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Research article

Policy sequencing for early-stage transition dynamics – A process model and comparative case study in the water sector

Katrin Pakizer[a,b,c,*], Eva Lieberherr[c], Megan Farrelly[d], Peter M. Bach[b,d,e], David Saurí[f], Hug March[g], Miriam Hacker[h], Christian Binz[b,i]

[a] Institute of Innovation and Entrepreneurship, ZHAW Zurich University of Applied Sciences, Theaterstrasse 17, 8400, Winterthur, Switzerland
[b] Swiss Federal Institute of Aquatic Science and Technology (Eawag), Überlandstrasse 133, 8600, Dübendorf, Switzerland
[c] Institute for Environmental Decisions, Natural Resource Policy Group, Swiss Federal Institute of Technology, Zurich, Switzerland
[d] School of Social Sciences, Monash University, Clayton, Victoria, 3800, Australia
[e] Institute of Environmental Engineering, ETH Zürich, Zürich, 8093, Switzerland
[f] Department of Geography, Universitat Autònoma de Barcelona, Bellaterra, Spain
[g] Estudis d'Economia i Empresa & Internet Interdisciplinary Institute IN3, Universitat Oberta de Catalunya, Barcelona, Spain
[h] Water Research Foundation, 1199N Fairfax St #900, Alexandria, VA, 22314
[i] Centre for Innovation Research (CIRCLE), Lund University, P.O. Box 117, Lund, 22 100, Sweden

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ABSTRACT

Sustainability scholars increasingly recognize that policy mixes can positively impact socio-technical transitions. However, the temporal dimension of policy interventions remains under-researched, especially in the context of early transition dynamics that typically emerge in niche contexts. In this article, we explore how policy sequencing can play a key role in supporting the scaling-up of early-stage transition dynamics to drive wider system change. We contribute to transition research by proposing a process model for analyzing policy sequences by focusing on the interplay between policy instruments and institutional barriers. We conceptualize two ideal-type policy sequencing patterns - strategic and reactive - which we illustrate with empirical examples from early transition dynamics in the urban water sector of San Francisco (United States) and Sant Cugat del Vallès (Spain). Applying the process model to these case studies reveals how different sequences of policy (instrument) mixes can assist in overcoming institutional barriers, thus supporting transition trajectories.

1. Introduction

Transitioning toward more sustainable urban infrastructures is a complex and long-term process (Geels, 2004). To foster the uptake of transformative solutions, research suggest that complex mixes of policies with different objectives and instruments are important for addressing key barriers[1] to structural change (Kivimaa and Kern, 2016; Rogge and Reichardt, 2016). The impact of policies (and policy instruments) on transition processes depends, among other factors, on the timing of their implementation (Flanagan et al., 2011).

* Corresponding author.
E-mail address: paki@zhaw.ch (K. Pakizer).

[1] As barriers stem from social and technical structures, researchers usually differentiate between institutional and technical barriers (Fuenfschilling and Truffer, 2014). Due to our empirical focus on the water sector, we only investigate institutional barriers, as they are considered the most important impediment to the pathway towards more sustainable urban water systems (Kiparsky et al., 2013).

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Instead of being adopted all at once, policy mixes might be sequenced across time and at different levels of governance (Turnheim et al., 2015; Howlett, 2019; Howlett and Rayner, 2007). This evolution of policy mixes is commonly referred to as *policy sequencing* (Pahle et al., 2018; Howlett, 2019).

Sustainability transitions literature has only recently begun engaging with policy sequencing in the context of renewable energy transitions (e.g., Leipprand et al., 2020; Meckling et al., 2015; Huang, 2019) and related to (supra-)national climate policy strategies (e.g., Pahle et al., 2018; Furumo and Lambin, 2021), among others. Yet, the current conceptualization of policy sequencing focuses primarily on national, top-down strategies in sectors with rather advanced transition trajectories, as e.g., in the energy or automotive sectors. In these sectors, the literature focuses on how policy stringency can be increasingly ratcheted up toward an envisioned end state like e.g., net zero emissions or the phase out of internal combustion engines (ibid.). Thus, there is a gap when it comes to understanding whether and how transition dynamics at an earlier stage, which are often spatially confined and involve place-based experimentation processes in 'niche' contexts, may be supported with policy sequencing. We address this lack of understanding regarding how policy sequencing strategies may function in scaling-up transformative niche solutions.

Our aim is to conceptualize policy sequencing patterns for early-stage transition dynamics and to explore how policy sequencing may help to scale-up the impact of place-based experimentation toward broader system transformation. By explicitly linking the work on policy mixes in transition studies with policy sequencing literature, we develop a novel process model for analyzing policy sequencing that explains the scale-up of niche innovations. In doing so, we define key areas, in which institutional barriers usually emerge in early transitions and discuss which policy instruments can be used to overcome them and scale-up policy impact beyond the initial local or regional context. We then propose two ideal-type policy sequencing patterns (strategic vs. reactive), that differ substantively in terms of the sequences in which key institutional barriers to transitions are addressed and how scaling beyond early niche contexts is achieved. Juxtaposing our model with empirical evidence allows us to assess how mixes of policies (and policy instruments) differ between the two ideal-type sequencing patterns, highlighting interaction and trade-off effects potentially affecting transitions.

Empirically, we focus on transitions in urban water management – UWM, a sector that is under increasing transformation pressure, but very slow in structurally transforming (Quezada et al., 2016). Global drivers such as rapid urbanization and climate change put increasing pressure on the supply, delivery and demand of urban water management (Marlow et al., 2013; Lee et al., 2010).[2] A broad discourse thus exists around how to transform UWM toward more sustainable modes, which use less fresh water and are more adaptable to changing local context conditions (Leigh and Lee, 2020; Schramm and Felmeden, 2012; Wong and Brown, 2009; Farrelly and Brown, 2011). One such mode, which is the focus of this article, are decentralized water technologies for reusing rain-, gray-, or wastewater inside buildings (Hoffmann et al., 2020; Dunn et al., 2017; Leigh and Lee, 2020; Daigger 2009). These solutions radically diverge from the dominant regime in UWM, which relies on expansive pipe networks and treatment in large-scale treatment plants. Yet, inducing a transition toward these novel solutions has proven extremely difficult and prone with multiple systemic innovation problems (Kiparsky et al., 2013; Hoffmann et al., 2020). Transitions in UWM are thus still stuck in an early development phase and strongly depend on public policies and related policy instruments that create protective spaces for experimentation with radical system alternatives (Truffer et al., 2013).

As empirical illustrations of policy sequencing, we analyze the transitions of urban water systems in two case studies, which have both integrated system alternatives in the form of decentralized water reuse technologies into their conventional water infrastructures but vary regarding their policy pathways. The case of San Francisco (United States) represents a more advanced trajectory, as strategic policy sequencing has led to the uptake of transitions in other US cities and to scaling-up effects impacting the regional (State) and national policy level. While in Sant Cugat del Vallès (Spain), reactive sequencing has resulted in immediate and wide deployment at the local level, subsequent scaling-up processes have remained more limited, and have not (yet) affected key structures of Spain's UWM regime at the regional or national level.

The remainder of the article is structured as follows: Section 2 presents key concepts and introduces the process model. Section 3 outlines the research methods, followed by the results section (Section 4), which briefly introduces the empirical case studies before analyzing the mixes of policies and policy instruments addressing institutional barriers in each cases' UWM transition. In Section 5, we discuss and compare the sequences across the cases, shedding light on the different transition pathways, the importance of policy sequencing order and the role of policy entrepreneurs for advancing transition trajectories.

2. Sustainability transitions, institutional barriers, and the role of policies

Structurally transforming urban infrastructures that provide basic societal functions like water supply, sanitation, energy, or transportation requires fundamental shifts of their underlying socio-technical systems. Such systems denote the configurations of actors, institutions (rules, norms, and practices), technologies and infrastructures in a given sector that are highly interdependent, and which tend to solidify into fixed patterns of thinking and decision-making (Kemp et al., 1998). Once socio-technical configurations prevail and become "locked-in", self-reinforcing mechanisms reduce the chance for endogenous change (Hanger-Kopp et al., 2022). While the resulting systemic inertia provides stability and regularity to the provision of public services, it simultaneously reduces the system's ability to respond to new challenges (Matthews et al., 2015; March and Olsen, 1996). Integrating radically novel technologies and thereby shifting toward new socio-technical configurations is therefore an incremental and long-term process, necessitating

[2] The OECD projects that cities will absorb the total world population growth between 2010 and 2050 and by the year 2050, nearly 70% of the world population will be likely living in urban areas (OECD, 2015). Freshwater availability will be further strained, potentially affecting around 40% of the world population, while the global water demand is likely to increase by around 55% (ibid.).

changes of several system functions or dimensions in parallel (Geels, 2002; Markard and Truffer, 2008).

Policymakers can support these long-term structural change processes by implementing policies with concrete measures to induce and steer the uptake of novel socio-technical configurations (Markard et al., 2012; Weber and Rohracher, 2012; Kivimaa and Kern, 2016). The literature on socio-technical transitions and policy mixes indicates that due to the complexity of transitions, no single policy or instrument will suffice to induce structural change. Instead, mixes of policies are necessary, which combine different policy goals and instruments for pushing radical technological innovations and pulling wider demand for them (Bouma et al., 2019; Flanagan et al., 2011; Kern and Howlett, 2009; Reichardt et al., 2016; Rogge et al., 2017; Turnheim et al., 2015). Certain combinations of policies can be more complementary than others, depending on the interaction and trade-off effects between the policies' goals and instruments, leading to more or less consistent, coherent, and congruent policy designs (Howlett, 2019; Briassoulis, 2005).[3]

Whether instruments within a policy mix reinforce or undermine each other in pursuit of a goal depends on the instruments' design features, such as their level of enforceability, level of ambition or duration (Howlett and Rayner, 2013; Kern and Howlett, 2009; Rogge and Reichardt, 2016). The level of enforceability also relates to different instrument types, where policymakers can choose between legally binding regulatory tools or more voluntary ones like economic and informational instruments (see Table 1; Bali et al., 2021; Vedung, 2010; Peters and Van Nispen, 1998).[4] The choice to implement certain policy instruments has different effects on socio-technical transitions, influencing the activities of actors through "technology push" or "demand pull" mechanisms (Foxon, 2011). Evidence suggests that "technology push" policies are especially important during a technology's early development phase, creating resource effects e.g., through economic instruments that reduce private costs for generating knowledge and capabilities (e.g., R&D funding, tax reductions) or that create favorable investment conditions (Pierson, 1993; Edmondson et al., 2019; Costantini et al., 2015; Hekkert et al., 2007; Smith and Raven, 2012). As technologies mature or as policymakers aim to induce subsequent diffusion dynamics, "demand pull" policies become more effective (Hoppmann et al., 2013). For instance, implementing regulatory instruments can result in institutional effects, leading to the reconfiguration of institutional structures such as creating new standards and certification procedures or the creation of a market for alternative technologies (Pierson, 1993; Hoppmann et al., 2013; del Río et al., 2010).[5] This reconfiguration process can be supported by informational instruments, which facilitate compliance through interpretative effects, providing information and changing patterns of understanding and meaning (Pierson, 1993; Edmondson et al., 2019).

