurations based on statements of Indian actors

India, finally, exhibits discursive dynamics that again strongly differ from the cases described above. Like in South Africa, overall alignment among concepts is relatively high, with a density again close to or above 0.3 throughout all periods. This comparatively high alignment between configurations is interesting, given the spatially highly variegated distribution of critical moments in the country. Bangalore in the Southern State of Karnataka, for example, has seen constant drought pressure throughout the full 2011-2018 period. Pune in the mid-Western state of Maharashtra, in turn, has been facing extreme rainfalls ever since 2015. The northern capitol region around New Delhi, in turn, was getting into a drought during the 2014-2016 period, which continued into 2017-2018 (A5). Despite this variation, we can see that both centralized and modular concepts occupy central positions in the discourse in all three periods. Actors supporting centralized infrastructures emphasize concepts like the centralized paradigm, large-scale water reuse and centralized stormwater technologies. Actors supporting the modular approach, rather promote concepts like the modular paradigm, decentralized governance, onsite reuse and rainwater harvesting technologies. While alignments among these two groups vary in strength, the general pattern clearly shows a stronger alignment between centralized and modular infrastructure solutions in India than in any of the other cases. This is further emphasized by the continuously high average degree of the overall network structure (between 5.2 and 7.8). Our findings thus imply that the Indian water sector features a polycentric regime structure in which centralized and modular solutions co-exist as highly institutionalized approaches that deliver urban water services to different strata of society (centralized sewers in major metropolitan areas and modular solutions in informal settlements and smaller towns (see also van Welie et al., 2018, Dasgupta et al., 2021)).

Modular technologies are being promoted by a broad range of actors in India, including the Government (Figure 8c). Next to the drought-struck region of New Delhi, some geographical clusters in which modular technologies are frequently framed are Maharashtra in the West (with promoting coalitions in several large cities like Mumbai, Pune, Nagpur) where modular technologies like rainwater harvesting are envisioned to alleviate flooding pressures, and a strong hub in the drought-struck city of Bangalore (Karnataka, see also A5). An important constant proponent is the National Environmental Engineering Institute (NEERI) based in Nagpur.

4.3. Discussion

The empirical results presented above imply that recent reconfigurations in the UWM field can be conceptualized as a patchwork of change processes that happen both among global experts and inside a variety of national (and even regional) subsystems. How transition trajectories in various countries differ from each other and how they influence (or depend upon) 'global' regime structures could so far only be characterized conceptually or with generic, case-based research designs (Fuenfschilling and Binz, 2018, Lieberherr and Fuenfschilling, 2016, Bauer and Fuenfschilling, 2019). In contrast, the STCA methodology enables a direct mapping of the relevant (dis-)alignment processes at global and (sub-)national levels (see also Heiberg et al., 2020). This allows one to infer why and how transition trajectories differ between contexts despite being exposed to the same global regime structures or even similar external (landscape) pressures. At the same time, our approach enables new explanations on why transitions are more likely to occur in certain contexts (here: the USA / India) than in others (i.e. South Africa) (Heiberg et al., 2020).

