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

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Abstract

Classic accounts of transitions research have dominantly 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 a methodological nationalism and lack of generalizability of the insights gained. To address this gap, we propose a novel methodology – socio-technical network analysis (STNA) – to map and measure socio-technical alignment processes across time and space. STNA provides a relational and dynamic perspective on how social and technical elements get reconfigured and aligned into "configurations that work", allowing for the identification of differentiated transition trajectories at and across spatial context. The method's performance is illustrated by the empirical case of ongoing transition processes in the global water sector. Building on this illustration, we outline potential future avenues of research, sketching the contours of what we believe could become a very generative conceptual perspective and methodological approach for transitions research in the future.

Keywords: Socio-technical network analysis, Geography of transitions, Socio-technical alignments, Transition trajectories, Discourse, Modular water technologies

Highlights:

- Socio-technical network analysis (STNA) allows for a novel way to map and measure the (de)-alignment of socio-technical configurations across time and space
- Adding to the literature on discursive approaches to understanding transitions
- More open conceptualization of regimes as the highly institutionalized core of organizational fields
- The global water sector regime reveals varying degrees of institutionalization allowing for different transition trajectories at and across different spatial scales
- Droughts as phases of disruption reveal major re-configurations of dominant regime structure in the water sector

1. Introduction

Understanding fundamental sector transformation 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 and reconstructed 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). The configurational characteristics imply that if a certain set of actors, institutions and technologies is well-aligned and deeply institutionalized (or taken for granted), a sector will evolve along rather narrow trajectories for several decades before a next deep reconfiguration will take shape accommodating for major technical or societal discontinuities, a pattern termed as successions of "punctuated equilibria" (Markard et al., 2012, Geels, 2004, Markard and Truffer, 2008, Levinthal, 1998).

Due to the highly complex and systemic nature of socio-technical transformation processes, the vast majority of transition studies draw on historical or qualitative case studies, which allow for a detailed reconstruction of the dynamic processes that lead to the (dis-)alignment of technological and institutional elements, of struggles between proponents of alternative trajectories, as well as of the newly emerging (and ideally more sustainable) socio-technical configurations (e.g. see the famous case of the transition from sailing to steam ships by Geels, 2002). Even though transition studies have by now 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. As a result of this implicit methodological nationalism (Coenen et al., 2012, Hansen and Coenen, 2015), transition research tends to emphasize context-sensitivity, while 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 (Bauer and Fuenfschilling, 2019, Fuenfschilling and Binz, 2018, Sengers and Raven, 2015).

More substantively, over-relying on a case study approach implies that cross-comparisons and generalizations between transition trajectories in different spatial or sectorial contexts remains a challenge, which is likely to hamper progress in the future theoretical development of the field (Alkemade, 2019). One of the methodological challenges when aiming to move towards more quantitative assessments of socio-technical dynamics is that evolving configurations (i.e. dynamic relationships between different factors) have to be measured and assessed rather than specific values of independent factors, which is the core of conventional quantitative methods (Weber and Truffer, 2017). In the present paper, we therefore propose a semi-quantitative relational methodology for mapping shifts of socio-technical alignments over space and time, which we call socio-technical network analysis (STNA). The STNA method builds on (and substantially extends) a recently established method from 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 socio-technical transition processes.

The method builds on the coding of actor statements, which are recorded in publicly available document repositories, like newspaper databases, policy archives or user fora on social media sites. Depending on the temporal and spatial resolution of these databases, our approach enables a semi-quantitative reconstruction of the temporal and spatial (dis-) alignments of socio-technical configurations. We claim that by mapping statements by various actors referring to institutional and technological elements 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 to identify key mechanisms and actors that drive these processes. When analysed across different types of documents (daily newspaper, professional magazines, policy protocols, etc.), the method furthermore enables the combination of complementary actor perspectives on historical and ongoing transition trajectories.

We apply the STNA method to public discourses in national newspapers and global industry magazines. We follow Fünfschilling and Truffer (2014) in conceptualizing socio-technical transitions as shifts in the 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 an organizational field. Coherent combinations of such statements can be interpreted as proxy measures for the internal alignment of pre-existing or emerging socio-technical configurations. We expect that, in debates about future pathways, 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 and potentially regime-challenging configurations. A socio-technical transition will therefore be mirrored by a shift in the kinds of storylines that actors will mobilize in a field's public discourses. Over time, we would expect to see a shift from one (or several) well-aligned configurations/storylines to new one(s), mirroring the de- and re-institutionalization of regime structures.

We thus follow other transition scholars in applying a discursive lens for understanding the (de-) institutionalization of socio-technical configurations, as well as strategies of actors pushing for certain technological or institutional trajectories rather than others (Raven et al., 2015, Geels and Verhees, 2011, Rip and Talma, 1998). Smith and Raven (2012), for instance, argued that transition proponents may either adopt a fit-and-conform or a stretch-and-transform strategy to strengthen alternative socio-technical configurations, which lead to more or less radical transformative pressures on the prevailing regime configurations. Discourses thus reflect not only how technological and institutional elements get gradually (dis-)aligned in a transition process, but also how the advocates of different socio-technical configurations attempt to influence audiences across space and scales (Smith et al., 2014, Murphy, 2015). This opens various highly promising inroads for spatially more open and cross-comparative research designs.

While the STNA method can be applied to a broad set of transition dynamics, we will illustrate its analytical power by retracing the spatial and scalar variation in an imminent transition in the global urban water management (UWM) sector. This sector has historically developed along a highly institutionalized socio-technical regime of centralized treatment and bulk transports of water through sewers and water pipes (Fuenfschilling and Binz, 2018, Larsen et al., 2016). Over the past decade, decentralized, modular solutions have been increasingly 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. We will trace this variation by applying STNA to a selection of 576 articles drawn from 180 national and international newspapers during an eight year period from 2011-2018. This enables the mapping of ongoing (dis-)alignment processes around centralized and modular water technologies. From this we can identify transition potentials for different countries, derive spatially differentiated development pathways and draw implications on the potentially most effective policy and industry strategies.

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 in alignments. Section 3 introduces the STNA method and illustrates how it can be used for retracing socio-technical configurations over time and space. Section 4 illustrates the application of STNA to our empirical case in the global water sector. Section 5 discusses the implications of our findings and outlines the contours of a broader research agenda leveraging the full potential of the STNA method.

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

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 – e.g. in the fossil fuel industry) start to shift or get supplanted by one or several alternative configuration(s) that revolve around different core values and technologies (e.g. emergent renewable energy technologies). Typically these transformations are accompanied by major shifts in the underlying 'grammar' or 'deep structure', which guide the practices of actors in a field, i.e. the "socio-technical regime" (Geels, 2002). To understand a transition, one has to understand how regime shifts come about, i.e. how certain deeply institutionalized alignments of institutional, technical and material elements get supplanted with new ones or reconfigured to a radically different socio-technical configuration. Mapping and measuring these (dis-)alignments stands at the core of our intended contribution. Yet, before introducing this method, we have to elaborate on how to conceptualize the relevant dynamics.

2.1 Socio-technical configurations as alignments of field elements

As a conceptual starting point, we propose to depart from an institutional perspective on socio-technical transitions, which places the transformation of socio-technical systems at the level of organizational fields (Fuenfschilling, 2019). Fuenfschilling and Truffer (2014) (building on Thornton and Ocasio, 1999, DiMaggio and Powell, 1983) argued that an organizational field perspective helps framing socio-technical change processes in a more open way than other transitions frameworks, which depend on more dichotomous distinctions between regime, niche

and landscape structures (Hoogma et al., 2002, Geels, 2002, Rip and Kemp, 1998). Organizational fields have been initially 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 may get involved and 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 structured core of an organizational field (Fuenfschilling and Truffer, 2014). Transitions are provoked by emerging socio-technical configurations, which mature, get more and more aligned and institutionalized and start to reshape broader rules and alignments in the organizational field. The different elements of the new configurations may be more or less strongly aligned, challenging the predominant regime structures to a lesser or higher degree. This view opens up for capturing a wide variety of transformation processes and more differentiated transition trajectories that go beyond the conventional linear niche-regime substitution epitomized in earlier versions of the multi-level perspective (MLP) (as proposed by Geels and Schot, 2007). Our work here can, therefore, be seen in line with recent work on more multi-dimensional and differentiated conceptualizations of regimes or transitions trajectories (such as 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 other things, dependent on the number of competing field logics present in an organizational field (Thornton and Ocasio, 1999, Thornton and Ocasio, 2008). A strong regime, in this view 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 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 quite simple) among many potentially relevant transition trajectories (van Welie et al., 2018, Geels et al., 2016).

As a first intuitive depiction of how to conceptualize transitions in this framework, fig. 1 depicts three ideal-type constellations of socio-technical configurations in an organizational field. Building on the representation proposed by Fünfschilling and Truffer (2014), competing socio-technical configurations can be depicted as networked elements in a 'radar plot'. The centrality of social and technical elements in the radar plots represent their degree of institutionalization, whereas the presence and width of the links between them reflect the strength of their alignments. Radar plot I depicts a core-configuration with strongly aligned and institutionalized elements (solid filled nodes), which can be interpreted as the regime core. The pattern-filled, more emergent cluster of nodes represents a competing socio-technical configuration that is less aligned and supported by more peripheral actors. In plot II, the marginal configuration is getting partly integrated into the regime structure. Plot III, instead, shows a newly reconfigured regime constellation, which resulted from a strong merger of the formerly distinct configurations.