Throughout the transition process, multiple policy effects can be expected with sometimes unpredictable and unintended consequences (Edmondson et al., 2019). Especially due to the multi-level character of policy-making, policy effects and how they impact niches as well as system change might be conditioned by dynamics at different levels of governance (Miörner and Binz, 2021). For instance, policies implemented at the local level are not isolated from policy-making at the regional, national and international level, potentially leading to important interactions between levels (Smith, 2007; Dawley, 2014; Huang, 2019). Responding to unexpected policy effects and changing circumstances during transition processes therefore requires repeated refinements of the implemented policy instruments, e.g. through the use of procedural instruments to enable policy learning, re-selecting and re-adjusting implemented instruments (Howlett, 2019; del Río et al., 2010; Bali et al., 2021).[6] Such flexibility is important considering that policy mixes and their components develop incrementally over time and co-evolve with the socio-technical transition (Edmondson et al., 2019; Kern and Howlett, 2009).

2.1. Policy change and sequencing for the scaling-up of niche innovations

Given the above discussion, policies influence developments in socio-technical systems, whereby policy mixes are triggered through different feedback mechanisms, potentially resulting in policy change (Edmondson et al., 2019). Feedback mechanisms do not directly affect policies. They influence policymakers in their decision to either reinforce or undermine policies (Jordan et al., 2004).[7] Changes in public opinion, for instance, contribute to socio-political feedbacks that impact the support for a policy mix and its components (Edmondson et al., 2019). Fiscal feedbacks that result from budgetary changes can have an equally positive or negative effect on the support of a transition policy, just like administrative feedbacks that occur due to changes in reputation or internal morale of public bodies responsible for designing and implementing policies (Oberlander and Weaver, 2015). At the level of policy instruments, such feedbacks can lead to the strengthening or weakening of policies' underlying goals, leading to the introduction of new instruments or the redesigning of policies, e.g., through procedural instruments (Daugbjerg and Kay, 2019).

Policy change can also occur due to exogenous changes beyond the socio-technical system such as macro-economic trends,

[3] Note that this article predominately focuses on policy instruments as the concrete tools to impact transitions, however, without neglecting their embeddedness in policies (Rogge and Reichardt, 2016).

[4] Although these instruments are typically used by public authorities, private actors might also apply instruments on a voluntary basis e.g. informational instruments (e.g. information campaigns) or procedural instruments (e.g. public hearings).

[5] Note that technology-push and demand-pull policies are not necessarily implemented in a linear manner, following one after the other (e.g., tax reductions for spurring investments might still be in effect, as regulations are passed to create new standards) (see Grubb et al., 2017). While both types of policy can be implemented in parallel, we argue that depending on the stage of technological development, there is a dominant type of policy, which is chosen by policymakers based on its effect.

[6] Through cooperation between different societal actors e.g., in the form of inquiry commissions, advisory committees or public meetings, procedural instruments can also address limited administrative capacity, information asymmetries or inefficiencies of public service delivery (Bouma et al., 2019; Howlett, 2019).

[7] While this article considers the effects of feedback mechanisms on policies and their components, the actors causing the mechanisms are not the focus here.

Table 1
Key dimensions for enabling transition processes, associated barriers and policy instruments to address them (adapted from Hacker and Binz, 2021a).

Effect	Dimensions	*If not addressed*	Barriers	*To address*	Policy instruments
Technology-push	Knowledge & capabilities: Creation and diffusion of new technological knowledge; capabilities to design, install and run innovative technologies	→	Organizational: Lack of knowledge and skills regarding new technologies; unclear coordination and management structures	←	Economic: R&D programs Informational: Training modules for practitioners Procedural: Technology workshops and conferences
	Financial investment: Mobilization and allocation of financial investments for new technologies	→	Economic: Lack of investment incentives, returns on investment, pricing schemes; sunk and fixed costs of existing infrastructures	←	Economic: Grant programs, new pricing schemes, investment incentives, subsidies and loans
	Legal & regulatory framework: Regulations for structuring the design, installation and operation of new technologies	→	Regulatory: Lack of health codes, quality criteria, technology standards and other regulations for emerging technologies; Laws and regulations prohibiting certain technologies	←	Regulatory: Mandates for certain technologies, bans against others, thresholds for pollutants etc., permitting pathways, enforcement requirements
	Market structure: Development of a market for the new technology. Specification of user preferences and product variants, suppliers	→	Market: Lack of pre-defined market and industry structures, standardized user-producer interactions, and business models	←	Economic: Subsidies Regulatory: Codification of demand, exchange, and supplier structures, vetting high-quality products and suppliers
Demand-pull	Legitimacy: Alignment of innovation with the widely held norms, beliefs, and ways of doing things	→	Cultural-cognitive: Lack of political will, monitoring procedures, basic understanding of benefits and risks of emerging technologies	←	Informational: Education/outreach campaigns Procedural: Public participation programs Regulatory: Quality certification, safety protocols

demographic changes, or catastrophic events (Oberlander and Weaver, 2015). Such exogenous conditions can constrain or amplify feedback mechanisms and impact the rate and direction of change in socio-technical systems (Edmondson et al., 2019). Consequently, the timing of implementing certain policies and policy instruments impacts their potential effect as well as the resulting feedback mechanisms (Oberlander and Weaver, 2015; Edmondson et al., 2019).

Policy research has been increasingly concerned with policy "trajectories" and issues of timing, recognizing that policymaking is "an inherently temporal process, in which policy content and outcomes shift over time, leading to patterns of the sequencing of different policy elements in a trajectory of events and activities in any specific policy area" (Howlett, 2019: 31; Daugbjerg, 2009). During the slow and incremental processes of change, policies are often not based on strategic design choices, instead, new policies and their components are often added sequentially to pre-existing policy mixes (so-called "policy legacies") (Briassoulis, 2005; Flanagan et al., 2011). Such processes of unintentional sequencing are also referred to as layering and drift (Rayner and Howlett, 2009; Capano, 2018).

In recent years, scholarly attention has shifted from unintentional sequences of policies and policy measures evolving over time (Howlett and Rayner, 2007; Kern and Howlett, 2009) or co-evolving with socio-technical change (Rogge and Reichardt, 2016; Flanagan et al., 2011) to intentional sequences (Furumo and Lambin, 2021; Howlett, 2019). Intentional sequences as a policy design tool might be used to enhance actor and instrument coordination by controlling for expected spillover-effects of policies, facilitating synergies or 'ratcheting up' policy stringency over time by incrementally developing measures for overcoming wicked problems such as e.g., climate change (Taeihagh et al., 2013; Howlett, 2019).

In recent studies combining transitions with policy sequencing literature scholars have almost exclusively focused on such 'ratcheting up' processes, mostly in relation to macro-level transition processes like tropical deforestation or climate and energy policies in the EU and US (Meckling and Biber 2021; Furumo and Lambin 2021; Leipprand et al., 2020). These studies focus on how to weaken path dependencies in locked-in sectoral regimes (i.e., car manufacturing, forest deforestation, and energy sectors in different countries) through gradually tightening and increasing regulatory thresholds at the (supra-)national level. This perspective has been very fruitful for conceptualizing policy sequencing in sectors with relatively mature system alternatives (i.e., electric cars and renewable energies), whose wide diffusion can be coined as a clearly defined, aspirational 'end-goal' of policy sequencing (e.g. 100% electric cars, net zero energy provision, etc.). However, this approach is constrained when a dominant system alternative has not yet formed and been institutionalized to the same degree and where the relevant transition processes are still limited to spatially confined, often place-based experimentation processes in 'niche' contexts. Yet, understanding potentially effective policy sequencing patterns in these early transition trajectories, as in UWM, is arguably equally – if not more – important (Wolfram, 2018; Huang, 2019). Therefore, this article aims to advance our understanding regarding what sequences of policies might be most conducive to support the early development, scaling up and diffusion of transformative socio-technical configurations that emerge from protective spaces in certain cities or regions.

2.2. Institutional barriers and the policy instruments to address them

The early stage, place-based and experimental innovation dynamics that happen in niche contexts differ quite fundamentally from the more mature, multi-scalar transition dynamics typically covered by policy sequencing literature. A key challenge within a given city or region experimenting with transformative infrastructure solutions is to create a stable protective space, in which technological innovation, interactive learning and the gradual alignment of technical and social elements around a novel socio-technical 'configuration that works' can occur (Kemp et al., 1998). The concrete barriers to transformative change that arise at this stage and level of governance are usually highly place-dependent and may range from economic disincentives, lack of cultural acceptance, to knowledge gaps with technology suppliers or customers. The literature on technological innovation systems (Bergek et al., 2008; Hekkert et al., 2007) and recent work on innovation in the water sector (Hacker and Binz, 2021a; Reymond et al., 2018) provides a heuristic for the generic types of barriers that innovators in these niche contexts encounter. This scholarship identifies five dimensions in which institutional barriers to transitions typically arise: *knowledge & capabilities, financial investment, legal & regulatory frameworks, market and industry structures*, and *legitimacy*. These five dimensions cover different aspects of the institutional structure required to be built around a transformative socio-technical configuration, and which collectively enable the development, diffusion, and scaling of a new solution. Disregarding one or several of these dimensions typically leads to barriers or even organized opposition against the emerging innovation (ibid).