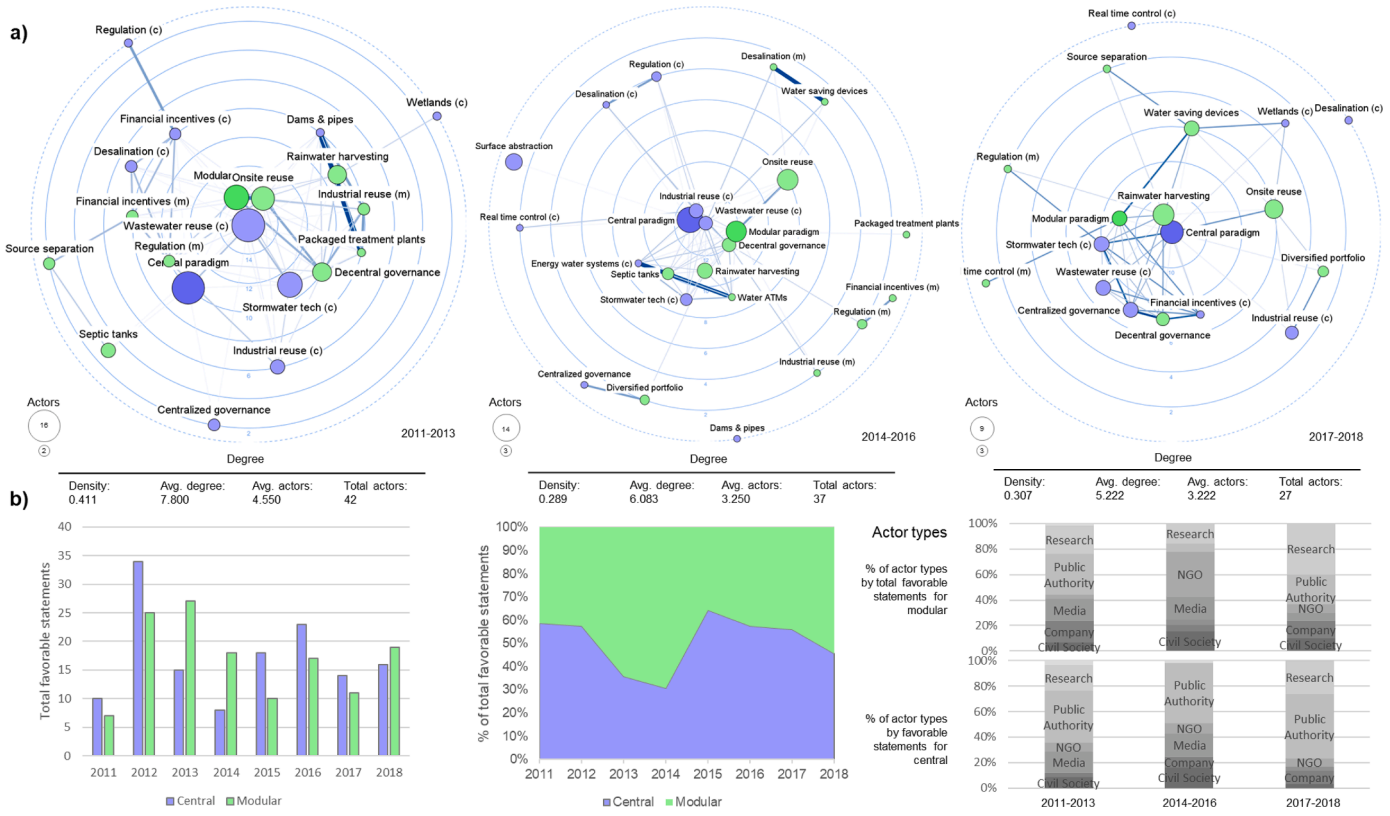

Fig. 7. **a)** Socio-technical configurations based on Indian actors' statements, three phases. Blue: Conventional, centralized water systems, Green: Emerging, modular water systems. **b)** Total and % of annual favorable statements for centralized (blue) and modular (green) elements. **c)** Dominant actor types as % of favorable statements, three phases.

Our findings revealed the prevalence of a highly institutionalized configuration around centralized, large-scale water infrastructures both at a global expert level and in most of the analyzed national subsystems. This core configuration remains comparatively stable over time, thus hinting at the existence of a locked-in global socio-technical regime in UWM (Fuenfschilling and Binz, 2018). At the same time, emerging configurations around small-scale, modular UWM are increasingly showing signs of institutionalization in particular spatial subsystems like the USA and India. This finding is in line with recent research showing that landscape factors, such as external shocks, may help transform socio-technical regimes by creating windows of opportunity for reconfiguration processes (Turnheim and Geels, 2013, Rosenbloom et al., 2016). However, the STCA revealed some striking differences in how these reconfiguration processes play out across geographical contexts and whether they prove to be sustainable. While statements in the US suggest that modular water systems may actually have gained legitimacy among national stakeholders, the same dynamic is not evident from the data on South African actors. In India, in turn, the STCA shows that modular and centralized concepts may co-exist for longer periods of time in a stable polycentric regime structure (van Welie et al., 2018). Eventually, in the global expert discourses, specific modular concepts are increasingly recognized as compatible with large-scale municipal wastewater reuse. Wastewater reuse, can thus be seen as a potential 'boundary object', around which future hybridization dynamics of the UWM regime may unfold. Our analysis thus confirms previous findings that critical moments and landscape pressures triggering them can, may lead to major reconfiguration processes, but not necessarily so (Turnheim and Geels, 2013, Yuana et al., 2020).

5. Implications and future research

In the present paper, we developed a novel methodology to investigate socio-technical configurations and their development across time and space. While transition scholars have used a discursive lens for analyzing socio-technical transitions before (Geels and Verhees, 2011, Smith et al., 2014, Raven et al., 2015, Rosenbloom et al., 2016), we maintain that studying shifting socio-technical configurations through textual databases allows for a more systematic understanding of the dynamic and geographically variegated nature of socio-technical transitions. We extended the recently developed discourse networks analysis (DNA) method (Leifeld, 2017) into a methodological approach for mapping and measuring socio-technical reconfiguration dynamics (STCA). This novel approach will enable a new perspective on core transition mechanisms like "motors of innovation" and creative destruction in the context of socio-technical change (Suurs and Hekkert, 2009, Kivimaa and Kern, 2016), strategies of field re-configuration, such as fit-and-conform and stretch-and-transform patterns (Smith and Raven, 2012), as well as incumbent's strategies like regime maintenance or appropriation of new concepts (Turnheim and Geels, 2013, Patala et al., 2019). As outlined in more detail in the empirical part, the methodology furthermore enables the comparison between transition pathways in different spatial and sectoral contexts (Geels and Schot, 2007, Hansen and Coenen, 2015, Murphy, 2015).