This configurational representation enables a new inroad into analysing transitions and a more systematic comparison between different transition trajectories, such as those happening in different places and at different spatial scales (Coenen, 2012, Truffer et al., 2015). Transition dynamics may play out very differently within different countries, regions or cities, due to different degrees of institutionalization of competing socio-technical configurations in different cultural and socio-economic settings. At the same time, alignment processes may extend well beyond national boundaries and thus strongly shape potential transition dynamics in various

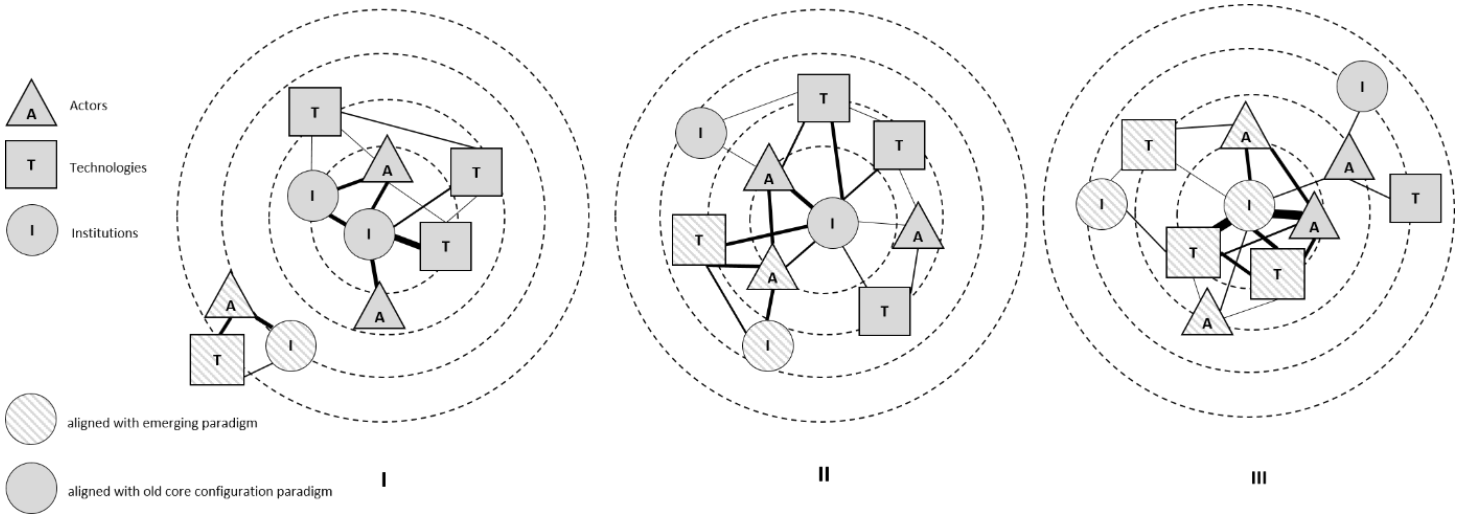

Fig. 1 Socio-technical configurations as alignments of field elements. Own illustration.

places and at various spatial scales at once (Sengers and Raven, 2015, Binz and Truffer, 2017,

annonymized, submitted). Fuenfschilling and Binz (2018) argue that multi-scalar interdependencies may be crucial in explaining how and why certain socio-technical configurations may represent dominant templates that diffuse to various national contexts by "global regime" structures. Hence, in our conceptual terminology, the core of an organizational field may form in different places and at different spatial scales at once. Seeking to map and measure these spatial and configurational complexities of socio-technical alignment processes, we will in the following section propose a discursive approach that builds on exiting conceptual and empirical explorations of discourses in transition studies.

2.2 Mapping and measuring configurational dynamics through discourses

The empirical assessment of changes 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 through process tracing by means of in-depth historical and qualitative case studies. This approach provided deep insight into core mechanisms that drive specific transition processes, but made it rather difficult to generalize mechanisms that operate across different technologies, 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 conditions for new knowledge generation, which can rely on 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 propose a methodological approach, which builds on textual recordings of discourses. Discourses have been defined as "*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"*(Hajer and Versteeg, 2005, p. 175). Discourses may serve as a suitable lens to reconstruct transition processes because they will reflect different actors' arguments for or against the need for change in a given field. Especially under conditions of looming change or crisis, 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).

Discursive approaches have already been applied to various problems in socio-technical transition studies. They have been used to analyse 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 (Rosenbloom et al., 2016).

Framing, in this context, can be defined as an act of sense making that renders events or objects meaningful and guides collective action (Benford and Snow, 2000). In some cases, the framing of technological and/or institutional field elements may evolve around antagonistic pro- and con- patterns (Rip and Talma, 1998), but in most cases it will follow more nuanced strategies of empowerment and obstruction (Raven et al., 2015). While, for example in discourses around policy issues, the relevant framings often split into antagonistic and partisan camps, experts voicing opinions about the most desirable future infrastructure system (as e.g. in the energy transition) will likely rather try to highlight a certain socio-technical configuration's benefits to a given audience. Framing in this sense, becomes a subtle, yet powerful type of embedded agency through which actors attempt to influence and make sense of wider institutional and material contexts (Battilana et al., 2009).

Discourses and framing 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 in a period of crisis or contestation, specific field elements, say a technology and a piece of regulation, are repeatedly co-mentioned by certain organizations, we would expect that they are closely aligned. A cluster of such closely aligned field elements, may in turn be interpreted as a (socio-technical) "configuration that works" (Rip and Kemp, 1998). The more often a certain constellation of elements is mobilized in a discourse and the more actors endorse it, i.e. positively evaluate it, the more institutionalized this alignment will be. Hence, we expect that the number of statements in which certain elements are co-mentioned provides a proxy measure for the degree of institutionalization of a corresponding socio-technical configuration.

One key advantage of this conceptual lens is that extensive textual databases exist, through which discourses can be empirically reconstructed. Potential databases comprise a wide array of textual media, such as newspapers, conference proceedings, government protocols, online blogs or industry magazines. The availability of document stocks over long time spans and

across a wide variety of spatial ranges enables the reconstruction of longer term developments and the comparison between geographical units in a systematic way. The discursive lens, thus, also improves our ability to retrace the geography of socio-technical transition processes, since it allows to empirically assess the places and scales at which both transition proponents and opponents, as well as their audiences are voicing their opinions (Smith et al., 2014). As an example, we can distinguish conceptually between expert discourses that are forming in the professional circles of a (global) sector, and policy discourses that are carried out in specific national/regional/urban spatial subsystems. In the former case, key actors will be internationally operating companies, NGOS, consultants or investors that will frame certain technical approaches as superior solutions at international conferences, trade fairs, as well as in professional industry magazines, blogs, etc. In the latter case, fierce power/framing battles will be fought by the proponents and opponents of certain technological solutions in the context of national / regional or even urban policy arenas. The relevant framing activities will be staged in local/regional/national newspapers as well as in parliamentary debates, roundtables, policy fora, and the like.

3. Method

Based on the above conceptual basis, we will now further specify our semi-quantitative relational approach for reconstructing the (dis-)alignment of socio-technical configurations across time and space. To this end, we depart from an established method in political sciences, Discourse Network Analysis (Leifeld, 2009, Leifeld and Haunss, 2012, Leifeld, 2017), which allows the mapping of salient framing constellations by various actors, which may help specifying the dynamic and semi-coherent fabric of socio-technical change.

3.1 Discourse network analysis (DNA)

The core idea of DNA rests on the relational characteristics that scholars have attributed to policy debates, arguing that coalitions between actors may emerge from discourses as a consequence of similar beliefs, arguments or policy stances, which once established, usually remain stable over many years (Leifeld, 2009, Leifeld, 2017). The method then builds upon two conceptual ideas that are crucial to define their object of interest, “advocacy coalitions” (Sabatier, 1988) and “discourse coalitions” (Hajer, 1995). The core difference between the two can be found in the analytical level at which they conceptualize a debate or discourse. While

advocacy coalitions may form in broader, problem oriented policy debates around multiple issues with actors discussing multiple policy proposals, discourse coalitions rather concern the debate around the pros and cons of one specific policy issue, for which multiple justifications may be used (Leifeld, 2017). DNA builds on these ideas by maintaining that analyzing advocacy or discourse coalitions allows for a quantitative mapping of the level of cooperation and conflict among actors in a systemic context.

Complementary to advocacy and discourse coalitions, also concepts can be linked to each other. The common uttering of two concepts by the same actor(s) implicates some degree of ideological and intrinsic compatibility between the concepts, and hence their mutual congruence. While the individual agreement or disagreement of a concept can be understood as an evaluation process, the congruent evaluation of several concepts, may be operationalized as the integration of evaluations into a coherent storyline (for such an operationalization see also Leifeld and Haunss, 2012). Fig. 2 illustrates the network intuition behind DNA and links it to

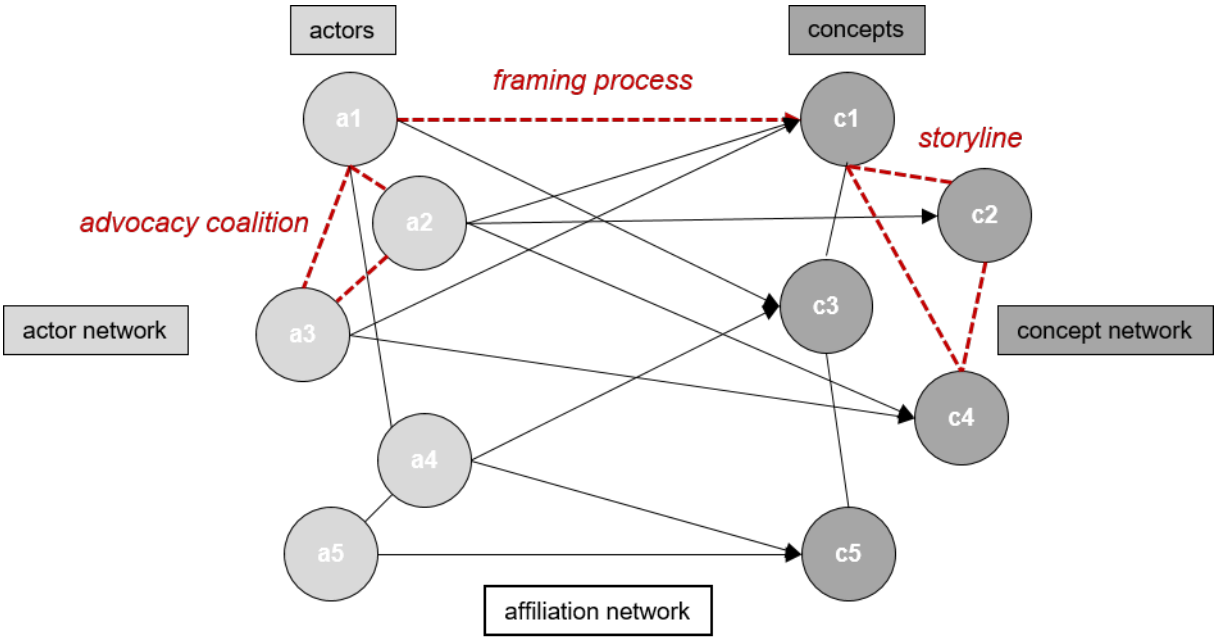

Fig. 2 DNA network intuition. Adapted from Leifeld, 2017

the conceptually defined terminologies.