Table 1 defines each dimension, summarizing key institutional barriers related to each dimension, and the policy instruments adopted to address the barriers. The table thus provides a generic heuristic for thinking through the potential complexity of barriers and policy responses that may emerge in niche innovation processes.

To specify what types of barriers typically emerge in niche innovation and scaling processes and how policies may be intentionally sequenced to address them to support long-term structural change, we propose a generic process model.

2.3. Generic process model of policy sequences addressing institutional barriers in niche upscaling trajectories

2.3.1. Transition phases and barriers

Following Koehrsen et al. (2019), we differentiate between three phases of niche formation processes that lead to the construction and diffusion of a novel socio-technical configuration: *initiation, expansion,* and *consolidation* phase. These phases build on each other in a non-deterministic way with many conceivable iterations between them.[8] Key inflection points between the phases, however, might be hindered by different barriers, which therefore need to be addressed for a radical innovation to successfully scale-up.

Generally, the initiation phase begins with exogenous and/or endogenous transition pressures that reveal cracks in the incumbent socio-technical configuration. Thus, it opens a window of opportunity for policy entrepreneurs (e.g., firms, politicians, civil servants, or interest groups) and bottom-up initiatives, who negotiate with different stakeholders and advocate for policy change, radical technological innovation, and the creation of protective spaces for experimentation with radical system alternatives (Mintrom, 2019). Due to their socio-spatial embedding and responsiveness to communities, ministerial bureaucrats and civil servants might be crucial for advancing policy proposals on a certain problem and ultimately for implementing them (Schnapp, 2000). The implementation of emerging technologies, however, might be hindered due to the lack of knowledge and skills of how to operate them (organizational barrier). This in return might also affect their perceived legitimacy (cultural-cognitive barrier), causing low understanding for new technologies and resulting in status quo bias toward conventional solutions (Moser and Ekstrom, 2010; Azhoni et al., 2018; Winz et al., 2014). Other cultural-cognitive barriers that potentially need to be tackled at this early stage are a lack of political will (e.g., due to lack of urgency or motivation) to introduce new technologies amongst decision-makers (Matthews et al., 2015). If these institutional barriers are actively addressed in a given niche context, important learning processes can take place, which allow actors to jointly develop new ways of thinking, doing and interacting (Kemp et al., 1998; Schot and Geels, 2007).

Once enough positive learnings are gained (e.g., validating initial expectations) and the barriers of the initiation phase are sufficiently addressed, an expansion phase can unfold, where the new socio-technical configuration is increasingly diffused beyond the initial niche context (Geels and Raven, 2006; Wanzenböck and Frenken, 2020; Bours et al., 2021). Inconsistencies and frictions between the dominant socio-technical system and the emerging alternative 'niche' configuration become more visible during this phase,

[8] We apply a "weakly" linear framing to technological development, which is structured into phases to illustrate the different stages that novel technologies have to follow to full deployment (see Grub et al., 2017). Nonetheless, we acknowledge that such transition pathways also contain retracements of steps or even dead-ends, and therefore, transition phases might also unfold in a non-linear way (e.g., with overlaps or iterations).

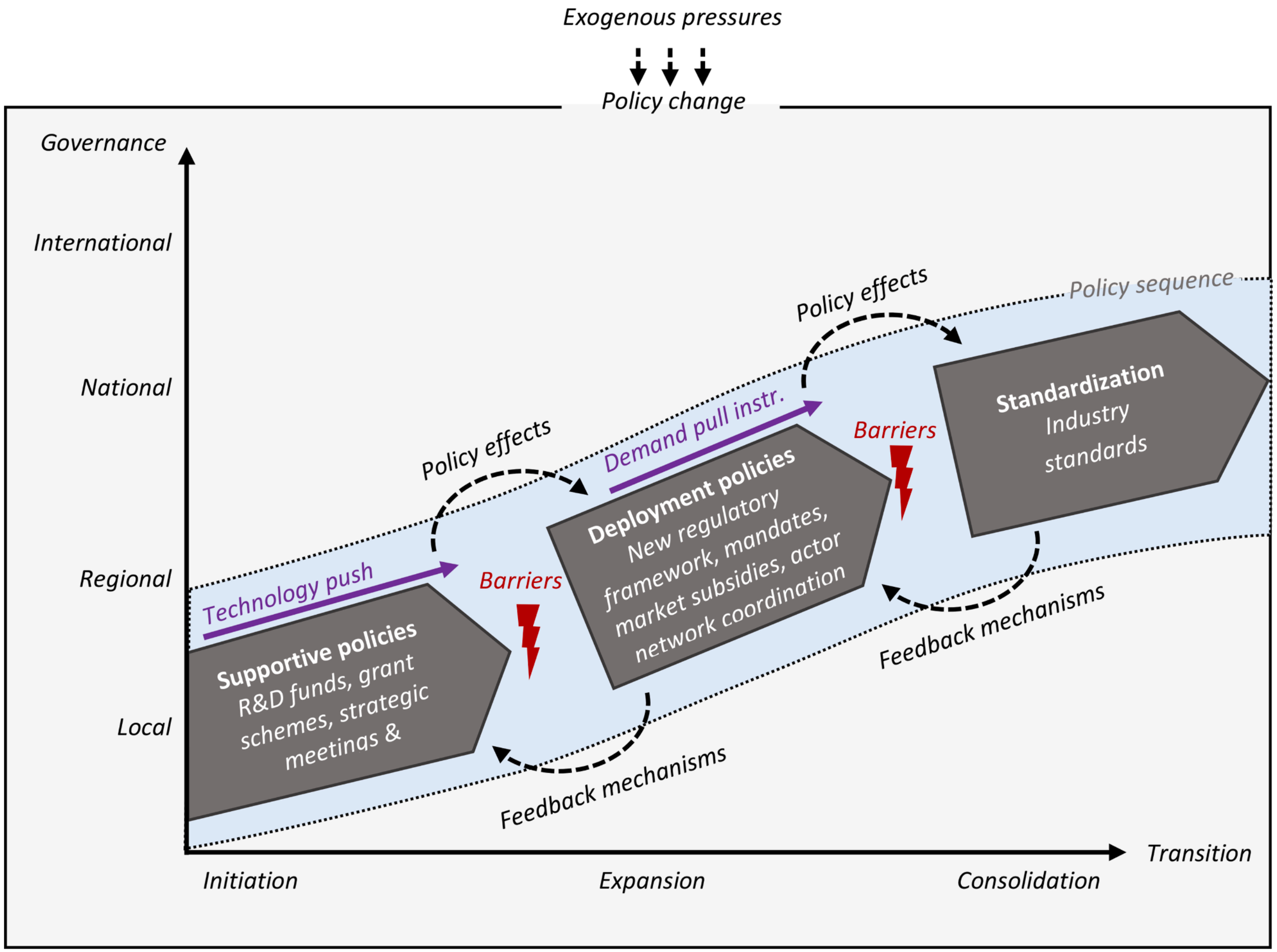

Fig. 1. Generic process model of strategic policy sequencing (own illustration).

thus spurring contestation in public debates (Geels 2002; Hacker and Binz 2021a). More actors get involved in activities to promote the new configuration, raising public awareness and forming advocacy networks to shift political priorities in their favor (Ó Tuama, 2015b; Karnøe and Garud, 2012; Chlebna and Mattes, 2020). As the configuration is implemented in more and more projects and places, the need for changes at the local and regional level might cumulate and become a growing disruption to the existing socio-technical system, creating potential "ripple effects" that impact multiple scales and higher levels of governance (Ó Tuama, 2015a). Thus, policymakers and other key stakeholders are likely to seek out policy mechanisms to steer and/or regulate the emerging alternative configurations and to address the existing and/or anticipated regulatory barriers (e.g., inconsistent polices across political levels due to missing health codes or technology standards), organizational barriers (e.g., lack of coordination and management structures within or between different public agencies) and economic barriers (e.g., lack of investments or market protection) (Bichai et al., 2018; Winz et al., 2014; Walker et al., 2015; Kivimaa and Kern, 2016).

If the barriers present in the expansion phase are overcome, the novel socio-technical configuration becomes increasingly institutionalized and integrated into or transformative to the dominant socio-technical regime. In this consolidation phase, actor constellations are stabilized, new industry structures solidify, and the novel socio-technical configuration further diffuses across scales and space (Koehrsen et al., 2019; Chlebna and Mattes, 2020). For example, governments might go beyond a local-case-by-case approach by adopting generic and trans-local policies and standards (Wanzenböck and Frenken, 2020). Consequently, the main institutional barriers in this phase revolve around standardizing the new way of doing things, as actors monitor and evaluate the new socio-technical configuration and continuously improve its overall functionality (Moser and Ekstrom, 2010).

There are multiple "sequencing options" for overcoming each transition phase's specific constellations of institutional barriers. The inherent uncertainties and complexity of change as well as innovation, however, create a formidable challenge for (policy) actors trying to anticipate and govern a transition (Loorbach, 2010). We nonetheless deem it important to conceptualize generic sequencing patterns for transitions based on existing literature. Accordingly, we specify two ideal-type sequences that policymakers can follow when supporting early stage, place-based transition dynamics.

2.3.2. *Strategic policy sequencing*

Drawing on 'strategic niche management' literature (e.g., Kemp et al., 1998; Schot and Geels, 2008), we propose a *strategic policy sequencing* pattern. As shown in Fig. 1, this pattern starts with setting up a transition arena or "incubation space" in the *initiation phase*, usually in the form of local experiments around a given socio-technical innovation. The process begins with "technology push" policies that create protective spaces for experimentation, lowering costs of new technologies and broadening political support for them, thus addressing potential economic and cultural-cognitive barriers. Supportive policies initially rely on softer tools such as economic incentives (e.g., R&D funding, financial support for pilot projects) instead of legally binding (mandatory) policy instruments (Nemet, 2009; Rip and Kemp, 1998). Providing space for experimentation and the use of procedural instruments (e.g., establishing regular meetings, strategic planning) facilitates important learning processes (Sengers et al., 2016; Rogge and Reichardt, 2016). Based on these learning-by-doing processes, technical aspects and design specifications, market and user preference, effective policies and policy instruments or cultural and symbolic meaning can form and get clarified (Schot and Geels, 2008; Meckling et al., 2015; Rip and Kemp, 1998; Howlett, 2019). Once these collective learning processes have happened and the innovation is locally validated, it is ready to leave the initial experiment (von Wirth et al., 2019; Ansell and Bartenberger, 2016).