The methodology arguably opens up for a novel configurational epistemology for studying transition processes, which encompass a long-term research agenda that combines STCA with other, complementary approaches (Miller, 1986, Furnari et al., 2020). Collecting relational, two-mode network data from textual sources and analyzing them with help of social network analysis enables the visualization and analysis of dynamic relational patterns, for example, among a variety of actors, projects or localities on the one hand, and technological or institutional concepts, on the other hand. Hereby, STCA goes beyond the conventional case narrative approach in transition studies, and will enable a more systematic and rigorous form of configurational theorizing

(Furnari et al., 2020, Svensson and Nikoleris, 2018, Weber and Truffer, 2017). As we have demonstrated, the STCA methodology allows for mapping and measuring meso-level structures and processes in an organizational field, without losing the connection to in-depth qualitative information. Our application to an emerging transition in the UWM field could only illustrate the potential and potency of this approach. But it opens up a whole series of potentially highly relevant future lines of investigation.

First, we maintain that the STCA methodology offers a new inroad for exploring key transition mechanisms like early innovation system formation, niche upscaling, directionality or industrial shake outs. As Raven et al. (2015) have shown, emerging socio-technical configurations may not only link up to different types of paradigms but also align with - or contradict - various socio-political agendas like a job creation imperative, a national sustainability strategy, or lead-market and export opportunities. An illustrative example could be the case of Uber entering the Netherlands adhering to a socio-political agenda around more innovative and flexible personal transport, but contradicting a political agenda emphasizing the security of jobs in the Dutch Taxi sector (Pelzer et al., 2019). STCA could provide an interesting methodology to investigate the tensions and interactions between an emerging socio-technical configuration around a newly forming TIS and its wider socio-political context. In this line of research, one could explore the fight among different technologies, paradigms and logics within a TIS before a dominant design has emerged (Yap and Truffer, 2019, Heiberg and Truffer, 2021). For research contexts, in which actual configurational alignments within an organizational field shall be analyzed, and not only their representation through discourses, STCA may be based on interview transcripts or other textual data sources (for a recent implementation, see Heiberg and Truffer, 2021).

Second, it was beyond the scope of this paper to deeply elaborate on the policy implications that may be derived from an STCA analysis. But it seems clear that for transformation-oriented innovation policy (Weber and Rohracher, 2012) or the identification of effective transformative policy-mixes (Rogge and Reichardt, 2016, Kivimaa and Kern, 2016), it is crucial to understand the dynamic and multi-scalar nature of socio-technical alignment processes. STCA provides a tool for identifying the most important regime-maintaining storylines and logics (and the most powerful / interested actors behind them), which might be weakened by targeted policy interventions. Correspondingly, the methodology may help to identify - and strategically support - certain emerging socio-technical configurations that have the most transformational potential for an organizational field. Mapping who is maintaining dominant regime configurations based on what storylines and at what spatial scale(s) may in turn help to identify the power positions of advocacy coalitions in more targeted ways. In this way, STCA may also provide an interesting tool for scholars investigating the interplay of power and agency in transitions (Avelino et al., 2016) and by this address earlier identified directionality failures (Weber and Rohracher, 2012)

Third, we see a great potential in mobilizing STCA for a deepened exploration of the geographical and sectorial specificities of transition processes. In terms of geographical perspectives, our approach allows for spatially open, comparative research designs, as outlined in the empirical case study of this paper. We only scratched at the surface of the multi-faceted socio-technical alignment processes that take place *at* and spanning *across* various spatial scales (Miörner and Binz, 2021, van Welie et al., 2020). In a next step, one could complement our global mapping with an in-depth investigation of the differences between socio-technical alignment struggles in the US, South African or Indian state-level discourses, while still capturing the various ways of engagement with national-scale and global-scale actors. Such a more regionally embedded STCA analysis could reveal how the storylines and narratives in a region may rest on the absorption of national or global narratives into a regional discourse (Späth and Rohracher, 2012, Heiberg et al., 2020). It would also allow for a more thorough analysis of the actor coalitions maintaining and potentially disrupting specific configurations. STCA could in this sense, become a key methodological contribution to the toolbox of the 'geography of transitions' field (Binz and Truffer, 2017, Gosens et al., 2015, Binz et al., 2014).

Along very similar lines, STCA may help to further tease out and theorize about how transition dynamics differ between sectors as diverse as energy, water, transport, agro-food or healthcare. The relative monolithic regime structure we observed in most countries in the water sector could be compared with polycentric or even fragmented regime configurations one could expect in the urban mobility or public health sectors. Cross-comparing the resulting regime reconfiguration dynamics with STCA could lead to more sector-specific transition concepts, which could, in turn, substantively improve policy advice (Binz and Truffer, 2017). At the same time, STCA could be used to analyze multi-sectoral interactions in transitions (Andersen et al., 2020, Malhotra et al., 2019), or interactions along value chains (van Welie et al., 2019). In particular, using both actor and concept congruence networks the methodology enables a more systematic exploration of how actors from unrelated fields use (discursive) strategies to bridge between - and increasingly align - initially incompatible technologies and institutional elements in transition processes.