Following this intuition, actors can be associated with concepts, in a so-called affiliation network. An actor who is linked to a concept indicates that the actor has in some way framed the concept, e.g. made a statement regarding a specific policy proposal. On one hand, actors linked in an actor network are connected to each other because they have referred to the same concept. The link between concepts in the concept network, on the other hand, can be reconstructed by references to concepts that are jointly mentioned by the same actors. Further, references to concepts can be qualified by a binary variable for a positive (e.g. the agreement

with a policy proposal) or negative (e.g. disagreement) evaluation. Congruence among concepts then emerges out of actors' joint agreement, or joint disagreement regarding a concept, whereas conflict arises from oppositional evaluations of a concept. The weight of an edge in a congruence or conflict network can then be interpreted as the strength of the congruence or conflict between two actors or two concepts. If for example, two actors congruently frame several concepts in a specific period of analysis, the weight of the edge between them will reflect the number of concepts they agree on, or (in a weighted network) the number of instances that they have jointly agreed on concepts.

DNA has been applied to socio-technical transition studies already, however mostly in the form of analyzing policy debates, especially in work on the politics and power of transitions (Kern, 2011, Markard et al., 2016). For example, Sabatier (1988)'s advocacy coalition framework has been an important reference for the study of technological innovation systems from the very beginning (Bergek, 2008), and more recently it has gotten ample attention by transitions scholars interested in the policy related aspects of transitions (Markard et al., 2016, Kern and Rogge, 2018, Schmidt et al., 2019). Similarly, Hajer (1995) conceptualization of discourse coalitions has resonated with scholars interested in discourses related to transitions policies (Kern, 2011, Rosenbloom et al., 2016). Based on this, the application of DNA within the realm of transition policy debates seems like a highly promising avenue for future research (see also Schmidt et al., 2019). However, as we will elaborate, our focus on socio-technical alignment goes clearly beyond the realm of policy debates. Rather, similar to Geels and Verhees (2011) and Konrad et al. (2012), the STNA perspective perceives societal, political and professional discourses as mirror images of aligned socio-technical configurations. Mapping and measuring socio-technical alignment processes from a network perspective has several deep implications, which we will elaborate next.

3.2 Socio-technical discourse network analysis (STNA)

As Geels and Verhees (2011) have shown, technology proponents do not only need to discursively portray their technology itself or its performance as positive, but they also need to make sense of its implications with regard to broader social, political and economic agendas. Hence, STNA not only aims at capturing individual organizations' policy stances but rather their full portfolio of evaluations related to institutional and technical elements, such as infrastructure solutions, policies, forms of regulation or sector norms. Analytically, this shifts the focus away from discourse coalitions around specific policies towards broader and less coherent advocacy coalitions that assemble around different technologies and institutions and

logics in an organizational field. This has various implications for what we can expect from the analysis.

At the actor level, we do not expect the partisan advocacy coalitions that emerge from policy discourses, but rather a patchwork of alignments that will supposedly be stronger among actor groups that share common rulesets, beliefs and norms. While this may result in networks that are less dense and slightly more difficult and fuzzy to interpret at the actor level, it is at the level of concepts, where we see a major contribution of STNA.

Concept congruence networks allow for a novel, relational assessment of the internal alignment and degree of institutionalization of different socio-technical configurations. Through concept congruence networks, STNA is able to map not only the most prevalent social and technological elements in societal/expert storylines, but also the strength of their internal alignment. To see how this can be directly operationalized through the computation of a concept congruence network and centrality measures, let's have a look at a slightly altered version of our example I in Fig.1 (Fig. 3). Note that our representation here does not include actors, since we are looking at the one-mode transformation of a concept network, that is, a network of the technologies and institutions that are being co-mentioned by actors.

The degree of alignment between field elements is operationalized visually through a radial centrality layout. In this network representation, each nodes' position reflects its "network centrality score". In the simplest form, degree centrality measures the number of other concepts that a concept is linked to. 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, a higher degree centrality reflects the fact that actors have used a concept conjointly with many other concepts. A central concept then appears as highly compatible with many other concepts with which it may form coherent storylines, represented by clusters of concepts. Hence, centrality provides a proxy-indicator for the level of alignment of different field elements. The most strongly aligned field elements (with the highest degree centrality), may therefore be interpreted as the highly institutionalized core configuration of an organizational field, i.e. its regime. In contrast, if certain elements are not well aligned with the core configuration(s), they will co-occur with fewer, and more diverse concepts in less stable temporal patterns and be more often either openly challenged or side-lined by the actors supporting a competing socio-technical configuration.

For illustrative purposes, we have differentiated between different institutional field elements in fig. 3 (circled nodes), including different infrastructure or governance design paradigms (e.g. centralization vs. decentralization of utility services), different types of regulation, and the field

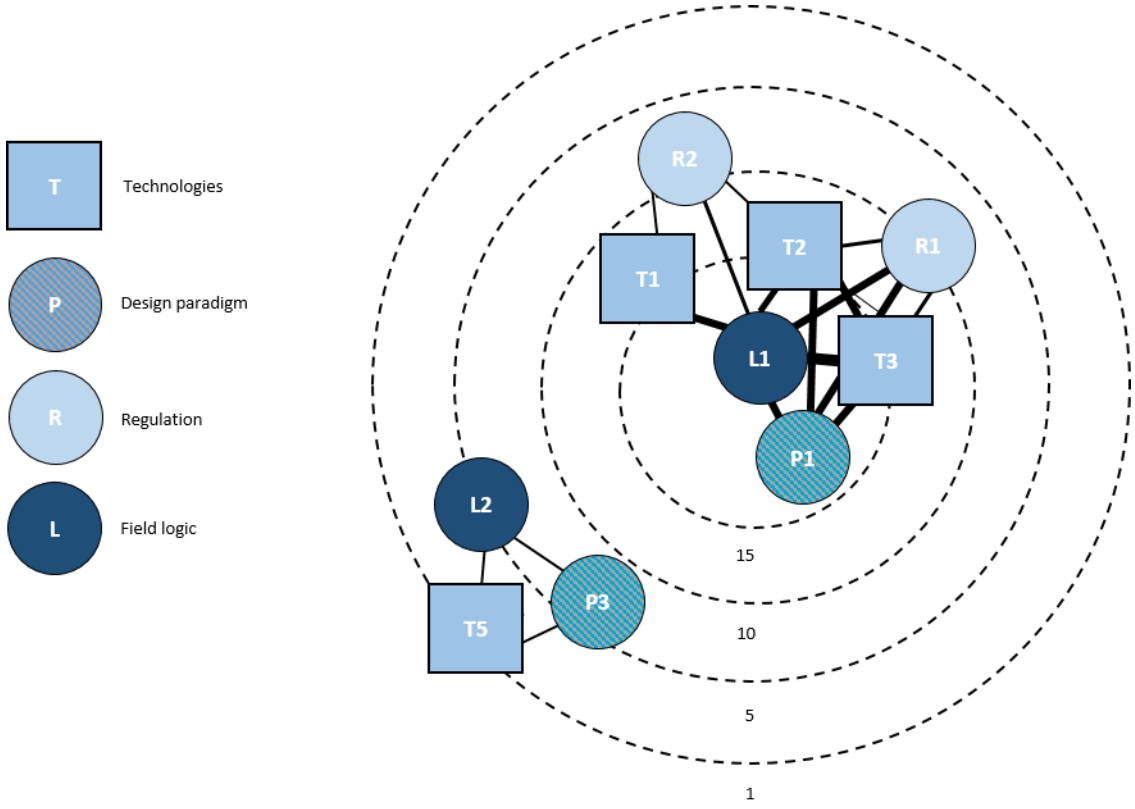

Fig. 3 STNA: Concept congruence networks as a measure of socio-technical alignment. Own figure, numbers on concentric circles indicate centrality score of each field element.

logics, of which one is structuring the core configuration (here L1) and one is aligned with an emerging configuration (L2). This list of elements chosen here is non-exhaustive, and will vary according to the organisational field under investigation. Each node is positioned according to its weighted degree centrality, that is, not only taking into account the fact that concepts have been conjointly used in a congruent manner, but also the number of times that this has happened. E.g. the link between the central field logic L1 and its adjacent technology T3 is visualized by a thicker line than the link between T3 and regulation R1, indicating that the congruent combination L1-T3 is used more frequently than T3-R1. The positionality of T3 on the concentric circle for a weighted degree of 15, then indicates that T3 was congruently used with its adjacent nodes P1, L1 and R1 15 times overall. The centrality network plot thus provides a visual interpretation of the centrality of various framed elements, which takes into account both their institutionalization (as measured in the frequency of their use) and their alignment with other elements (as measured through the strength of their congruence links).