In the *expansion* phase, policy actors can incrementally introduce more ambitious and stringent deployment policies in the form of regulatory instruments (e.g., mandatory), subsidies (e.g., grants for household and community), and information campaigns (Peters et al., 2012; Leipprand et al., 2020). These policies stimulate a market pull through institutional, resource and interpretive effects, which enables increasing technology diffusion. As the new solution diffuses and gains visibility, changes needed in the legal and regulatory dimension get increasingly revealed (Meckling and Biber, 2021). Additionally, procedural instruments support diffusion, as for instance, coordinating growing actor networks beyond local experiments might lead to positive feedback mechanisms that are supportive for the new technology (Bali et al., 2021; Brown et al., 2013).

In the consolidation phase, the new solution moves toward general validation and diffusion. Policy actors are thus increasingly concerned with standardization, formulating industry norms and facilitating the development of mass markets also in other cities, regions or countries (Miörner and Binz, 2021). This general upscaling and diffusion process has been illustrated in numerous single-case studies in transitions literature, e.g., on the diffusion of biofuels (van der Laak et al., 2007), photovoltaic power (Dewald and Truffer, 2011), or steam ships (Geels 2002).

2.3.3. *Reactive policy sequencing*

Second, following Pahle et al. (2018) and Hoppmann et al. (2014), we conceptualize a *reactive policy sequencing* pattern. As shown in Fig. 2, this trajectory is initiated by a highly ambitious deployment policy, i.e., drawing on legally binding regulatory instruments supplemented by e.g., subsidies and information campaigns (economic and informational instruments) causing institutional, resource and interpretive effects to facilitate the broad uptake of a socio-technical innovation 'from scratch'. Contrary to strategic policy sequencing, this pattern begins with a doing-by-learning approach, where practical knowledge is not derived from practice but based on what theoretically works (Loorbach and Rotmans, 2006). Policy interventions in this context focus on certain key bottlenecks in a rather ad-hoc manner, i.e. by first solving a technological challenge, then setting up an updated subsidy scheme, followed by developing an improved regulative and legal framework. An illustrative example of this sequencing pattern in UWM is the city of Bangalore, which directly mandated the implementation of on-site water reuse systems at a city-wide scale and then gradually adapted its policy strategies over time (Reymond et al., 2020).

In the expansion phase, a chain of policy adaptations are triggered, as actors react 'on-the-go' to challenges that arise from broadly

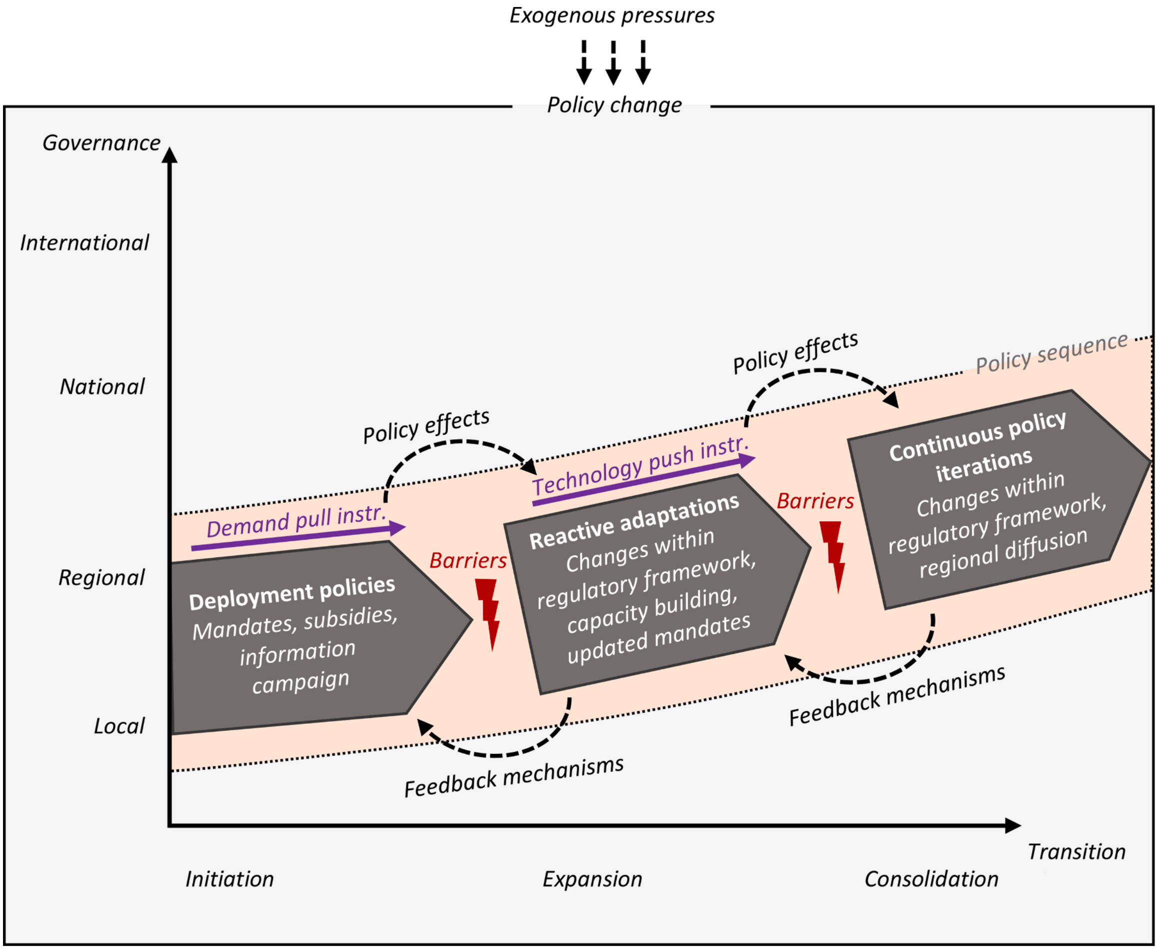

Fig. 2. Generic process model of reactive policy sequencing (own illustration).

employing the innovation and altering the existing socio-technical system, resulting in unforeseen policy failures or technology dynamics (Pahle et al., 2018; Nemet, 2009; Hoppmann et al., 2014; Ansell and Bartenberger, 2016). Learnings about technological, social and institutional possibilities and barriers take place in a more ad-hoc and reactive manner than in the case of strategic policy sequencing described above. Consequently, while the transition process might be faster, it is also at higher risk of being stymied by technology failures, institutional barriers and organized opposition -and therefore also negative feedback mechanisms- resulting from the distributed learning processes and the lack of clear sequencing and guidance in the knowledge, regulatory, market, financial, or legitimacy dimensions. Achieving increasing coordination among actors in the newly opened market (e.g., by creating industry associations) is thus of key importance in the expansion phase. This phase can be supported by intermediary actors, who overcome coordination failures and focus on the removal of institutional barriers (van Welie et al., 2020).

If the actors reach a stable form of coordination and intermediaries are able to connect the components of multi-level innovation systems (Klerkx and Leeuwis, 2009), the transition trajectory may move into the consolidation phase. To get there, more policy iteration cycles are needed than in the strategic sequencing pattern (Pahle et al., 2018). The relevance and potential effectiveness of this sequencing pattern has been illustrated empirically by e.g., Hoppmann et al. (2014) in the German energy transition and in studies analyzing the Chinese approach of transitioning to electric vehicles (Tyfield, 2014).

3. Research design, data and methods

For our analysis, we translated the generic process model into an analytical grid (see Appendix 1). Beyond general questions about the transition projects (such as the implemented technology or contextual factors), the analytical grid consists of three blocks with each block representing one of the transition phases. For each phase, the grid elucidates how long the phase lasted, whether institutional barriers existed, what policies and policy instruments were used, and by whom they were implemented. We use the trajectories in the model as a reference point and assess to which degree the identified barriers and policies (and instruments) in our empirical cases associate with the specified sequencing pattern in our model. In this way, we aim to reveal which policy pathway exists in each case.

We applied the analytical grid to case studies of UWM transition projects in San Francisco (United States) and Sant Cugat del Vallès

(Spain). We adopted a comparative case study approach to reflect the complexity of UWM, where the context affects the case in a real-world situation with many uncontrollable variables (Yin, 2018). We selected cases of transition projects based on the diverse case method, which allows us to show a maximum of variance along relevant dimensions, e.g., in this case the policy dimension (Seawright and Gerring, 2008). To investigate the different policy sequencing patterns and their outcome, the San Francisco case was chosen to provide an emblematic example of the strategic sequencing pattern, while the case of Sant Cugat del Vallès illustrates the reactive one. The outcome ranges from high uptake with scaling effects in the case of San Francisco to more limited uptake in Sant Cugat del Vallès. The cases also differ in terms of the type of policymaking: in San Francisco, the key actors are the local utility and different city departments (executive branch), whereas in the case of Sant Cugat policymaking is driven by politicians (legislative branch). To enable some level of comparability, the cases share a similar context, as they both experience water stress, which is addressed at the local level due to the countries' federalist systems and they implemented decentralized water reuse technologies into their infrastructural system in an effort to introduce more sustainable practices.

We developed the empirical foundation for the case study analysis in four steps: first, we conducted a literature review of academic and gray literature concerning potential case studies, barriers to socio-technical transitions and the role of policy (instrument) sequences in this regard. Second, we drew on the authors' existing extensive work in the field and their access to data on the selected case studies. The authors had previously conducted in-depth studies of these cases, using a variety of methods, e.g., interviews, surveys, and stakeholder workshops, to identify how policies have addressed barriers to the introduction of decentralized water reuse technologies, thus highlighting different pathways to socio-technical transitions in UWM (see Table 2 for more information on the related data collection).