Of course, given the novelty of the proposed methodology and the global search lens applied in our illustrative case, STCA could be improved in various ways. Future research should explore in more depth what kind of document stocks are most suitable in capturing socio-technical alignment processes at different scales and in different contexts. While we have attempted to both collect data from global industry magazines and more nationally-bound public newspapers, future applications may want to exclusively focus on more concise transition cases.

Additionally, the various network measures and indicators employed to identify coherent socio-technical configurations could (and should) be further refined, expanded and adapted to the specific needs of a given research question and design. In the mid-term future, we envision that different ideal-type applications of STCA are developed that combine specific databases, network indicators and interpretative schemes to research questions that may revolve around issues as diverse as the maturation of TIS structures, multi-scalar niche-regime interaction, policy battles around transformative innovation or the role of institutional logics and complexity in transition trajectories. All told, we maintain that STCA provides a novel and potentially highly productive methodological approach to strengthen configurational theorizing in transition studies. Through its virtue of representing a semi-quantitative approach, STCA may constructively bridge quantitative and qualitative approaches that have long lived parallel lives in transition studies and the social sciences more broadly. If anything, we believe that we have here only been able to scratch the surface of what could become a very generative perspective for transitions research in the future.

Credit author statement

Jonas Heiberg: Conceptualization, Methodology, Software, Data curation, Writing-Original draft preparation, Visualization, Investigation. **Bernhard Truffer:** Supervision, Conceptualization, Writing-Reviewing and Editing, Investigation, Ressources, Project administration, Funding aquisition. **Christian Binz**: Supervision, Conceptualization, Writing- Reviewing and Editing, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A1. – Outlets screened in Nexis Uni

Source	Count of statements	Scale of audience	City of headquarter	Availability in Nexis Uni	Type of publication
The Times of India (TOI)	279	IND	Dehli	2010-now	daily newspaper
Africa News	219	ZAF +	various	1991-2018	newspapers & newsletters
The Jerusalem Post	113	ISR	Jerusalem	1989-now	daily newspaper
The Guardian(London)	88	GBR	London	1975-now	daily newspaper
The Straits Times (Singapore)	81	SGP	Singapore	1992-now	daily newspaper
Chemical Week	52	GLO	New York	1975-now	global biweekly expert magazine
San Francisco Chronicle	49	USA	San Francisco	1985-now	daily newspaper
The New York Times	44	USA	New York	1980-now	daily newspaper
The Business Times Singapore	41	SGP	Singapore	1992-now	daily newspaper
The Edge Singapore	36	SGP	Singapore	2002-now	weekly newspaper
Mining Magazine	34	GBR	London	1981-now	monthly magazine
New Scientist	33	GBR	London	1998-now	weekly magazine
Tampa Bay Times	31	USA	Tampa	1987-now	daily newspaper
The Christian Science Monitor	31	USA	Boston	1980-now	daily newspaper
The Irish Times	30	IRE	Dublin	1992-now	daily newspaper
Business Day (South Africa)	29	ZAF	Johannesburg	1997-now	daily newspaper
The Herald (Harare)	25	ZIM	Harare	2010-now	daily newspaper
The International Herald Tribune	25	GLO	New York	1991-now	global daily newspaper
New Straits Times (Malaysia)	24	MYS	Kuala Lumpur	1995-now	daily newspaper
Financial Mail (South Africa)	20	ZAF	Johannesburg	1997-now	weekly magazine
The New Times Kigali	19	RWA	Kigali	2009-now	daily newspaper
The Globe and Mail (Canada)	18	CAN	Toronto	1977-now	daily newspaper
The Economic Times	17	IND	Mumbai	2010-now	daily newspaper
The Conversation Africa (Johannesburg)	15	ZAF	Johannesburg	2012-now	newspaper
National Post's Financial Post & FP Investing (Canada)	14	CAN	Toronto	1985-now	daily newspaper
Canberra Times (Australia)	13	AUS	Canberra	1997-now	daily newspaper
Natural Gas Week	13	GLO	Vancouver	2002-now	global weekly expert magazine
The West Australian (Perth)	13	AUS	Perth	2004-now	daily newspaper
BBC Monitoring: International Reports	12	GLO	London	1979-now	daily newspaper
The Washington Post	11	USA	Washington D.C.	1977-now	daily newspaper
BusinessWorld	9	PHL	Manila	1997-now	daily magazine
The Independent (United Kingdom)	9	GBR	London	1988-now	daily newspaper
The Korea Herald	9	KOR	Seoul	1998-now	daily newspaper
The Australian	8	AUS	Sydney	1995-now	daily newspaper
Business Monitor News	7	GLO	London	2004-now	global daily business magazine
The Times of Zambia (Ndola)	7	ZAM	Ndola	2010-now	weekly magazine
The Toronto Star	7	CAN	Toronto	1985-now	daily newspaper
South China Morning Post	6	CHN	Hong Kong	1992-now	daily newspaper
The Namibian (Windhoek)	6	NAM	Windhoek	2010-now	weekly newspaper
Addis Fortune (Addis Ababa)	5	ETH	Addis Ababa	2010-now	weekly newspaper
Investment Week	5	GBR	London	2009-now	daily newspaper
Korea Times	5	KOR	Seoul	1998-now	daily newspaper
New Era (Windhoek)	5	NAM	Windhoek	2010-now	daily newspaper
Nikkei Asian Review	5	JPN	Tokio	1980-now	weekly magazine
USA Today	5	USA	Tysons Corner	1989-now	daily newspaper
Utility Week	5	GBR	London	2005-now	monthly magazine
Inter Press Service (Johannesburg)	4	ZAF	Johannesburg	2010-now	daily newspaper
Sunday Times (South Africa)	4	ZAF	Johannesburg	1997-now	weekly newspaper
The Advertiser/Sunday Mail (Adelaide, South Australia)	4	AUS	Adelaide	1986-now	daily newspaper
The Edge Malaysia	4	MYS	Kuala Lumpur	2001-now	weekly newspaper
The Gazette (Montreal)	4	CAN	Montreal	1991-now	daily newspaper
The Herald (Glasgow)	4	GBR	Glasgow	1992-now	daily newspaper
Mail on Sunday (London)	3	GBR	London	1992-now	daily newspaper
Sunday Age (Melbourne, Australia)	3	AUS	Melbourne	1991-now	daily newspaper
The Nation (Thailand)	3	THA	Bangkok	1997-now	daily newspaper
The Press (Christchurch, New Zealand)	3	NZL	Christchurch	1996-now	daily newspaper