Since the relational data can also be represented as actor networks, it is further possible to retrace the driving (or blocking) actors behind changing configurations, allowing to answer questions regarding the importance of different actor types, the emergence of novel technology proponents, and the shifting role of incumbents in socio-technical transitions. If for example a growing institutionalization of an emerging configuration can be associated with increasingly resourceful types of organisations, one may interpret this as indications for an increasing maturation of the underlying system of innovation, in the sense of a structural equivalent of what Suurs and Hekkert (2009) called "motors of innovation". This could be further extend to a notion of motors of creative destruction (Kivimaa and Kern, 2016), if these organisations' storylines involve both the legitimation of novel and the de-legitimation of core regime concepts. While such an analysis would focus on the formation of an emerging innovation system, STNA could equally be applied to the alignment processes around the establishment of a dominant design within a specific technological field, like the membrane bioreactor technology in the Chinese UWM sector (Yap and Truffer, 2018).

In following, however, we will apply the method to the analysis of spatially variegated socio-technical alignment processes in an emerging transition in the global UWM sector. Prior research has shown that the global regime around centralized water infrastructures and associated technologies has been established to varying degrees across countries and is strongly reinforced through organizations that operate at the global-scale, such as multi-national companies, consultancies, NGOs and associations (Fuenfschilling and Binz, 2018). Hence, in following section, we will briefly elaborate on STNA's ability to capture geographical and scalar information, allowing us to map and measure socio-technical alignments in organisational fields that from in different spatial contexts and at different spatial scales.

3.3 Capturing multi-scalar regime structures through STNA

To exemplify a geographically sensitive STNA analysis, we need to elaborate on how the choice of data sources not only defines what part of the organizational field is investigated, but also its geography. As outlined above, media outlets may target audiences that are active in different regions or across different spatial scales. The readership of global industry magazines and blogs, will likely encompass actors that are organized globally and may potentially shape global regime structures (Fuenfschilling and Binz, 2018), while daily newspapers typically target national or regional public discourses (Raven et al., 2015). A geographically sensitive STNA should explicitly account for the geographical reach of the audience, which is being addressed by the media channel analysed. Capturing this geographical dimension allows for the

construction of concept networks at different spatial scales, and open up for comparative analysis of different audiences in different regions. In addition, transition trajectories may also be defined through the dominant scale of activity of the organizations that form the field. Here, STNA can capture the dominant scale of activity of the evaluating organizations; e.g. international organizations and multi-nationals at the global, political parties at the national, or grassroots organizations at the local scale. The combined analysis of the geography of audiences and actors then allows for the identification of multi-scalar evaluation and legitimation processes that influence the transformation organizational fields (annonymized, submitted).

4. Analyzing and mapping emerging transitions in urban water management

Applying STNA to the case of the global water sector seems promising since it is facing strong transformation pressures and boasts a highly complex global actor structure that can be expected to exhibit relevant activities in different locations and at different scales. The dominant (global) socio-technical regime in the UWM sector revolves around a deeply institutionalized and taken for granted core field logic, which is neatly aligned with an infrastructure paradigm around custom-built, large-scale, centralized infrastructures for water supply, wastewater treatment and stormwater management (Fuenfschilling and Binz, 2018). With an estimated annual investment volume of 500 billion US dollar 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).

Based on an in-depth case study of transition dynamics in Australia, Fuenfschilling and Truffer (2014) identified three core competing field logics in the UWM sector: the hydraulic logic defending the status quo, a water market logic, putting economic efficiency up front, and a water sensitive logic, highlighting environmental sustainability and community-related issues. As they argue, proponents of each of these rationalities favour and reject different types of technologies, governance modes and types of policy to varying degrees, conjointly forming the semi-coherent fabric of the dominant regime in UWM. Especially in light of mega-trends (like

neoliberalism) or grand challenges (like climate change and urbanisation), the market and the sustainability related rationality have substantially gained importance. An illustrative example of the increasing importance of the market rationality, can be seen in the increasing marketization of desalinated seawater, produced in large-scale desalination plants, e.g. in Australia after the Millenium drought, and in Southern California more recently (Fuenfschilling and Truffer, 2016, Williams, 2018).

At the same time, scholars and practitioners alike are increasingly highlighting the importance of making UWM practices more sustainable, resilient against shocks, and fit-for-purpose based on more modular and decentralised technologies and modes of operation (Larsen et al., 2016, Hoffmann et al., 2020). The argument for this alternative paradigm is that applying the Western-style, 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). The premise of modularized and decentral technologies, in turn, rests on the idea 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 in terms of management and service provision, and more efficient in terms of closing resource cycles (Wilson et al., 2020, Dahlgren et al., 2013, Larsen et al., 2016).

The emergent socio-technical configurations, which embrace this alternative water sensitive modular paradigm, are still at a nascent stage globally, comprising relatively few industrial actors, and with funding and support mostly originating from private venture philanthropy (especially the Bill and Melinda Gates Foundation – BMGF), NGOs, research and development agencies (OECD, 2019). Yet, based on the aforementioned transformation pressures on UWM globally, we would expect their increasing visibility in relevant discourses in recent years.

4.1 Database and methods

To apply STNA to the UWM sector, we first screened the global newspaper repository Nexis Uni for outlets and articles dealing with technological solutions to water problems in various English speaking countries and in global-scale industry magazines during 2011-2018. A set of 180 outlets (App. 1) classified as quality newspapers and industry magazines by Lexis Uni from most OECD countries, plus newspapers from India, South Africa, China and Singapore, was filtered with a search query around technology terms that relate to centralized or modular water systems (App. 2). Of initially around 800 articles, 576 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 (App. 3) before teaching a second coder in consistently applying it

throughout the dataset, involving feedback rounds and inter-coder reliability checks. The coding differentiates several innovative water technologies both within the centralized and modular realm, which may be framed in a legitimizing or de-legitimizing way. Further, we distinguished individual concepts for the centralized vs. modular infrastructure paradigm, for different types of policy and for different types of rationalities, that actors would mobilize in the context of their discursive evaluations.

Wherever applicable, direct or indirect statements by organizations were coded separately according to their evaluation of the infrastructural paradigms (modular/central), and if further specified, of specific technologies, as well as of related policies, and the related rationalities. Rationalities here simply refer to larger topics which actors may mobilize in order to justify their support or rejection of specific field elements, such as security, sustainability or profitability. For each code, the agreement variable specifies, if a paradigm, technology or policy was being supported or criticised. In the case of rationality codes, the agreement variable illustrates if the rationality was reinforced or weakened, i.e. criticized through an actors' statement. Eventually, for each code, we captured the dominant spatial scale of activity of the organization evaluating a concept, (i.e. global for multinational companies, (sub-)national for governments or local utilities, etc.), based on separate desk research. Further, the scale of the audience of the outlet, in which an evaluation of a concept was identified, was separately captured.

The code-co-occurrence matrices crated with DNA software were later filtered with help of R to calculate concept congruence networks based on actors affiliated with the global-scale field level, and within specific countries. The networks were parted in three time-slices, isolating a period between 2014 and 2016. This period was chosen since several droughts associated with an El-Nino event hit countries like the USA and South Africa at this time (Baudoin et al., 2017, NIDIS, 2018). Since media in these countries were covering water debates extensively during this period, it resonates with the idea that external shocks or pressures lead to higher activity of statements expressing socio-technical (dis-)alignments (Rosenbloom et al., 2016, Turnheim and Geels, 2013, Wooten and Hoffman, 2016).

The constructed networks were analysed regarding basic network indicators and were visualized with the software package *visone* (Baur, 2008). The underlying datasets of these global and national socio-technical alignment dynamics were further analysed with help of the qualitative text data and descriptive statistics regarding the driving actors and actor types during each period. To this end, we identified the organizations behind all *conducive* evaluations,

which we defined by the aggregation of those evaluations that were supportive of field elements associated with the modularization paradigm, and of those that were obstructing elements associated with the centralized paradigm in a given period and spatially delimited field. We chose an actor-based perspective here, filtering the dataset for all evaluations made by organizations that dominantly operate in a specific country, or at the global scale.

In the remainder, we will demonstrate the results for socio-technical alignment dynamics by global actors (4.2) and by actors from three contrasting country cases that proved to be discursive hotspots (see also, annonymized, submitted): the USA, South Africa and India (cf. section 4.3). These three countries, taken together, account for half of all country-level evaluations captured from over 30 countries (see App.4). The USA and South Africa, furthermore, both experienced major droughts between 2014-2016 (Baudoin et al., 2017, NIDIS, 2018), while in many regions of India, water stress is a constant problem.

4.2 Socio-technical alignments by global scale actors

At a most aggregate level, our data reveals considerable stability at the global-scale where we would expect to find many proponents of the existing global regime (Fuenfschilling and Binz, 2018) with large multi-national companies and non-governmental organizations reinforcing the dominant paradigm around centralized urban and industrial water management (Fig. 4). The regime is dominated by a stable core alignment around centralized industrial and municipal reuse as well as centralized desalination and the centralization paradigm, confirming what one could expect based on the previous sections. More emergent socio-technical configurations around modular technologies (indicated in green), in turn, appear on the fringes of the plot in the 2011-2013 period. Yet, a gradual inclusion of the sustainability rationale and increasing alignment between elements from the core and the emerging configurations is observable from 2014 onwards. While during 2014-2016 this was predominantly driven through joint references to the sustainability rationale by transition proponents and incumbents, in 2017-2018, we find indications for a novel alignment around centralized and modular wastewater reuse that aligns with the sustainability rationale.