In a third step, the co-authors filled out the analytical grid (*c.f.* Appendix 1) by re-interpreting their data from previous in-depth case analyses. Adopting a uniform means for structuring the data enabled the creation of case-specific time-lines, which allowed writing a narrative of each cases' transition process, analyzing the relevant sequencing of policies and cross-comparing them. Finally, the analysis was carried out in the following steps:

(i) we re-traced barriers, polices and policy measures as well as other relevant factors (e.g., actors, transition pressures) in the transition process for each case study in line with the analytical grid;
(ii) we compared the identified (policy) sequences in the transition process between the case studies; and,
(iii) we examined our generic process model against the empirical findings, identifying advantages and disadvantages of the sequencing patterns for transition processes.

4. Empirical application of policy sequencing patterns in place-based transitions

In this section, we illustrate the two policy sequencing patterns of our generic process model by drawing on the empirical example of San Francisco for the strategic pattern and Sant Cugat del Vallès for the reactive one. Each sub-section starts with general information about the case, followed by an illustration and discussion that accounts for the case's transition trajectory.

4.1. Strategic policy sequencing: San Francisco

The case of San Francisco highlights how strategic policy sequencing enabled the integration of decentralized water reuse technologies into the city's urban water system. Driven by a series of recurring droughts throughout California, the city engaged in a non-potable water reuse program, implementing on-site water reuse systems (including rainwater, greywater, blackwater, and foundation drainage systems) for non-potable reuses (such as irrigation, toilet flushing, or cooling tower operations) at the building and district scale (Rupiper and Loge, 2019). Fig. 3 shows the transition phases, exogenous transition pressures as well as the interplay of barriers and adopted policies and policy instruments that were instrumental for transitioning toward on-site water reuse systems in San Francisco. The gray boxes illustrate policies and associated policy instruments are pictured above the box in purple and with an arrow. Green arrow boxes signify policies and policy instruments that are proposed by policy entrepreneurs, while institutional barriers are shown in the color red.

4.1.1. Initiation phase: "Living machine, living city" (1991–2012)

Population growth and vulnerability to climate change (e.g., in the form of droughts, as experienced in 2007–2009 and 2012–2016) have increased the pressure on urban water systems in the San Francisco area, opening a window of opportunity for reimagining the established systems and advancing recycling efforts (Luthy et al., 2020; Rupiper and Loge, 2019; Hui and Cain, 2018; Hacker and Binz, 2021b).[9] Culminating in a wider trend among Californian cities to 'diversify the water portfolio', the local water utility of San Francisco -San Francisco Public Utilities Commission (SFPUC)- developed a new focus on onsite water reuse, with the intention of generating more locally sourced water, increasing self-sufficiency and reliability, and resolving infrastructural challenges in the quickly expanding city center (Rupiper and Loge, 2019). As a first step to initiate a broader on-site water reuse program, SFPUC in 2006 implemented an integrated rain-, gray-, and blackwater reuse system in their new headquarters in downtown San Francisco,

[9] Following California's long history (since the early 1900s) of municipal wastewater reuse for agriculture and irrigation, San Francisco initially pursued centralized water recycling, however, the city's steep topography and related pumping costs proved to be a challenge for such efforts (CDWR, 2003).

Table 2
Detailed information on data collection of previously conducted in-depth case studies of the cases.

Case	Method	Respondents/ interviewees	Data collection period	Type of actors	Publications (using these data)
Sant Cugat del Vallès (Spain)	Survey	278	July 2008	Users (residents in buildings equipped with decentralized water reuse systems)	Vallès-Casas et al. (2016) Domènech et al. (2015) March et al. (2013) Domènech and Saurí (2010)
San Francisco (United States)	Interviews	23	Feb. 2020-Jan. 2021	Technology suppliers, engineering firm, operator firm, developers, regulators, tech corporation, academia, sustainability consultants, environmental organization, utilities	Wagner et al. (2023) Osman et al. (2023) Hacker and Binz (2021b) Hacker and Binz (2021a)

called *The Living Machine.* This public demonstration project was strategically used as a procedural instrument, generating interpretive effects by showcasing the viability of onsite water reuse systems and proactively addressed cultural-cognitive barriers among project developers and citizens (Hacker and Binz, 2021b), for instance, regarding the reuse of the full wastewater stream.

Such small-scale approaches at the building or district scale, however, faced considerable regulatory, economic, and organizational barriers in the initiation phase. At the local and regional level, tech-specific regulations for small-scale onsite systems were initially missing (regulatory barrier) and therefore, existing regulations that were designed for centralized wastewater treatment plants were applied to these systems (Hacker and Binz, 2021b). For instance, the monitoring requirements of Title 22 of the *California Code of Regulations* were framed around quality monitoring procedures in centralized wastewater treatment plants, requiring very frequent monitoring and reporting by independent laboratories, which applied to small-scale systems created economic barriers in the form of excessive monitoring and compliance costs. In addition, as the different source waters used by the onsite systems were typically regulated by different local and regional authorities, developing a streamlined permitting pathway for onsite water reuse systems required deepened and new forms of coordination across the (public health, building inspection, water board, etc.) departments (organizational barrier).[10]

SFPUC identified this lack of appropriate regulation for water reuse at the building or district scale as heavily restricting the adoption of onsite wastewater reuse technologies. Therefore, SFPUC became a policy entrepreneur, advocating for the development of onsite water reuse system program at the local level and taking on an intermediary role by coordinating between various regulatory authorities (procedural instrument) responsible for the different water sources (WE&RF, 2017). This was a particularly important step for reforming institutional structures by overcoming the lack of integration between departments, as initial discussions between the local health department and building department about responsibilities regarding onsite systems showed that they did not fit into the existing jurisdictional responsibilities. Due to the proactivity of SFPUC, the *Onsite Water Reuse Program* was developed. Within this local policy program, the key policy instrument was Article 12C, which was adopted in 2012 without much public opposition. The ordinance (regulatory instrument) caused institutional effects, allowing for the collection, treatment and usage of greywater, rainwater and foundation drainage as sources for non-potable use in commercial, mixed-use and multi-family buildings of a certain size (Weiner, 2012). By first enabling and not mandating the use of such onsite water reuse systems, this approach can be considered "soft", allowing civil servants, project developers and citizens to slowly adapt to the new systems. Additionally, the policy required developers to calculate what water savings (regulatory instrument) they would have if they offset their potable supply with alternative water sources (Hacker and Binz, 2021b). A potential cultural-cognitive barrier for onsite water reuse systems was aptly and skillfully mitigated by the utility (together with a local sustainability consultancy), who developed expansive outreach materials with interpretive effects by educating developers and building owners about Article 12C and helping them meet requirements (informational instrument).

4.1.2. Expansion phase: "From allowing to mandating onsite water reuse" (2012–2015)

In 2015, Article 12C was amended to mandate onsite water reuse systems (regulatory instrument) for new buildings with a construction area of over 250,000 square feet. Increasing policy stringency at this phase of the transition process signified a change to a deployment policy with more assertive policy instruments. Using a mandate (regulatory instrument) set the precedent for onsite water reuse systems, and since then, the utility has continuously strengthened implementation. A combination of an underdeveloped market for onsite technological solutions and still restrictive performance-based regulations (e.g., Title 22), however, made designing and

[10] For instance, if the water source contained blackwater, statewide criteria had to be complied with, while other water resources (such as greywater or rainwater) were regulated and monitored by local authorities, creating different monitoring and reporting requirements across the state of California (Rupiper and Loge, 2019).

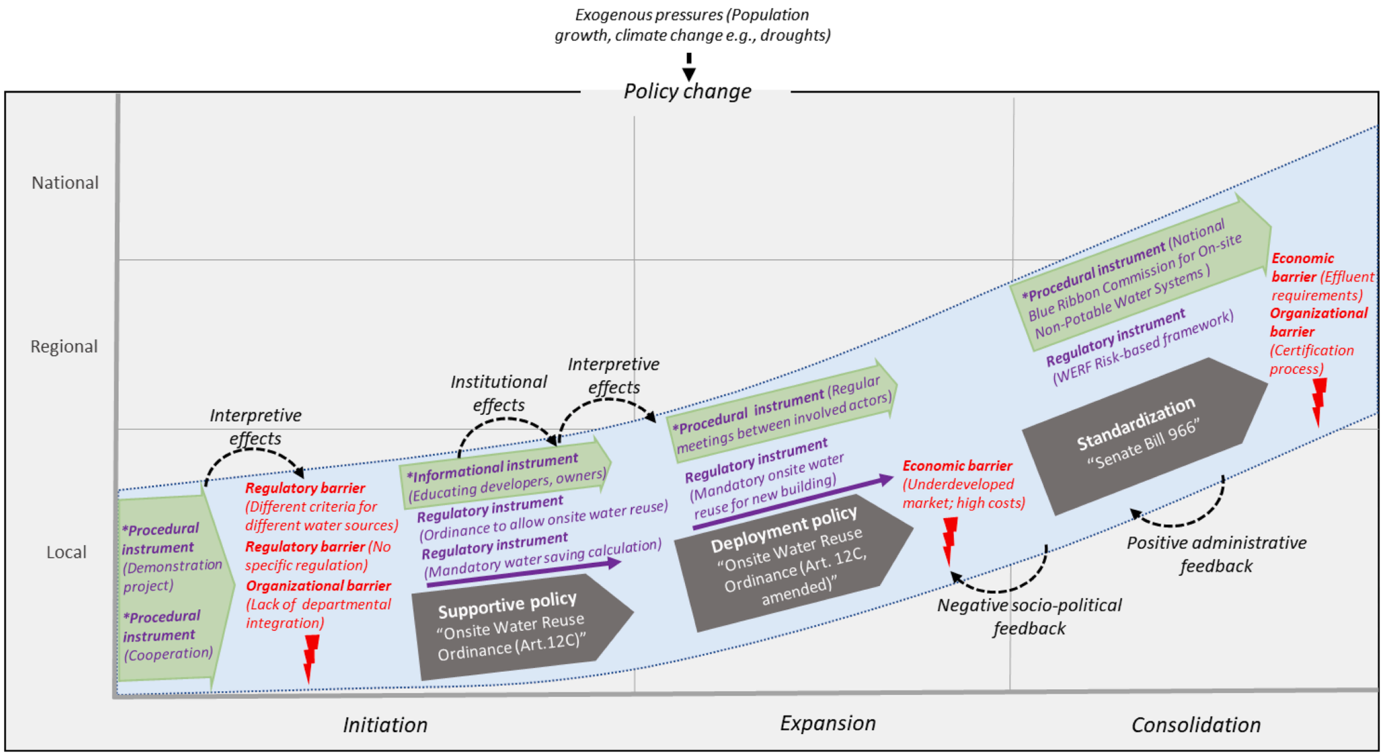

Fig. 3. Policy sequence of the San Francisco case (own illustration).

installation quite expensive, posing economic barriers that caused negative socio-political feedbacks and potentially slowed down the uptake and diffusion (Hacker and Binz, 2021b). The regulator's perception in turn was that those who qualify for the mandate already have enough money to build a large development (over 250,000 sq. ft), so they could most likely also afford taking on the cost of an onsite system. Developers in San Francisco accordingly framed the extra costs of installing onsite systems as a cost associated with building in the city.