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Belfast Telegraph	2	GBR	Belfast	1996-now	daily newspaper
Daily News (New York)	2	USA	New York	1995-now	daily newspaper
Global Capital Euroweek	2	GBR	London	1999-now	daily expert magazine
The Courier Mail/The Sunday Mail (Australia)	2	AUS	Queensland	1985-now	daily newspaper
The Daily Telegraph (London)	2	GBR	London	2000-now	daily newspaper
The Observer(London)	2	GBR	London	1990-now	weekly newspaper
Daily Trust (Abuja)	1	NGA	Abuja	2010-now	daily newspaper
Farmers Weekly	1	GBR	Sutton	1998-2020	weekly expert magazine
Ghanaian Chronicle (Accra)	1	GHA	Accra	2010-now	weekly newspaper
Investors Chronicle - magazine and web content	1	GBR	London	1990-now	weekly newspaper
Sunday Tasmanian (Australia)	1	AUS	Hobart	1887-now	daily newspaper
The Independent (United Kingdom)	1	GBR	London	1988-now	daily newspaper
The New Zealand Herald	1	NZL	Auckland	1998-now	daily newspaper
World Oil	1	GLO	Houston	2001-2018	global monthly expert magazine

Additional outlets in the search base which did not yield any relevant articles to code statements: Accountancy Age (UK), Accounting Today, Advertising Age, ADWEEK, Airline Business, Al Jazeera - English, Audio Week, Australian Financial Review, Automotive News, Baltic News Service, Belfast News Letter, Belfast Telegraph Online, Billboard, Birmingham Evening Mail, Birmingham Post, Brand Strategy, Brisbane News, Builder, Business & Finance Magazine, Campaign, CFO, City A.M., CMP Information, Computer Weekly, Computing, Contract Journal, Control and Instrumentation, Creative Review, Daily Record and Sunday Mail, Daily Variety, Design Engineering, Design Week, Electronics Weekly, Employee Benefits, Estates Gazette, Euromoney, EXE, Financial Adviser, Financial Director, Flight International, Herald Sun/Sunday Herald Sun (Melbourne, Australia), Het Financieele Dagblad (English), Hindustan Times, Hobart Mercury/Sunday Tasmanian (Australia), Industry Week, Insurance Age, International Money Marketing, ITAR-TASS, Korea Herald, Lawyers Weekly, Legal Week, Lianhe Zaobao, Maghreb Confidential, Management Today, Marketing - UK, Marketing Week, Mergers and Acquisitions, The Dealmaker's Journal, Middle East Newsfile (Moneyclips), mirror.co.uk, Mobile Communications Report, Money Marketing, Moscow News, MTI Econews, Music Week, MWP Advanced Manufacturing, New Media Age, New Musical Express, Newsweek, Nikkei Asian Review, Northern Territory News (Australia), Off Licence News, Ottawa Citizen, Plastics News (tm), Platts Energy Business & Technology, Platts Megawatt Daily, Polish News Bulletin, Precision Marketing, Process Engineering, Professional Broking, Retail Week, Revolution, Rubber & Plastics News, Satellite Week, standard.co.uk, Sydney Morning Herald (Australia), TechNews, telegraph.co.uk, The Age (Melbourne, Australia), The Banker, The Daily Mail and Mail on Sunday (London), The Daily Telegraph (Australia), The Deal Pipeline, The Dominion (Wellington), The Dominion Post (Wellington, New Zealand), The Electricity Journal, The Engineer, The Evening Post (Wellington), The Evening Standard (London), The Express, The Grocer, The Investors Chronicle, The Japan News, The Japan Times, The Jerusalem Report, The Lawyer, The Mirror (The Daily Mirror and The Sunday Mirror), The Moscow News (RIA Novosti), The Moscow Times, The New York Times - International Edition, The New Yorker, The People, The Pharma Letter, The Philadelphia Inquirer, The Sunday Herald (Glasgow), The Sunday Telegraph (London), The Weekly Times, Travel Trade Gazette UK & Ireland, Wall Street Journal Abstracts, Waste News, What's new in Industry, Xtreme Information