To further interpret these alignment patterns, we use the qualitative data from the coded newspaper articles and the underlying actor type patterns (Fig. 4c). The global scale in our dataset is populated with evaluations of various elements by the largest multi-national water technology companies in the world, international associations like International Water Association, International Desalination Association, and various intergovernmental organizations (UN, World Bank, WEF, WarterAid among others). Among the companies, we

capture evaluations by Dow, GE, Veolia, Kemira, Grundfos, BASF, LG, Lanxess, Hyflux as well as several larger engineering consultants. Looking at the dominant global actor types (4c) contributing to the discourse, we can see that the core configurations are dominantly maintained by multi-national companies, whereas the emerging configuration shows a larger proportion of 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 including modular technologies explicitly in their storylines. While this may reflect a purposeful framing strategy, it also indicates a slight shift in configurations between 2011 and 2018. The BMGF appears as an important and stable proponent of decentralized UWM approaches from around 2014 onwards, which resonates with the course of their global "Reinvent the toilet challenge" (Eckhoff and Wood, 2011). Additionally, in the latest period, some NGOs that were not as strongly represented in the previous period appear as newcomers legitimizing emerging technologies by emphasizing similarity with elements of the core configuration. With Fluence Corp., a new multi-national player appears in media (a joint venture between the US firm RWL water and the Israeli Water specialist Emefcy), which explicitly targets the global market for packaged small-scale treatment plants in the latest period.

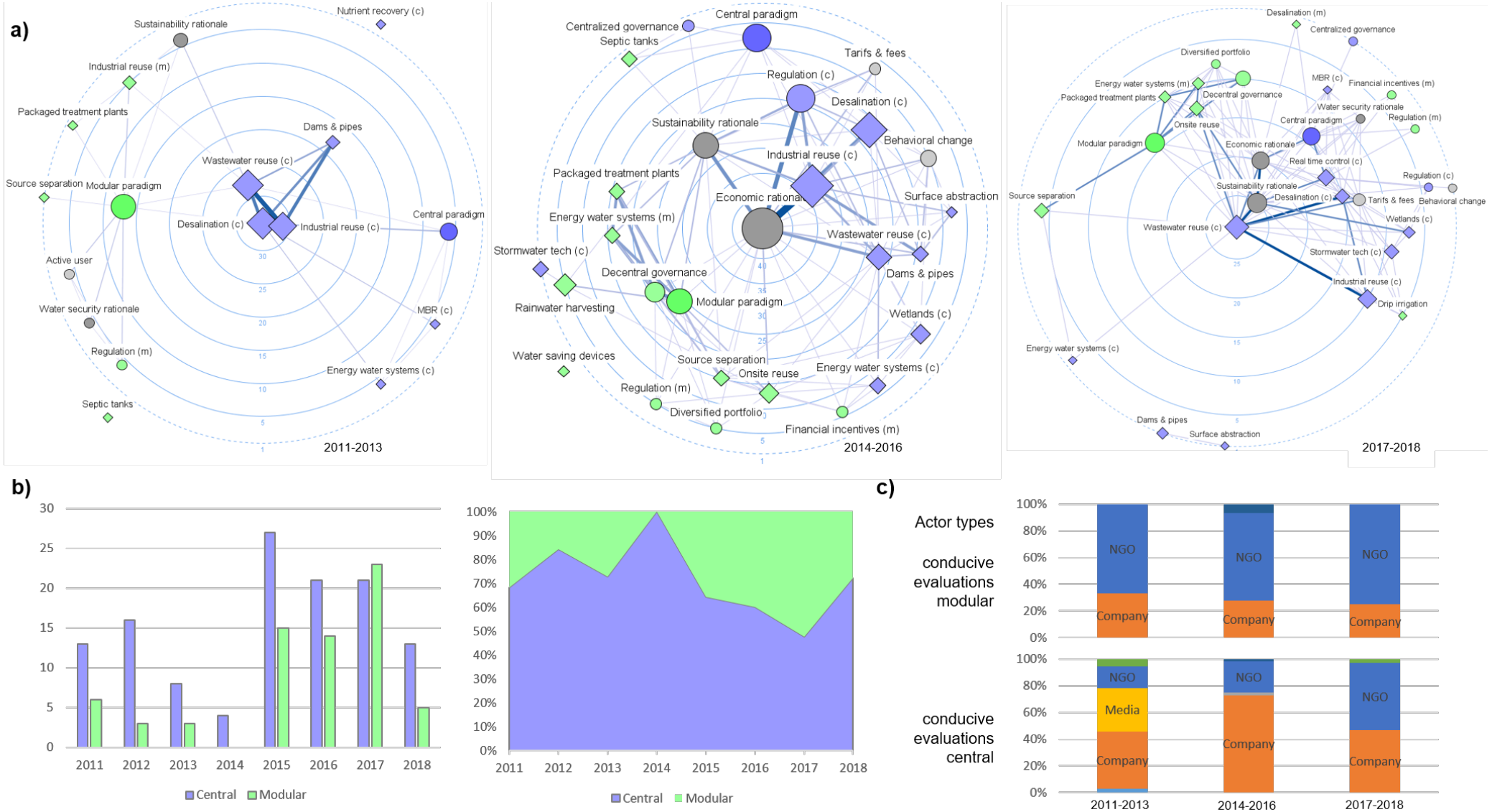

Fig. 4: a) Socio-technical configuration alignments based on global actors' evaluations, three phases. Blue: centralization paradigm. Green: modular paradigm. Size: frequency of evaluations. Round shape: institutional elements. Cubic shape: technological elements. **b)** Absolute and relative amount of annual conducive evaluations for central (blue) and modular (green) elements. **c)** Dominant actor types three phases.

Taken together the data indicates that although the core configuration around centralized technologies remains vital, emerging concepts and the sustainability rationale are increasingly integrated into the core configuration. The increasing linkages between emerging and core configurations also show signs of a fit-and-conform development pattern. Hence, it seems as if modular water technologies are increasingly moving onto the agendas of global scale actors (especially, also of big multi-national companies) which may indicate an increasing institutionalization of the modular water technology configuration in the global UWM regime.

4.3 Socio-technical alignments by US, South African and Indian actors

We will in the following elaborate on the evaluation patterns of US, South African and Indian actors and interpret socio-technical alignment processes driven by these actors. These three countries represent about 50% of the statements that we recorded in our database (App. 4).

US actors

US-actors' evaluation activities during 2011-2018 exhibit some similarity with the global regime, especially regarding the storylines supporting centralized reuse, the general infrastructure paradigm, and the increased uptake of modular elements since 2014 (Fig. 5). In the US, this seems to be triggered by a heavy drought in the Western states (California, Arizona, Nevada etc.) in 2015/2016 (NIDIS, 2018), during which discursive activity increased strongly. In this period, one can see a new storyline emerging, which aligns modular packaged wastewater treatment and energy recovery systems and on-site reuse systems (e.g. used in buildings and households). Also incumbent actors now partly include these emerging concepts into their storylines and the sustainability rationale is reaching higher centrality during this period. In 2017/2018, after the hype, the emerging elements remain in the centre, indicating that the alignment of the modular UWM paradigm and related technologies has become more institutionalized than before the drought. The general pattern may be interpreted as a stretch-and-transform dynamic pattern, since the core configuration is transforming substantially in the latest period.

A look at the actor type distribution (Fig. 5c), and the qualitative data from the articles confirms this picture. Whereas the coalition of actors advocating classic regime concepts remains surprisingly stable throughout the whole period (only with some smaller deviation during the drought), the coalition supporting modular UWM technologies seems to have changed its

composition. While in the beginning NGOs and research institutes dominate in the discourse, they are increasingly replaced by public authorities and companies in the latter years. We would interpret this pattern as an increasing maturation of systemic alignments around modular water technologies. Indeed the qualitative data reveals that while in the beginning, the emerging configuration is promoted by some smaller charities and larger universities (CalTec, Harvard, and Stanford), since 2014 new actors appear in the media. Especially Californian actors contribute to a big surge in conducive evaluations around 2015 and 2016 (Fig. 5a). 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 Standford University, who are combining emerging and core configurational concepts in their storylines.

At the same time, also political stakeholders, like the board of supervisors of the city of San Francisco, appear as new legitimizers of modular greywater systems at the building scale (onsite-reuse). Additionally, there is a new recurrent pattern of Californian Breweries that are starting to install on-site wastewater reuse systems during the drought period. In turn, large-scale desalination, a relevant concept of the core US storyline in 2011-2013, is 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) are getting more prominent. While Californian actors' influence fades from the discourses in the 2017-2018 period, the emergence of new proponents, e.g. public authorities in Arizona and larger firms (e.g. Solenis, RWL Water) as co-legitimizers of the former emergent concepts points to an increasing institutionalization of modular water technologies in the US.