To further streamline the permitting process, the utility (together the local sustainability consultancy) played an active role in facilitating regular meetings with regulators, real estate developers and building owners (procedural instrument) to discuss the progress of permitting for active projects, preventing negative feedback mechanisms or organizational barriers at the project level. When the mandatory ordinance was established, certain onsite systems no longer met the effluent requirements, forcing technology suppliers to upgrade their systems (Rupiper and Loge, 2019). Resulting refurbishment costs posed an economic barrier for building owners and distanced their project from a viable return on investment. Frequent meetings between the utility, developers, operators, and regulators thus occurred to keep the process up to date and mitigate challenges for retrofitting systems (procedural instrument).

4.1.3. Consolidation phase: "Creating standards" (2015-ongoing)

To tackle the high capital and monitoring costs, SFPUC created an initiative to develop a novel, 'risk-based' framework for onsite water reuse systems, which would define new performance and quality sampling criteria that were specifically adapted to different onsite water reuse systems and their inherent risk levels. The new standards were developed together with the Water Environment & Reuse Foundation (WE&RF) ,[11] as well as key firms, regulators and intermediaries and officially applied by the city of San Francisco in 2017 (WE&RF, 2017). The advocacy of SFPUC for a standardization policy shows once more how the utility engaged in policy entrepreneurship, which is also not limited to the local or regional level. Jointly with the US Water Alliance, SFPUC convened the National Blue Ribbon Commission for On-site Non-Potable Water Systems ('National Blue Ribbon Commission'), consisting of high-level representatives from major utilities around the nation. The commission aimed at advancing best management practices for onsite non-potable water systems and to support other US cities in implementing their own on-site water reuse programs (Hacker and Binz, 2021b; Rupiper and Loge, 2019). Additional potential for an accelerated diffusion of on-site water reuse has emerged more recently with the acceptance of the California Senate Bill 966, however, the California State Water Resources Control Board is still in the process of rolling out these standards (regulatory instrument) and implementation remains to be seen. Nonetheless, this impact on regional and national policymaking highlights the positive administrative feedbacks that the standardization policy received.

By 2021, more than 90 on-site reuse systems were in the planning, commissioning, or operation phase in San Francisco. While the transition to on-site reuse has progressed quite quickly and widely in the context of San Francisco, some key barriers remain. The lack of return on investment still poses an economic barrier for some developments in the city. Lacking/under-specified operator certification processes for onsite water reuse systems, in turn, constitute an organizational barrier. In the US, there are still multiple levels of operator certification for different types of systems. Onsite water reuse systems involve wastewater and treatment processes that make the quality sufficient for non-potable reuse, but a hybrid operator certification is not available, requiring operators to have two types of certifications. The SFPUC therefore continues to work with multiple stakeholders (procedural instrument) to develop a certification program for onsite water reuse system to support operators (Hacker and Binz, 2021a).

4.2. Reactive policy sequencing: Sant Cugat del Vallès

The use of reactive policy sequencing can be observed in the case of Sant Cugat del Vallès (Sant Cugat), where local legislators initiated the uptake of decentralized water reuse technologies 'from scratch'. Responding to the need to reduce piped water usage in the light of recurring water crises (due to droughts), the suburban municipality in the Metropolitan Area of Barcelona mandated the implementation of decentralized greywater reuse systems and rainwater harvesting systems (Vallès-Casas et al., 2016). Fig. 4 shows the transition phases, exogenous transition pressures as well as the interplay of barriers and adopted policies and policy instruments for integrating the decentralized greywater reuse systems into the conventional UWM in Sant Cugat. The gray boxes illustrate policies and associated policy instruments are pictured above the box in purple and with an arrow. Green arrow boxes signify policies and policy instruments that are proposed by policy entrepreneurs, while institutional barriers are shown in the color red.

4.2.1. Initiation phase: "Global challenges, local solutions" (1999–2002)

Confronted with multiple, severe drought periods across Spain (1998–2002, 2004–2005, 2007–2008), public calls, e.g., by the grassroots movement *Nueva Cultura del Agua*, for a more efficient and sustainable water policy accelerated (Masjuan et al., 2008; Domènech et al., 2015; March et al., 2014). While the Spanish government continued to support centralized solutions, Catalan municipalities increasingly began considering new water supply solutions at the regional level. A particular exogenous transition pressure that opened a window of opportunity for rethinking UWM, was the Local Agenda 21 policy process, which initiated water consumption appraisals in many Catalan municipalities (Vallès-Casas et al., 2016). Among the Catalan municipalities who developed Local Agenda 21 plans, Sant Cugat became a pioneer in local water resource management, enacting the first local water saving ordinance (regulatory instrument) (Domènech et al., 2015). The audit (1999–2001) for Sant Cugat highlighted the need for reducing freshwater consumption, having one of the highest water consumption rates per person in Metropolitan Area of Barcelona (Domènech et al., 2015;

[11] In collaboration with the National Water Research Institute (NWRI) Panel and a Stakeholder Advisory Committee.

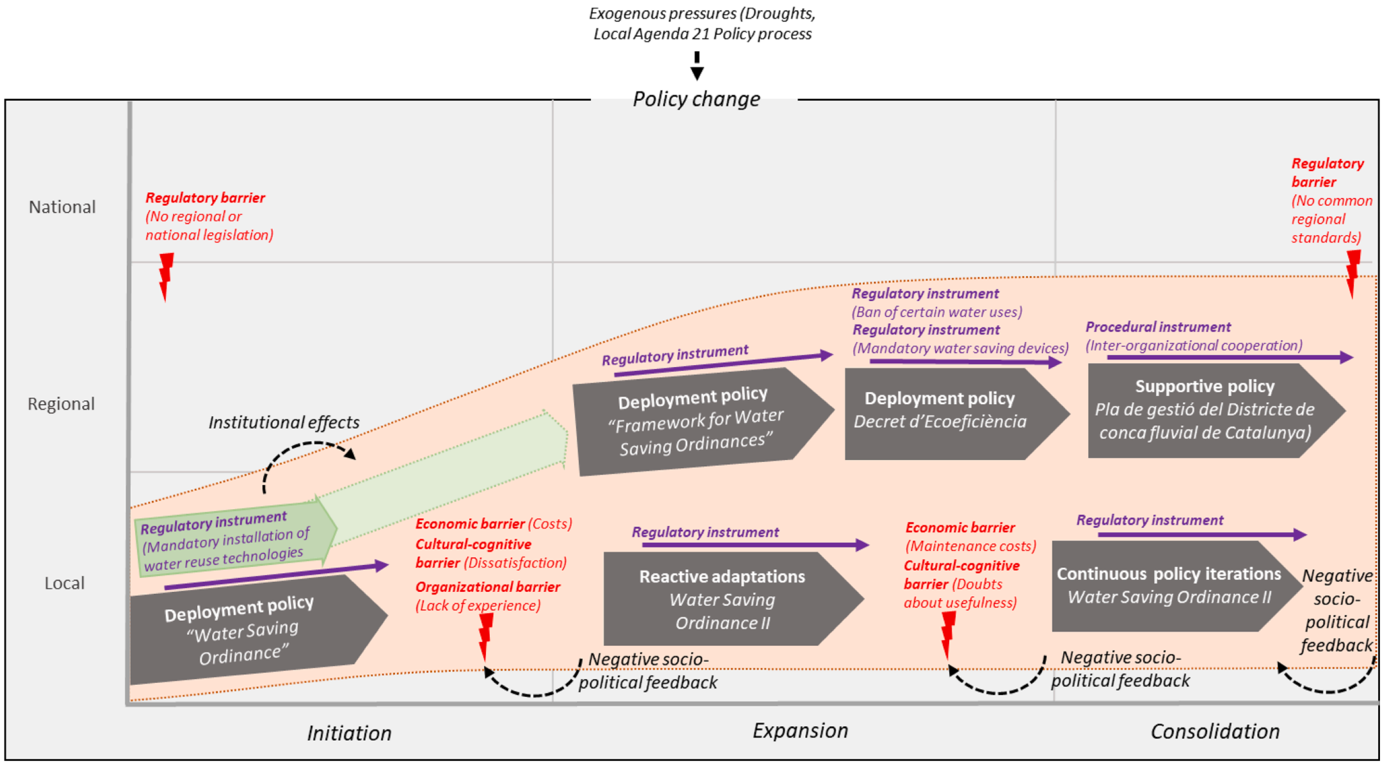

Fig. 4. Policy sequence of the Sant Cugat case (own illustration).

Vallès-Casas et al., 2016). Due to the lack of regional and national legislation (regulatory barrier) concerning water reuse technologies in urban areas, the municipality took over the role of a policy entrepreneur by developing its own local policies.

Choosing a deployment policy, the water saving ordinance of Sant Cugat immediately mandated the installation of decentralized greywater reuse technologies (regulatory instrument) in all residential buildings with eight or more apartments as well as other buildings in which the annual consumption of water equaled or exceeded 400 m^3/year (Water Ordinance, 2002, art.11.1). The ordinance had institutional effects and created a strong "demand pull" for the implementation of decentralized water reuse technologies, but failed to resolve certain key challenges. For instance, the procurement, operation, and maintenance costs were entirely covered by the apartment owners without any public support (except for rainwater tanks), which was a considerable economic barrier. Moreover, ensuring the adequate installation and maintenance of the systems posed an organizational barrier, due to the limited experience with water reuse systems (Domènech and Saurí, 2010). Some companies developed their own technologies that were often quite rudimentary (requiring involvement by users), which caused complaints and dissatisfaction among users, culminating in negative socio-political feedbacks that affected the perceived legitimacy and social acceptance of the systems (cultural-cognitive barrier) (Vallès- Casas et al., 2016).