A2. – Search terms and query for article selection in Nexis Uni

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((small-scale OR building-scale OR on-site OR onsite OR non-grid OR
nongrid OR decentral! OR modular OR smart OR distributed OR integrated OR
household) PRE/2 (water OR wastewater OR blackwater OR greywater OR graywater OR
stormwater OR rainwater OR seawater) PRE/2 (recycling OR reuse OR treatment OR
infrastructure OR desalination)) OR ((water OR wastewater OR blackwater OR
greywater OR graywater OR stormwater OR rainwater OR seawater) PRE/1 (recycling OR reuse OR reclamation OR
  harvesting OR desalination))
OR (membrane PRE/1 bioreactor)
OR (sequencing PRE/1 batch PRE/1 reactor)
OR (microbial PRE/1 fuel PRE/1 cell)
OR (membrane PRE/1 aerated PRE/1 biofilm PRE/1 reactor)
OR (nano PRE/1 membrane)
OR (nano PRE/1 adsorbent)
OR (nano PRE/1 photocatalyst)
OR (septic PRE/1 tank)
OR (package PRE/1 treatment PRE/1 plant)
OR (point PRE/2 use PRE/1 treatment)
OR ((dry OR composting) PRE/1 toilet)
OR (dual PRE/1 flush PRE/1 (plumb! OR toilet))
OR ((urine OR source) PRE/1 separation)
OR (water PRE/1 saving PRE/1 device)
OR (inlet PRE/1 control)
OR (infiltration PRE/1measure)
OR (sustainable PRE/1 urban PRE/1 drainage)
OR (NoMix) OR (jokhasou)
OR (ecosan) OR (ecological PRE/1 sanitation)
OR (water PRE/1 sensitive PRE/1cities)
OR (green PRE/1 roof)
OR (water W/7 (resource PRE/1 recovery))
OR (reverse PRE/1 osmosis)
OR (zero PRE/1 liquid PRE/1 discharge)
OR (capacitive PRE/1 deionisation)
OR (desalination)
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OR ((direct OR indirect) PRE/2 potable reuse)
OR (real PRE/1 time PRE/1 control)
OR (autonomous PRE/1 housing)
OR (closed PRE/1 water PRE/1 system)
OR (energy PRE/1 water PRE/1 system)
AND HLEAD(water) AND ATLEAST3 (water) AND ATLEAST2 (treatment)

The search query was developed in an iterative process by the first author. First research articles were searched that already had defined terms to classify innovative water technologies into categories like modular/decentralized and conventional/centralized. In the end, a rather comprehensive list of terms by Makropoulos and Butler (2010) was complemented with adjustments based on Singh et al. (2015), Gehrke et al. (2015), Marlow et al. (2013), Sharma et al. (2013), Dubois and Boutin (2018), Dahlgren et al. (2013), Willis et al. (2013). Additionally, five interviews were conducted with water and wastewater engineers at the author's home institution, Eawag, to further judge which technology terms were actually part of ongoing discussions, and how they may be called in different geographical contexts. The resulting search query was constructed in order to capture articles covering any of the term combinations connected through OR, as well as primarily dealing with "water", as the last line indicates. Since water technologies, such as seawater desalination, wastewater reuse, stormwater/rainwater harvesting, are generally scalable and can be applied in a decentralized or centralized fashion, searching for general AND specific technological terms for innovative water technologies was very important to avoid a bias in our search. The most important part of the search query is the most generic combination ((water OR wastewater OR …) PRE/1 (recycling OR reuse OR … desalination)). It covers all types of technologies. Many of the other technology-terms are specific but also scalable: e.g. "reverse osmosis", "sequencing batch reactor", "membrane bioreactor" can all be applied in centralized or decentralized systems. The few specific search terms, like "package treatment plant", which is specifically a decentralized niche type of technology, are very rarely used but were included as an optional filter to make the search as specific to our technological focus as possible.