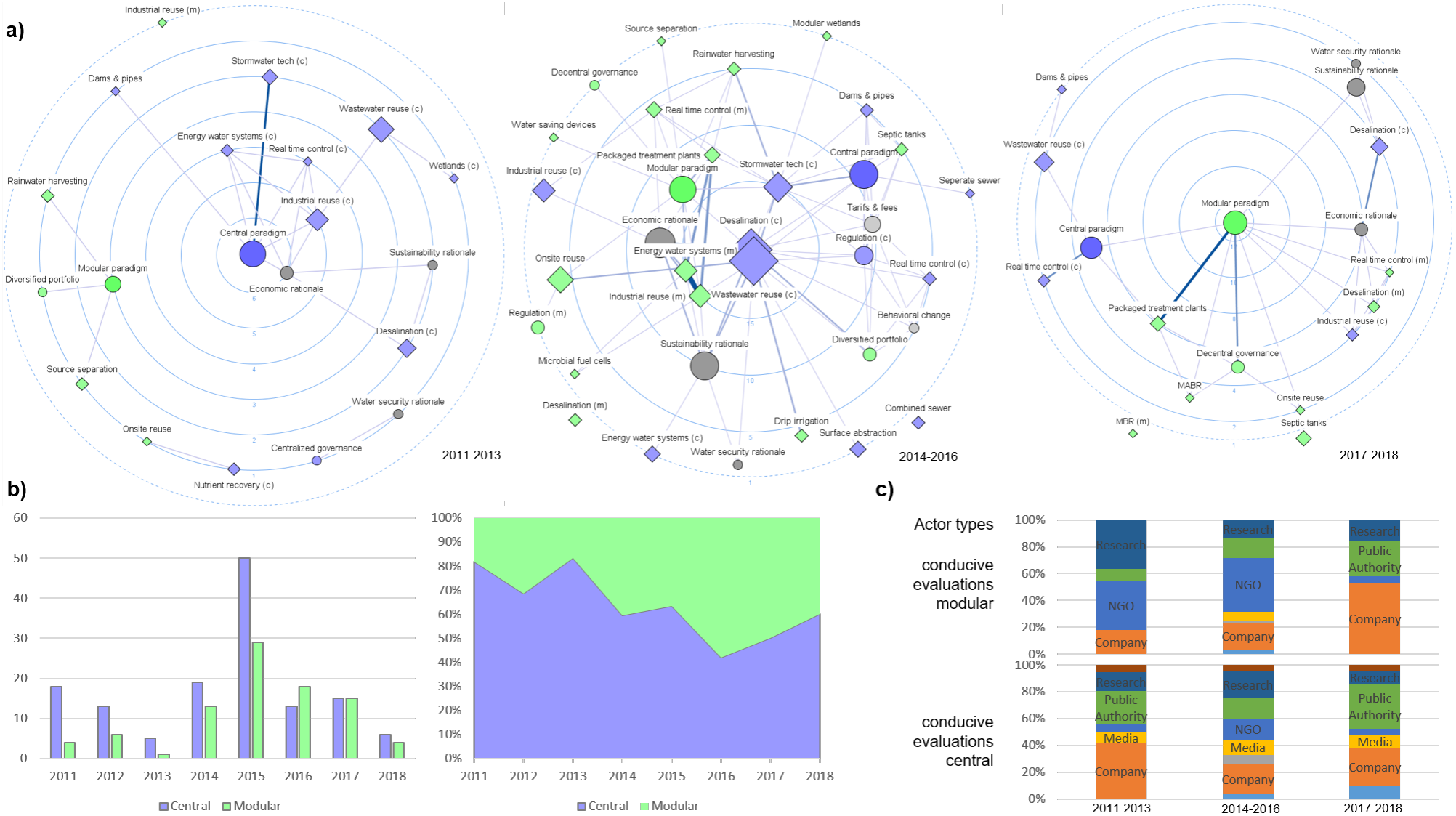

Fig. 5: a) Socio-technical configuration alignments based on US actors' evaluations, three phases. Blue: centralization paradigm. Green: modular paradigm. Size: frequency of evaluations. Round shape: institutional elements. Cubic shape: technological elements. **b)** Absolute and relative amount of annual conducive evaluations for central (blue) and modular (green) elements. **c)** Dominant actor types three phases.

South African actors

South Africa provides an interesting comparative case to the US, since both countries have been strongly affected by heavy droughts between 2014 and 2016. Indeed, similar to the US, South Africa sees a strong entry of emerging field elements during the time of increased environmental pressure (2014-2016). However, as a striking difference to the US pattern, modular UWM configurations are largely absent before and after the drought period (Fig. 6). Their advocates are comprised of three groups: The Government based in Pretoria, the City of Durban, its local University of KwaZulu Natal and a company with expertise in industrial water treatment (Murray and Roberts). The Government turned towards modular technologies, especially rainwater harvesting during the 2015-2016 drought, while otherwise heavily investing in large-scale desalination in Cape Town and other places. The strong alignment of the emerging and core configurations during the drought period suggest that South Africa exemplifies a fit-and-conform pattern. It fits into the picture that modular rainwater harvesting technologies are strongly promoted. They require relatively little adjustments of the existing socio-technical regime, since they are relatively low-tech, cheap solutions that require only small regulative adjustments, and are already part of the UWM system in some South African cities (Mwenge Kahinda and Taigbenu, 2011). The city of Durban and the University of KwaZulu Natal, are experimenting with more radical on-site urine treatment technologies (source separation) strongly driven by international funding through the BMGF (see also Sutherland et al., 2015), which is reported about in the early period (2011-2013). In 2018, Murray and Roberts announced to build onsite-treatment facilities for hospitals in Cape Town, when these were running out of water. Such, more radical emerging configurations, however, remained scarce and not well-aligned with the core storyline in South Africa. Comparing the discursive reactions to the droughts by US and South African actors, we find one similarity standing out. The external environmental pressures clearly have an at least temporary effect on the alignment of socio-technical configurations and on the underlying rationalities, usually in favor of a sustainability rationale (R2) and new field elements. The increasing importance of the sustainability rationale may reflect the social construction of the landscape that Rosenbloom et al. (2016) was referring to: both transition proponents and opponents are increasingly drawing on a novel rationality (sustainability) responding to the drought, and try to connect it to their existing storylines (around technology concepts).

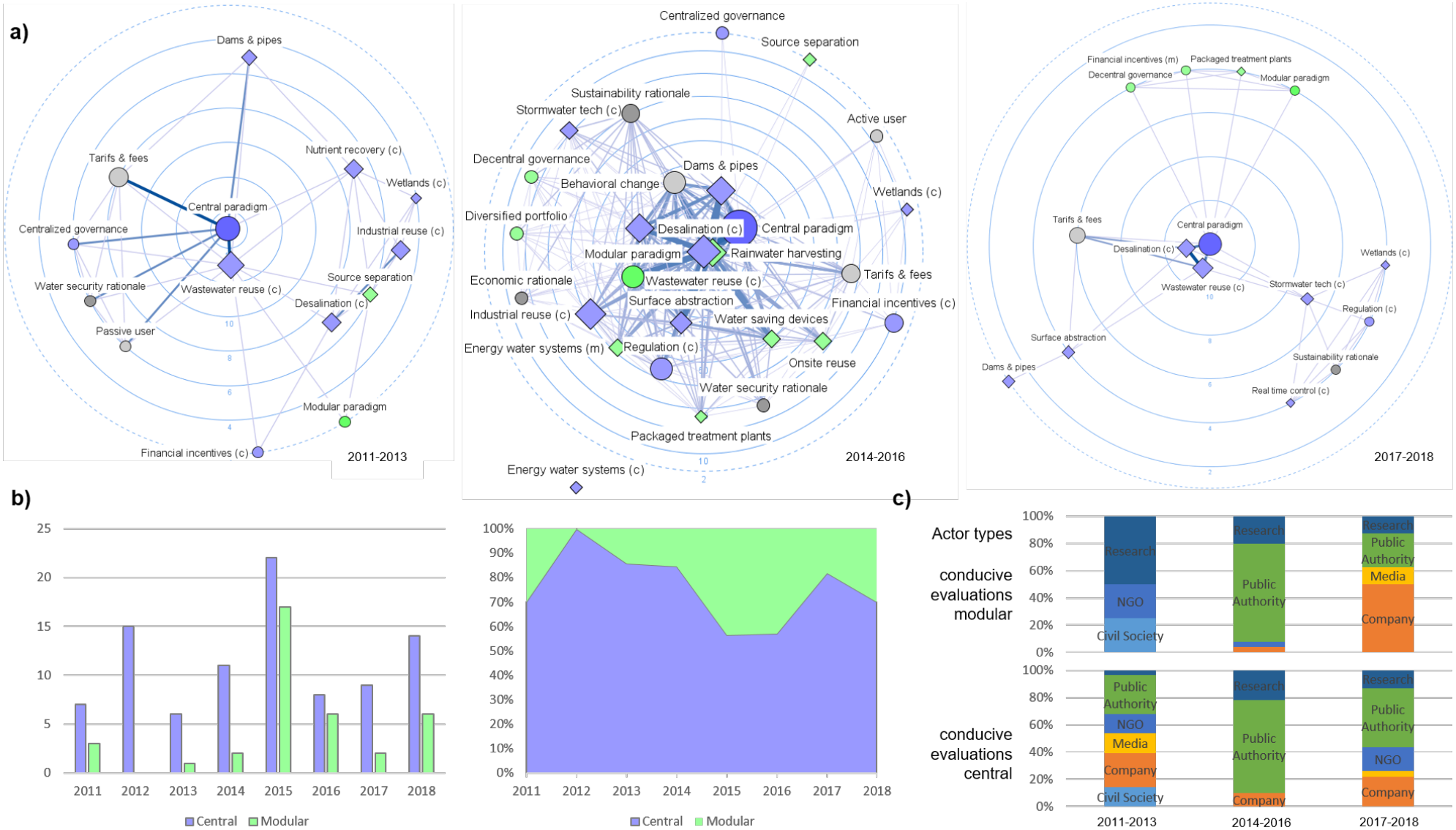

Fig. 6: a) Socio-technical configuration alignments based on South African actors' evaluations, three phases. Blue: centralization paradigm. Green: modular paradigm. Size: frequency of evaluations. Round shape: institutional elements. Cubic shape: technological elements. **b)** Absolute and relative amount of annual conducive evaluations for central (blue) and modular (green) elements. **c)** Dominant actor types three phases.

Indian actors

India constitutes a somewhat special case, which is illustrated by the fact that at times (like in 2013-2014 or 2018) over half of all evaluations are conducive to modular UWM configurations (Fig. 7), which may not surprise given the country's low connection rate to centralized sewers. In 2017, only 11% of households were connected to central sewers, while 1/3 had decentralized septic systems installed and 28% were lacking any access to safely managed sanitation infrastructures (WHO and Unicef, 2020). In this context, socio-technical configurations around modular UWM systems are consistently not only present but also strongly aligned with various regime-related configurations. In this sense, we would characterize the Indian context as a "polycentric regime" (van Welie et al., 2018), consisting of different paradigms that coexist and are more or less consistently aligned with each other. Modular technologies are being promoted by a broad range of actors, including the Government (Fig. 7 c). Next to the 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), Uttar Pradesh and Himachal Pradesh in the North (several cities like Allahabad, Moradabad, Meerut, Shimla) and a strong hub in Bengalore (Karnataka). An important constant proponent is the National Environmental Engineering Institute (NEERI) based in Nagpur.