4.2.2. *Expansion phase: "Regional diffusion despite local dissatisfaction" (2002–2008)*

Since 2002, the policy was gradually adapted in 2008 and 2018, however, without changing the main regulations concerning greywater reuse. By not addressing negative socio-political feedback, cultural-cognitive and economic barriers developed, especially after the shift towards more technically complex systems (e.g., from chemical to physical-biological). Maintenance has been considered more expensive by the system users (economic barrier) and a survey conducted among users in Sant Cugat del Vallès showed that the initial high level of acceptance of greywater reuse technologies slightly decreased since their introduction (Domènech and Saurí, 2010).

Nonetheless, the ordinance had "ripple effects" beyond the local level, triggering some degree of regional diffusion, as other municipalities approved similar water saving ordinances and the provincial government (*Diputació de Barcelona*) developed a regional framework for drafting such ordinances to foster further uptake (regulatory instrument) (ibid.). In 2006, the installation of water saving devices in new buildings was also enforced (regulatory instrument) at the national level in the form of the Spanish Building Code (*Código Técnico de la Edificación*) (policy). However, only the Catalan eco-efficiency decree (*Decret d'Ecoeficiència*) (policy) mentioned greywater reuse as an eligible measure (ibid.).[12] Additionally, the Catalan Water Agency (the regional water authority) temporarily banned (regulatory instrument) certain water uses during the last drought episode (2007–2008), such as irrigating private gardens or filling swimming pools, while the city of Barcelona imported water via sea tankers (Domènech et al., 2015). The high costs of emergency measures and rising awareness among the public created momentum for the debate on new water supply solutions (March et al., 2013).

4.2.3. *Consolidation phase: "Sustaining the transition beyond crisis" (2008-ongoing)*

Coordination, which is important for the consolidation phase, developed in the form of inter-organizational cooperation efforts (between the Health Department, Environmental and Housing Department and the Catalan Water Authority) as part of the Catalan River Basin District Management Plan (*Pla de gestió del Districte de conca fluvial de Catalunya*). The aim of this cooperation (procedural instrument) is to establish criteria for regulating the use of greywater on the regional level, as more than 50 Catalan municipalities have already adopted local water saving ordinances by the end of 2011 (Domènech et al., 2015). The lack of common standards at the regional and national level has led to a diversity of local regulations, which has been a matter of complaint and negative socio-political feedback voiced by builders and promoters who have called for uniform and coherent policies in this regard (regulatory barrier) (Vallès et al., 2011; Vallès-Casas et al., 2016).

Despite some level of regional diffusion and coordination efforts, the negative socio-political feedback by system users at the local level has still not been addressed, lacking concrete instruments that could cause interpretive or resource effects. Consequently, some residents of Sant Cugat complained about the use of decentralized greywater reuse technologies, questioning their overall usefulness, especially during times when water supply is not threatened by droughts or other scarcity conditions (ibid.). The acceptance of these systems is challenged in the absence of any exogenous pressure, which is aggravated by lack of information, as 50% of survey respondents felt they were not properly informed about the technology (ibid.). This was also confirmed during the municipalities' on-site inspection of existing systems (2010–2013), identifying the need to promote acceptance of decentralized water reuse system through campaigns and the diffusion of more advanced technologies with subsidies (Vallès-Casas et al., 2016). Although Sant Cugat has continued to enforce the water ordinance and as of 2021, more than 200 greywater reuse systems are in operation (covering a third of the total population), a wider diffusion of such decentralized technologies beyond the local level has stagnated, especially due to the lack of regional and national political support. However, since the partial recovery of the housing sector and the recurrence of droughts (2021–22), the transition appears to have caught momentum again, having led to increased public support for decentralized water reuse technologies.

[12] In Article 6, point j ("Ecoefficient Parameters of Systems and Materials of Construction") greywater reuse appeared as one of the possible options among others for buildings to obtain a minimum eco-efficient score.

5. Discussion

The two transition trajectories fundamentally differ, unfolding through strategic policy sequencing in the case of San Francisco and through reactive sequencing in Sant Cugat del Vallès. Our analysis reveals both case studies exhibit unaddressed or insufficiently addressed institutional barriers that could potentially hinder further transition processes. Indeed, in the case of Sant Cugat, several unaddressed barriers have negatively impacted on the transition dynamics. Although few barriers have also been left unaddressed in the San Francisco case, most barriers were addressed, resulting in a more advanced trajectory as the niche solution has been taken up in other US cities and scaling-up effects have impacted the regional (State) and national policy level. In the case of Sant Cugat, although local uptake and the creation of a "ripple effect" (as multiple municipalities adopted similar policies) have led to some degree of diffusion, the transition process has stagnated and failed to scale-up to the regional and national level.

We identify several key reasons that explain the different transition outcomes. The initial set of reasons pertain to process factors. First, policy sequences, which continuously apply supportive policies with procedural instruments from the onset, can enable interactive and important learnings about new technologies and facilitate the formation of supportive actor networks (Bali et al., 2021; Shot and Geels, 2008; Meckling et al., 2015; Howlett, 2019). In the case of San Francisco, the focus was first on technology push policies that generated basic knowledge and capabilities, which were needed for overcoming organizational barriers. Second, by focusing on aspects of legitimacy from the onset, the actors in San Francisco also overcame potential cultural-cognitive barriers. This type of barrier was addressed with procedural tools (developing and promoting a demonstration project) and informational instruments (outreach and education programs for housing developers and future technology users). The importance of an early focus on growing knowledge, capabilities, and legitimacy to create a favorable environment for a new socio-technical configuration has also been observed by Hoppmann et al. (2014) in the context of the German energy transition. While in many other countries the challenge of reacting to unexpected issues might have induced policymakers to cancel (or not even start) the support scheme, in Germany the high public support for renewables and PV, the existence of a domestic industry with related jobs and the political will of keeping markets open to new entrants prevented such a development.

Third, San Francisco also illustrates that employing procedural tools that foster stakeholder interactions are of key importance: Through policy-induced inter-organizational cooperation, for instance, regulatory frameworks unconducive for decentralized technologies and the lack of integration between different state departments (regulatory and organizational barriers) were successfully addressed. This finding is in line with Walker et al. (2015) who suggest that certain technological solutions might require actors to coordinate more within and between different public agencies (e.g., in the case of wastewater reuse technologies), using procedural instruments to prevent organizational barriers (Walker et al., 2015).

In contrast, policy sequencing in Sant Cugat relied on strong deployment policy at an early stage of the transition process, which led to major economic, organizational and cultural-cognitive barriers. In Sant Cugat, regulatory instruments, such as mandates, were applied to address e.g. the lack of supportive regional/national legislation for implementing greywater recycling technologies (regulatory barrier) during the initiation phase. Involved actors (e.g., building developers, users) had little experience with handling these novel water reuse technologies and received limited guidance (organizational barrier), leading to a "doing by learning" approach. Moreover, as the high costs of decentralized water technologies are borne by the apartment owners (economic barriers) and as maintenance problems have persisted (organizational barriers), the usefulness of the novel technologies has been increasingly questioned (cultural-cognitive barriers), especially as no droughts had occurred and economic concerns have gained relevance. Most of the mentioned barriers have not been addressed, which has led to negative socio-political feedbacks and low public acceptance (cultural-cognitive barriers). This in return has impacted the political will to support decentralized water reuse systems, which contributed to the stagnation of the transition trajectory, especially between 2010 and 2017.

A further set of key reasons why the transition trajectory of San Francisco has been able to advance more than in the Sant Cugat case relates to structural and agency factors. We have found that the different levels of policymaking and the varying ability to take on roles as policy entrepreneurs matters. In San Francisco, policymaking and action was taken at the public-administrative level (agency-led policy) whereas in Sant Cugat, the action occurred at the "legislative" political level. As an administrative actor, SFPUC might have more easily transcended their classical role as service provider to become a policy entrepreneur and critical intermediary, than e.g., local political actors who typically rotate positions every four years. SFPUC essentially acted as policy entrepreneur by advocating for a local onsite non-potable water reuse program and organizing support for reforming institutional structures. Later (during the consolidation phase), SFPUC again took a central role as policy entrepreneur by initiating the development of a novel regulatory framework, which achieved strong institutional effects beyond the local level. Following Moss et al. (2010), SFPUC also acted as an intermediary actor, which continuously brought together the relevant stakeholders, facilitated knowledge exchange, reconciled actors with different interests and effectively supported strategic policy sequencing. This observation is in line with the literature, which suggests that – that under some circumstances– incumbent utilities can play a key role in sustainability transitions (Lieberherr and Truffer, 2015; Kiparsky et al., 2013).

Despite being a legislative actor, the municipality in Sant Cugat also acted as a policy entrepreneur, as it developed its own policies in the context of lacking regional and national regulations regarding greywater reuse. However, the nature of these policies (deployment with regulatory tools from the onset) did not prevent a recurring stagnation of the transition trajectory, as no instruments were implemented to address the wavering public support for the new technologies or the lack of interactive learnings among key stakeholders. This led to complaints and dissatisfaction among certain users, thus creating strong cultural-cognitive barriers. Legislative actors, who typically rotate positions every four years, are typically more affected by public opinion regarding their entrepreneurial decisions (Meier et al., 2019). Consequently, the very political nature of the actors in Sant Cugat seems to have been a detrimental factor for the stagnation of transition dynamics, as the lower social acceptance negatively affected the political support for further diffusing the novel technological solution. In contrast, the more long-term nature of the executive branch of government might enable a higher degree of experience and professionalization, which seem to have been pivotal for supporting the scaling-up transition process in San Francisco.