A3. Coding scheme

Central paradigm related statements Technologies Wastewater Treatment		Modular paradigm related statements	
MBR (c)	Large-scale applications of membrane bioreactors	MBR (m)	Membrane bioreactors primarily for small-scale applications (like industrial waste water treatment)
Real time control (c)	real time control in large-scale treatment/ harvesting units	Real time control (m)	real time control for small-scale treatment units
Seperate sewer	large-scale separate sewer systems for stormwater & wastewater (also fits in HT3)	MABR	Membrane aerated biofilm reactors for small-scale treatment units
Combined sewer	large-scale combined sewer systems for stormwater & wastewater (also fits in HT3)	Nanotech (m)	Novel nano-membranes primarily for small-scale applications
Wetland (c)	customised constructed wetlands (such as zero discharge willow systems)	Septic tanks	small-scale septic tanks, cesspits
Nanotech (c)	nano-filtration techniques to improve large-scale infrastructures	Packaged treatment plants	Small-scale, modular, on-site, package treatment plants
		Microbial fuel cells	Small-scale, modular, on-site, treatment based on MFC
Water supply			
Desalination (c)	large-scale desalination plants and technology related to improving them (including nano-materials)	Desalination (m)	small-scale to plant-scale applications of desalination, incl. Capacitive/ electric deionisation or graphene
Dams and pipes	large-scale water supply dams and pipelines over long distances	Water saving devices	small-scale water saving/ point-of use devices
Surface abstraction	Large-scale OR small-scale groundwater or surface abstraction and/ or monitoring of the same	Drip irrigation	Modular irrigation systems for agriculture
Real time control (c)	real time control for optimised large-scale water supply networks	Water ATMs	Water ATM's with modular, decentralised on-site treatment
Stromwater management			
Stormwater inf. (c)	large-scale stormwater drainage & storage technologies like detention pools	Rainwater harvesting	small-scale/ development-scale rainwater harvesting modules (like tanks, pipes etc.)
Wetland (c)	Large-scale OR small-sclae ponds and/or constructed wetlands for stormwater storage and aquifier recharge	Modular wetlands	small-scale, scalable wetland modules
Integrated water management			
Energy water systems (c)	large-scale energy water systems	Energy water systems (m)	small-scale energy water systems, microbial fuel cells, heat recovery
Wastewater reuse (c)	large-scale sewerage wastewater recycling/ effluent dual reticulation, direct or indirect potable reuse,	Industrial reuse (m)	small-scale industrial wastewater reuse/ recycling
Industrial reuse (c)	plant-scale industrial wastewater reuse/ recycling, zero liquid discharge, common effluent treatment plants	Real time control (m)	real time control for small-scale wastewater reuse/ recycling
Nutrient recovery (c)	Nutrient recovery and reuse from large-scale wastewater treatment	Onsite reuse	small to development scale houshold wastewater reuse/ recycling
		Source separation	on-site sanitation, treatment and reuse via dry or composting toilets
		Autonomous houses	

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Central paradigm related statements Technologies Wastewater Treatment		Modular paradigm related statements	
			applications of on-site water technologies integrated in fully autonomous housing/buildings
Paradigms (Institutions)			
Central paradigm	statements highlighting the superiority of centralized, large-scale approaches to wastewater treatment. E.g. calling for efficiency improvements of sewers (leakage minimisation) or enhancement of existing sewage treatment plants enhanced	Modular paradigm	statements highlighting the benefits of water supply or treatment that organised more locally, making use of resilient and flexible onsite infrastructures replacing or adding on to the existing or new large-scale infrastructures
Policy, governance (Institutions)			
Centralized governance	centralised governance of water treatment, supply, stromwater drainage or recycling operations	Modular governance	decentralised governance of water treatement, supply, stormwater drainage or recycling operations
Regulation (c)	regulation promoting or facilitating the implementation of large-scale water infrastrucutre	Regulation (m)	regulation promoting small-scale, modular infrastructures
Financial incentives (c)	financial incentives and discounts to encourage water awareness and reduce consumption in centralised systems	Financial incentives (m)	financial incentives and discounts promoting small-scale modular infrastructures
		Diversified portfolio	uwm should include all sorts of technologies including modular