In terms of dynamics, one can observe that – somewhat contrary to the other cases - the core configuration of the global regime is gaining importance in Indian UWM sector. This is mostly driven by the government but also NGOs and universities that promote the further development of centralized infrastructures, especially in urban contexts that often still lack improved sanitation facilities (Fig. 7c). At the same time, an increasing interest in modular technologies can be observed in specific localities. Especially in Bengalore, where public authorities as well as civil society, research, and companies are starting to promote modular technologies much more strongly in the latest period (2017-2018), resonating with recent research on the case (Reymond et al., 2020). Parallel with this one can also see an increasing number of research institutes engaging in supportive narratives. This suggests, that while the alignments of configurations at the national scale may indicate stability, regional transition pathways may still excel in specific locations.

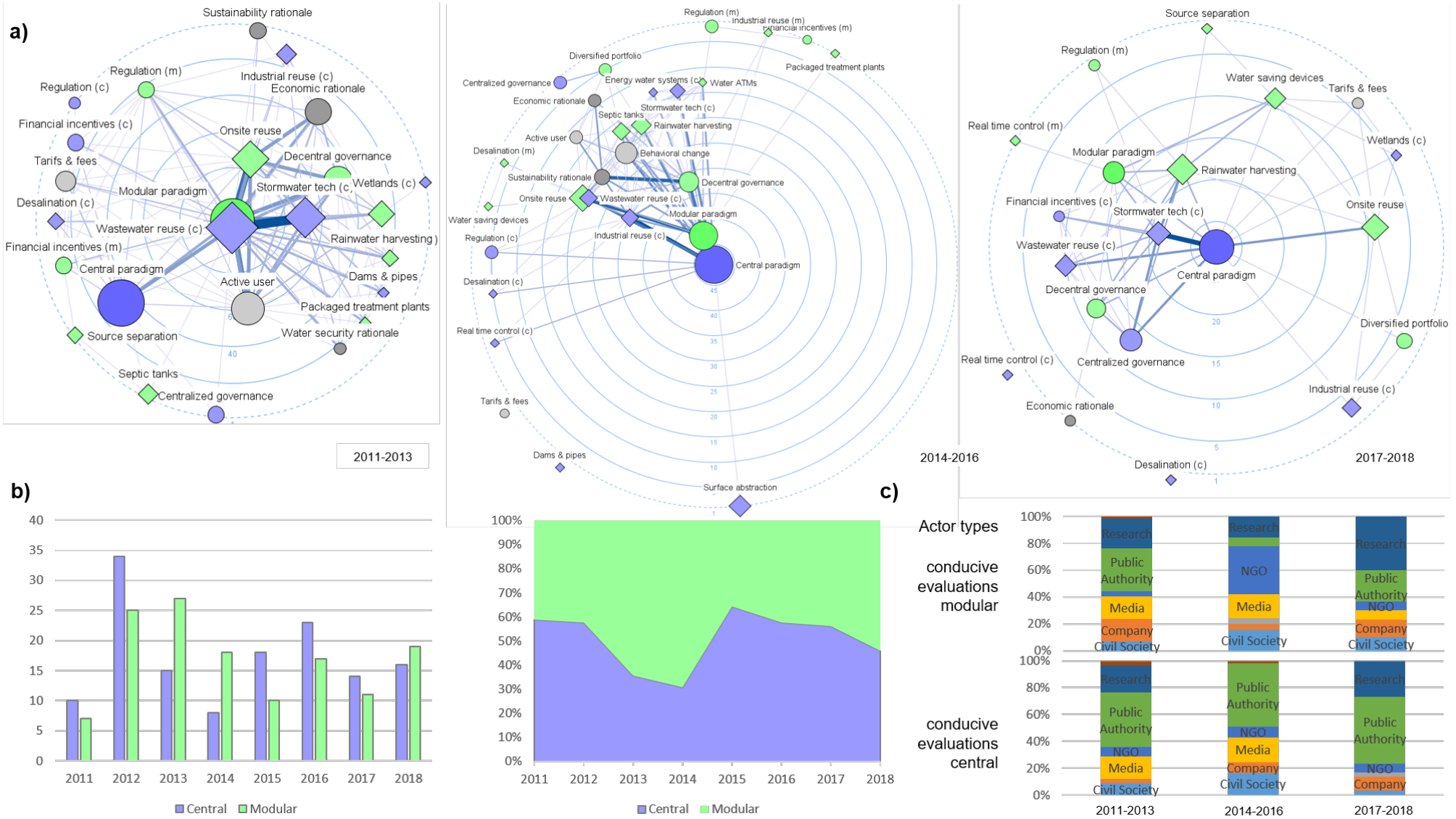

Fig. 7a) Socio-technical configuration alignments based on Indian actors' evaluations, three phases. Blue: centralization paradigm. Green: modular paradigm. Size: frequency of evaluations. Round shape: institutional elements. Cubic shape: technological elements. **7b)** Absolute and relative amount of annual conducive evaluations for central (blue) and modular (green) elements. **7c)** Dominant actor types three phases.

5. Discussion

The empirical results discussed above imply that transitions in the UWM field can be conceptualized as a patchwork of change processes that happen both at a global sector level 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 are dependent upon) 'global' regime structures could so far only be characterized conceptually or with very generic, cross-comparative research designs (Fuenfschilling and Binz, 2018, Lieberherr and Fuenfschilling, 2016). The STNA method in contrast enables a direct global mapping of the relevant (dis-)alignment processes at global and (sub-)national levels, which allows one to infer why transition trajectories are likely to look very different between different contexts (i.e. the USA vs. India) and are more likely to occur in certain contexts (here: the USA / India) than in others (i.e. South Africa).

The results of our global mapping exercise in fact resonate with previous findings from discursive approaches to transitions, underlining the proposed utility of our approach for future research. Our findings revealed a highly institutionalized core around the paradigm of centralized, large-scale water and wastewater infrastructures, which is closely aligned with certain technologies, such as desalination and large-scale wastewater and stormwater treatment . These large-scale, centralized technologies and concepts constitute the core of most storylines by incumbents from various domains, and they remain comparatively stable over time, reflecting the existence of a relatively stable and deeply institutionalized global socio-technical regime in this sector (Fuenfschilling and Binz, 2018).

The concept of small-scale, modular UWM and related technologies remain rather isolated and on the fringes of the relevant discourses in the field in the early 2010s. With the emergence of stronger environmental pressures and the global droughts in 2014-2016, a new rationality around sustainability is gaining importance in various countries and quickly invading the core discourse of the field (globally, as well as in the US and in South Africa), which seems to provide a window of opportunity for the proponents of modular UWM solutions to better align the decentralized infrastructure paradigm and modular technologies to a configuration that is able to challenge certain elements of the incumbent regime. At the same time, also incumbents increasingly include modular elements in their storylines. Reuse-oriented technologies in the

most current phase become the key boundary configuration, as both transition proponents and incumbents align behind the idea of water reuse as a 'sustainable' solution by proposing either large-scale centralized reuse schemes or small, modular reuse technologies (e.g. onsite household reuse). Reuse-related technologies accordingly constitute a novel socio-technical alignment that had hitherto not existed, and which may leverage further transition potential towards modular technologies.

With the entry of novel elements aligned with the modular paradigm into the core-configuration of the field, one may also argue that what we observe from 2014 onwards reflects a general fit-and-conform dynamic, as for instance in South Africa, and at the global discourse level. In the US, however, we can see first indications of more transformative change in the latest period (2017-2018), suggesting an underlying stretch-and-conform type of transition dynamic. In India, we find a clearly polycentric regime structure, which is comparatively stable but moves towards an increased adoption the global regime paradigm, despite some regional dynamics further promoting modular technologies. Overall, the slight indications of an imminent transition in the global regime structure thus co-evolves with spatially highly complex and variegated transition patterns in national contexts, which could now be explored and their interrelations with global transition dynamics be explained in much more detail.

6. Conclusions and future research

In the present paper, we developed a discourse-based methodology to the investigation of socio-technical alignment processes over time and space. While transition scholars have argued for the importance of technology framing processes in understanding innovation journeys, niche construction and multi-dimensional interactions in 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 discourse networks allows for a more comprehensive understanding of the dynamic and geographically variegated nature of socio-technical transitions (Fuenfschilling and Binz, 2018, Fuenfschilling and Truffer, 2014). We proposed to extend the recently developed method from policy discourse analysis – DNA (Leifeld, 2017) into a specific approach for mapping and measuring dynamics in socio-technical configurations (STNA). The novelty of this approach rests in its ability to display the internal

and external alignments of socio-technical configurations, through the investigation of storylines comprised of various congruently framed socio-technical elements over time.

Linking this information to the driving actors behind these dynamics, this approach enables the tracing of core mechanisms in transition processes like those described by the "motors of innovation" and creative destruction in the context of socio-technical change (Suurs and Hekkert, 2009, Kivimaa and Kern, 2016), their strategies of field re-configuration, such as fit-and-conform and stretch-and-conform (Smith and Raven, 2012), as well as incumbent's strategies like regime maintenance or appropriation of new elements (Turnheim and Geels, 2013, Patala et al., 2019). As outlined in more detail in the empirical part, the method furthermore enables the comparison between potential transition pathways in different spatial contexts (Geels and Schot, 2007, Hansen and Coenen, 2015, Murphy, 2015).

Thus, STNA enables the reconstruction of socio-technical dynamics over long time-spans and across different geographies. In a sense, we propose to complement the predominant "intensive" qualitative process tracking approach in transition studies with a more "extensive" approach in order to enable comparative studies, generalized mechanisms by this and ultimately extend the potential for theory building in the field. As we have demonstrated, the STNA method may allow for mapping and measuring meso-level structures and processes in an organizational field, without losing the connection to in-depth qualitative information. The exemplary application of the method to an imminent 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 investigations.