6. Conclusion

Sustainability transition studies increasingly apply policy sequencing with a focus on national, top-down strategies in sectors with rather advanced transition trajectories (e.g. Pahle et al., 2018; Furumo and Lambin, 2021). However, there is a gap when it comes to understanding whether and how transition dynamics at an early stage, which are often spatially confined and involve place-based experimentation processes in 'niche' contexts, may be supported with policy sequencing. In this article, we address this gap by revealing how sequencing strategies may function in scaling-up transformative niche solutions and conceptualize policy sequencing patterns for early-stage transition dynamics.

We have linked the work on policy mixes in transition studies with policy sequencing literature to develop a process model for analyzing policy sequencing with two ideal-type pathways: strategic and reactive policy sequencing. We then applied the process model to two cases of transition projects in urban water management that each represent one of the ideal-types. We chose a comparative case study approach to investigate the different policy sequencing patterns and their outcome.

We argue that the diffusion and scaling-up of transformative niche innovations depends on smart policy sequencing strategies, i.e., strategies that help to overcome institutional barriers and thus foster transition trajectories. Our results confirm that the order and mix of certain policy interventions (or the lack thereof) can either induce or hinder the scaling-up of niche innovation and subsequent wider system change. Although both case studies contain unaddressed or insufficiently addressed barriers that have led to negative policy feedback, the transition trajectories experienced different impacts due to these barriers. We identify two reasons to explain these differences. First, the process matters. Sequencing strategies that initially (and continuously) focus on aspects on legitimacy and apply supportive policies with procedural instruments appear to generate important learnings and facilitate the formation of supportive actor networks, which are both pivotal for advancing transition processes. Second, structure and agency also play a role, as we have identified that the level of governance involved in policymaking and action matters. The more long-term nature of the executive branch of governments (in contrast to the legislative political level) might provide the necessary experience and professionalization for facilitating the scaling-up of transitions. Here we have shown that the ability to take on roles as policy entrepreneurs is important for the outcome of transitions.

We contribute to the portfolio of empirical case studies on policy sequencing and socio-technical transitions. However, we have only applied the process model to two cases, and relied on data collected by our co-authors for the different projects. Hence, further case studies in other sectors and places are needed to validate our process model (and the two ideal-type policy sequencing patterns) and generate more widely generalizable theoretical propositions. Moreover, the model could be advanced by going more into depth regarding e.g., the design characteristics of the sequenced policy mixes, as we have mostly focused on the order of policies (and policy instruments) and their interplay with institutional barriers. Also, engaging further with policy feedback literature could be a promising research avenue. Recent studies in policy sciences, for instance, show how policy feedback can be designed to generate better policies and lead to the 'ratcheting-up' of policy ambitions, which could impact policy sequencing strategies (see e.g., Sewerin et al., 2020; Rosenbloom et al., 2019). Additionally, the general differences between policy sequencing in sectors with 'advanced' transition dynamics (e.g., energy and automotive) and sectors in which transformative socio-technical configurations still need to be developed and scaled-up (e.g., water and construction) could be teased out in far greater depth. The present article only scratches the surface of a potentially highly generative research agenda.

In sum, if our process model is applied to other contexts and concrete policy sequencing pathways, it could enable a highly promising and cumulative line of theorizing on how policy mixes can be designed and sequenced in ways that enable scaling-up of niche innovation and its impact on wider system change. We thus provide a critical stepping stone for future scholarship at this promising conceptual interface between transitions and policy studies.

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Declaration of Competing Interest

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

Data availability

The data that has been used is confidential.

Appendix 1. Analytical grid

Case

1. Case study *(project name, location)*
2. Type of region *(suburban or urban; distance to next big city center)*

Technology

3. Type of decentralized water reuse technology *(including rain-, gray-, black- and wastewater technologies; if there is more than one type of technology that you want to include, please state them and clearly indicate differences/similarities throughout the grid)*
4. When was the decentralized water reuse technology first implemented *(*e.g. *year of project approval)*?
5. Was the decentralized water reuse technology implemented within an existing infrastructure or was it a greenfield project *(meaning there was no previous infrastructure)*?
6. Were there any drivers that led to the introduction of d decentralized water reuse technologies? Were there any particular environmental, social, political or economic events that impacted their introduction?
7. How was the introduction of decentralized water reuse technologies financed *(e.g. governmental subsidies, private investments)*?

Actors

8. Who pushed for the introduction of decentralized water reuse technologies *(*e.g. *political actors, NGOs, communities, private companies)*?
9. During the process leading up to the implementation of decentralized water reuse technologies, was there any communication or exchange with other actors *(*e.g. *the users of decentralized water technologies)*?
10. Did any new actors appear in the water sector in the context of introducing decentralized water reuse technologies *(*e.g. *private actors*)?
11. Were new agencies/bureaus created in the context of introducing decentralized water reuse technologies *(*e.g. *new department/agency)*? Please specify what type of institution was created as well as its tasks

Responsibility

Conventional infrastructure

12. Who is regulating rain- and/or wastewater infrastructures in general *(including upholding standards, policy goals)*?
12.1 Who has the main responsibility for decisions regarding planning rain- and/or wastewater infrastructures in general (e.g. *utility, municipality/local government, an arm's length organization like an association, regional government or private actors)*?
12.2 Who is responsible for operating rain- and/or wastewater infrastructures *(*e.g. *utility, municipality/local government, an arm's length organization like an association, regional government or private actors)*?
12.3 Who is responsible for maintaining rain- and/or wastewater infrastructures *(*e.g. *utility, municipality/local government, an arm's length organization like an association, regional government or private actors)*?

Decentralized systems

13. Who is regulating decentralized water reuse technologies *(including upholding standards, policy goals)*?
13.1 Who is making decisions regarding planning and the type of decentralized water reuse technologies *(*e.g. *utility, municipality/local government, an arm's length organization like an association, regional government or private actors)*?
13.2 Who is responsible for operating decentralized water reuse technologies *(*e.g. *utility, municipality/local government, an arm's length organization like an association, regional government or private actors)*?
13.4 Who is responsible for maintaining decentralized water reuse technologies *(*e.g. *utility, municipality/local government, an arm's length organization like an association, regional government or private actors)*?
13.5 Have there been any shifts regarding who is responsible for regulating, planning, operating and maintaining decentralized water reuse technologies? *(*e.g. *different actors, business models)*

Barriers

Initiationphase

14. Please estimate how long the **initiation phase** lasted *(from year X to year Y)*
14.1 In the initiation phase, have there been any overarching policy/policies or policy goal(s) concerning the development of decentralized water reuse technologies?
14.2 Were there any **economic** barriers that had to be overcome in order to develop decentralized water reuse technologies? Please identify what policy (instrument) was used to overcome these barriers, stating also the political level *(national, regional or local)* and time *(in the year X; or from year X to year Y)*
14.3 Were there any **regulatory** barriers that had to be overcome in order to develop decentralized water reuse technologies? Please identify what policy (instrument) was used to overcome these barriers, stating also the political level *(national, regional or local)* and time *(in the year X; or from year X to year Y)*
14.4 Were there any **organizational** barriers that had to be overcome in order to develop decentralized water reuse technologies? Please identify what policy (instrument) was used to overcome these barriers, stating also the political level *(national, regional or local)* and time *(in the year X; or from year X to year Y)*
14.5 Were there any **cultural-cognitive** barriers that had to be overcome in order to develop decentralized water reuse technologies? Please identify what policy (instrument) was used to overcome these barriers, stating also the political level *(national, regional or local)* and time *(in the year X; or from year X to year Y)*

Expansion phase

15. Please estimate how long the **expansion phase** lasted *(from year X to year Y)*
15.1 In the expansion phase, can you identify an overarching policy/policies or policy goal(s) concerning the **implementation** of decentralized water reuse technologies?
15.2 Were there any **economic** barriers that had to be overcome in order to implement decentralized water reuse technologies? Please identify what policy (instrument) was used to overcome these barriers, stating also the political level *(national, regional or local)* and time *(in the year X; or from year X to year Y)*
15.3 Were there any **regulatory** barriers that had to be overcome in order to implement decentralized water reuse technologies? Please identify what policy (instrument) was used to overcome these barriers, stating also the political level *(national, regional or local)* and time *(in the year X; or from year X to year Y)*
15.4 Were there any **organizational** barriers that had to be overcome in order to implement decentralized water reuse technologies? Please identify what policy (instrument) was used to overcome these barriers, stating also the political level *(national, regional or local)* and time *(in the year X; or from year X to*

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(*continued*)

year Y)
15.5 Were there any **cultural-cognitive** barriers that had to be overcome in order to implement decentralized water reuse technologies? Please identify what policy (instrument) was used to overcome these barriers, stating also the political level *(national, regional or local)* and time *(in the year X; or from year X to year Y)*

Consolidationphase

16. Please estimate when the **consolidation phase** started *(from year X on)*
16.1 In the consolidation phase, can you identify an overarching policy/policies or policy goal(s) concerning the **operation** of decentralized water reuse technologies?
16.2 Were there any **economic** barriers that had to be overcome in order to operate decentralized water reuse technologies? Please identify what policy (instrument) was used to overcome these barriers, stating also the political level *(national, regional or local)* and time *(in the year X; or from year X to year Y)*
16.3 Were there any **regulatory** barriers that had to be overcome in order to operate decentralized water reuse technologies? Please identify what policy (instrument) was used to overcome these barriers, stating also the political level *(national, regional or local)* and time *(in the year X; or from year X to year Y)*
16.4 Were there any **organizational** barriers that had to be overcome in order to operate decentralized water reuse technologies? Please identify what policy (instrument) was used to overcome these barriers, stating also the political level *(national, regional or local)* and time *(in the year X; or from year X to year Y)*
16.5 Were there any **cultural-cognitive** barriers that had to be overcome in order to operate decentralized water reuse technologies? Please identify what policy (instrument) was used to overcome these barriers, stating also the political level *(national, regional or local)* and time *(in the year X; or from year X to year Y)*
16.6 Were any feedback loops introduced in order to monitor the effectiveness of the policies (e.g. *regular effectiveness evaluations)*? In case there were no "built-in" feedback loops, was the effectiveness of the introduced policies and policy instruments still somehow evaluated and if yes, by whom, how and how often?
16.7Was the effectiveness of the decentralized water reuse technologies evaluated and if yes, by whom, how and how often?

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