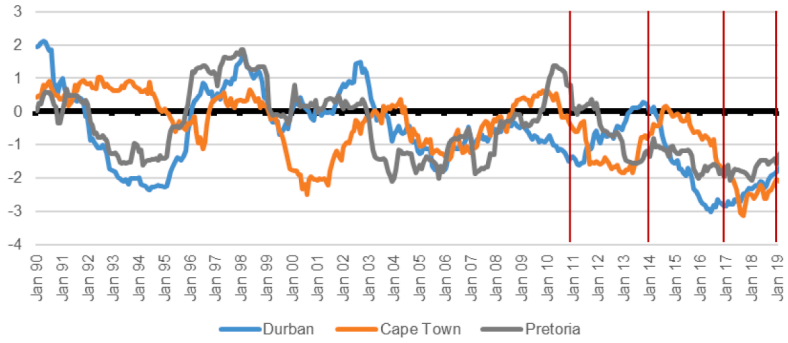
A4. Dataset

Years observed:	8	
Documents:	576	
Statements after duplicates/document cleared:	1589	
Statements conducive to conventional technologies	911	
statements conducive to modular technologies	524	
Rationality statements	154	
DNA Variables:		
Organisations:	568	
Organisation types:	8	
Concept codes (referred to in statements):	51	
Overall statements per country (or clustered in supra-national regions):	count	% of subtotal
India	286	20.94
USA	260	19.03
South Africa	135	9.88
Singapore	130	9.52
Israel	91	6.66
UK	52	3.81
East Africa	69	5.05
East Asia	46	3.37
Southern Africa	50	3.66
Oceania	55	4.03
Canada	49	3.59
Europe	63	4.61
Central and West Africa	31	2.27
China, Hong Kong, Taiwan	21	1.54
Other Africa	1	0.07
Middle East	23	1.68
Latin America & Carribean	4	0.29
subtotal	1366	100
% of subtotal (top-3 countries)	681	49.85

A5. Droughts and flooding in major cities covered in the dataset. Following the SPEI-36 drought monitor (negative values indicate high drought exposure, positive values indicate high exposure to flooding)

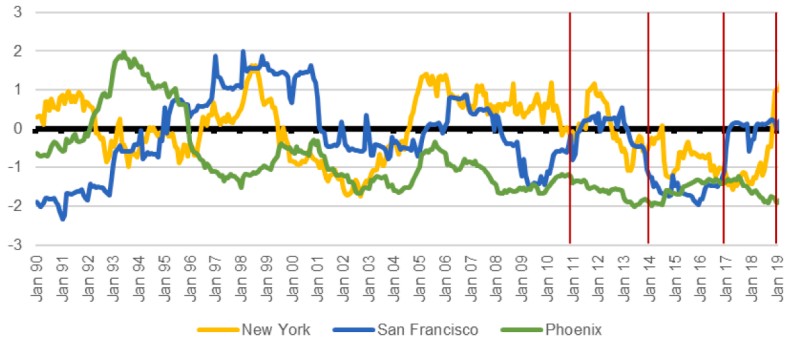
Durban, Cape Town,
Pretoria/Johannesburg region (ZAF)

Major newspapers included :
Business Day, Financial Mail, The Conversation, Sunday Times, Africa News



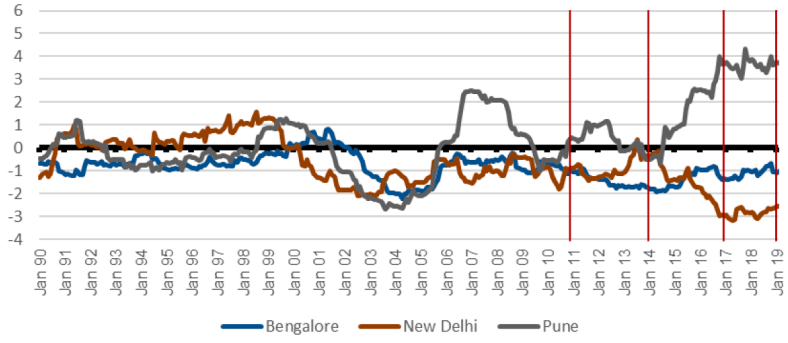
New York, San Francisco, Phoenix (USA)

Major newspapers included:
New York Times, San Francisco Chronicle, Daily News, Washington Post



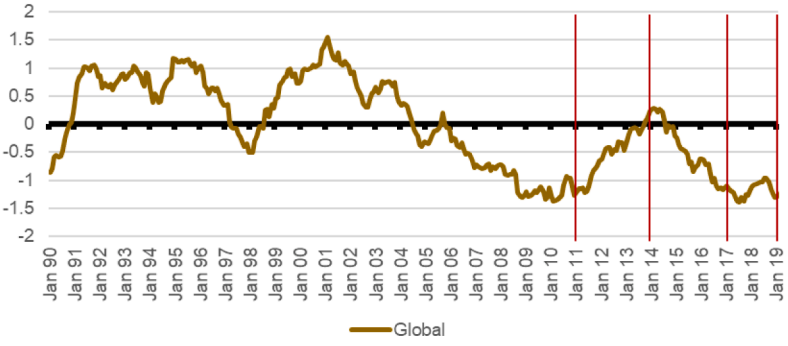
Bengalore, New Dehli, Pune (IND)

Major newspapers included:
Times of India, Economic Times



Global

Major newspapers included :
Business Monitor Online, Chemical News, New York Times International



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