First, we maintain that the STNA method has a wide application range for all sorts of transitions related problems. I.e. we expect the STNA approach to be applicable to transition processes like early innovation system formation, the scaling up of innovation systems or struggles for dominant designs, directionality and industrial shake out. More specifically, future research could explore the dynamics within an emerging technological innovation system (Bergek, 2008). As Raven et al. (2015) have shown, emerging socio-technical configurations may not only link up to different types of rationalities 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). STNA could provide an interesting methodology to

investigate these 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 should explore the fight among different technologies within a TIS before a dominant design has emerged (Yap and Truffer, 2018).

Second, it was beyond the scope of this paper to elaborate on the policy implications that may be derived from an STNA analysis. But it seems clear that for transformation oriented innovation policy (Weber and Rohracher, 2012) or the identification of effective re-configuration-oriented 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. STNA may provide a tool to identify the most important regime-maintaining storylines (and the most powerful / interested actors behind them), which might be weakened by targeted policy interventions. Correspondingly, the method 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 and based on what storylines may in turn help to address and weaken the power of the respective actors in a more effective way. In this way, STNA may also provide an interesting tool for scholars investigating the interplay of power and agency in transitions (Avelino et al., 2016).

Third and finally, we see a great potential in diving more deeply into the geographical dimension of transition processes. As outlined in the empirical part, our approach allows for spatially open and cross-comparative research designs that would hardly be attainable with in-depth qualitative case studies. Our analysis could only scratch on the surface of the multi-faceted socio-technical alignment processes that take place *at* and spanning *across* various spatial scales. In a next step, one could for example 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 STNA analysis could reveal how the use of storylines and narratives in a region may rest on the absorption of national or global storylines in a regional setting (Späth and Rohracher, 2012, annonymized, submitted). STNA could in this sense, provide a methodology to investigate how regional innovation and socio-technical alignment processes are coupled with dynamics taking place at other spatial scales, complementing the work on global knowledge pipelines and networks with a more institutional perspective (Binz and Truffer, 2017, Binz et al., 2014, Gosens et al., 2015).

Of course, given its explorative nature and the global search lens, the application of STNA illustrated in this paper has various limitations. Especially, future research should explore in more depth what kind of documents stocks are most suitable in capturing socio-technical alignment processes at different scales and in the different contexts outlined above. 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 transitions cases and focus their search exclusively to specific times of major discursive activity. Such a focus on selected times of disruption may further allow researchers to investigate the development of an organizational field over longer time-spans, lessening the very obvious time-intensity the method comes with.

To summarize, we maintain that STNA provides a novel and potentially highly productive methodological approach to strengthen transition theorizing in the future. It enables the mapping and measuring of socio-technical dynamics over long time spans and across geographies. It provides a very strong complement to conventional qualitative case study methods and can therefore contribute substantially to cumulative theory building. Furthermore, through the virtue of its semi-quantitative approach it may build bridges to more quantitative approaches and by this perhaps also help to connect to related scholarly fields which build more exclusively on quantitative approaches. If anything, we believe that we have only been able to sketch out what could become a very generative perspective for transitions research in the future.

App. 13000 words (incl. references)

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Appendix

App. 1 – Outlets screened in Nexis Uni

Africa News	The Sunday Herald (Glasgow)	The Japan News
The Advertiser/Sunday Mail (Adelaide, South Australia)	The Guardian(London)	The Japan Times
Brisbane News	Mining Magazine	Korea Herald
Canberra Times (Australia)	New Scientist	Korea Times
Hobart Mercury/Sunday Tasmanian (Australia)	The Daily Mail and Mail on Sunday (London)	New Straits Times (Malaysia)
Herald Sun/Sunday Herald Sun (Melbourne, Australia)	The Observer(London)	The Edge Malaysia
The Age (Melbourne, Australia)	The Investors Chronicle	New Era (Windhoek)
The West Australian (Perth)	The Independent (United Kingdom)	The Namibian (Windhoek)
Sydney Morning Herald (Australia)	BBC Monitoring: International Reports	Daily Trust (Abuja)
The Australian	The Daily Telegraph (London)	Het Financieele Dagblad (English)*
Australian Financial Review	The Engineer*	The New Zealand Herald
Northern Territory News (Australia)	The Mirror (The Daily Mirror and The Sunday Mirror)	The Press (Christchurch, New Zealand)
The Courier Mail/The Sunday Mail (Australia)	The Sunday Telegraph (London)	The Dominion (Wellington)*
The Daily Telegraph (Australia)	Accountancy Age (UK)*	The Dominion Post (Wellington, New Zealand)
The Gazette (Montreal)	Airline Business	The Evening Post (Wellington)*
Ottawa Citizen	Marketing - UK*	BusinessWorld
National Post's Financial Post & FP Investing (Canada)	mirror.co.uk	Polish News Bulletin
The Globe and Mail (Canada)	standard.co.uk	Sunday Times (South Africa)
The Toronto Star	telegraph.co.uk	GroundUp (Cape Town)
National Post (f/k/a The Financial Post)(Canada)	The Evening Standard (London)	The Conversation Africa (Johannesburg)
South China Morning Post	The Herald (Glasgow)	Business Day (South Africa)
Lianhe Zaobao	Travel Trade Gazette UK & Ireland*	Financial Mail (South Africa)
Baltic News Service	Ghanaian Chronicle (Accra)	The Moscow News (RIA Novosti)*
Addis Fortune (Addis Ababa)	The Times of India (TOI)	The Moscow Times*
Maghreb Confidential	Hindustan Times	Moscow News*
Belfast News Letter*	The Economic Times	The New Times Kigali
Belfast Telegraph	The Irish Times	The Straits Times (Singapore)
Belfast Telegraph Online	The Jerusalem Post	The Edge Singapore
Birmingham Evening Mail	The Jerusalem Report	The Business Times Singapore
Birmingham Post	Nikkei Asian Review	The Nation (Thailand)

The Christian Science Monitor	Computer Weekly*	MTI Econews*
The Philadelphia Inquirer	Computing	Music Week*
The Philadelphia Inquirer - Most Recent Two Weeks	Contract Journal*	MWP Advanced Manufacturing*
Advertising Age	Control and Instrumentation*	Natural Gas Week
Automotive News	Creative Review*	New Media Age*
The New York Times	Daily Record and Sunday Mail	New Musical Express
Chemical Week	Daily Variety*	Newsweek
The New York Times - International Edition	Design Engineering*	Off Licence News*
Accounting Today	Design Week*	Plastics News (tm)
ADWEEK	Electronics Weekly	Platts Energy Business & Technology*
The New Yorker	Employee Benefits	Platts Megawatt Daily
Waste News*	Estates Gazette	PR Week
Business Monitor News	Euromoney	Precision Marketing*
Tampa Bay Times	EXE*	Process Engineering*
The Washington Post	Farmers Weekly	Professional Broking*
The San Francisco Chronicle	Financial Adviser	Retail Week*
Daily News (New York)	Financial Director*	Revolution*
Los Angeles Times	Flight International	Rubber & Plastics News
PR Week (US)*	Industry Week*	Satellite Week*
USA Today	Insurance Age*	TechNews*
The Herald (Harare)	International Money Marketing*	The Banker
Audio Week*	ITAR-TASS	The Business*
Billboard	Lawyers Weekly*	The Deal Pipeline
Brand Strategy*	Legal Week	The Electricity Journal
Builder*	Management Today	The Express
Business & Finance Magazine*	Marketing Week	The Grocer
Campaign*	Mergers and Acquisitions, The Dealmaker's Journal	The Lawyer
CFO	Middle East Newsfile (Moneyclips)*	The People
City A.M.	Mobile Communications Report*	The Pharma Letter
CMP Information	Money Marketing	The Weekly Times
Xtreme Information*	What's new in Industry*	Wall Street Journal Abstracts

App. 2 – Search terms and query for article selection in Nexis Uni

Source: Major World Publications;Major World Newspapers; Times of India (TOI);Africa News*
Combined Source: Major World Publications;Major World Newspapers; Times of India (TOI);Africa News*
((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/1 measure)
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/1 cities)
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)
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) & ATLEAST2 (treatment)

App. 3 – Coding scheme

Central paradigm related evaluations		Modular paradigm related evaluations	
Technologies			
Wastewater Treatment			
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	applications of on-site water technologies integrated in fully autonomous housing/buildings

Central paradigm related evaluations		Modular paradigm related evaluations	
Paradigms (Institutions)			
Central paradigm	evaluations 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**	evaluations 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

Rationalities (Institutions)	
Economic rationale	evaluations, narration suggests an economic rationale
Sustainability rationale	evaluations, narration suggests a sustainability rationale
Water security rationale	evaluations, narration suggests a water security rationale
Regulation (Institutions)	
Passive user	User should not need to take on responsibility for their own water supply and treatment as this is taken care by public utilities/ firms (narrative)
Active user	Water user (households, firms etc.) should take over a part of the responsibility for their own water supply and treatment (narrative)
Tarifs, fees	tarifs and fees to punish overconsumption and encourage lower water consumption (multiple tier system e.g.) in context of centralised systems
Behavioral change	behavioral change promoting or facilitating the implementation of large-scale water infrastructre

App. 4 – Dataset

Years observed:	8
Documents:	576
evaluations after duplicates/document cleared:	1589
evaluations conducive to conventional technologies	911
evaluations conducive to modular technologies	524
Rationality evaluations	154

DNA Variables:

Organisations:	568
Organisation types:	8
Concept codes (referred to in evaluations):	51

Overall evaluations 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	100.00
% of subtotal (top-3 countries)	681	49.85

Overall global-scale actor evaluations:	count	% of total
Global-scale	223	14.03
% of Global-scale and top-3 countries		58.63
Total	1589	100.00