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Under which conditions can shocks stimulate transformative recovery: the Strategy Shock Implementation Reaction (SSIR) framework

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Abstract

Future shocks from climate change impacts will likely overstretch current individual coping capacities. Integrated policy strategies could foster sustainable and resilient reactions of households and businesses by rebuilding for transformative recovery instead of bouncing back to the pre-shock status. We present the Strategy Shock Implementation Reaction (SSIR) framework as a conceptual framework for bridging the design of policy strategies to their implementation after a shock and the following reactions of the affected households and businesses. We illustrate the SSIR framework using examples of climate resilience pathways that integrate climate change adaptation and mitigation policy: planned relocation and building renovation. The framework details how a shock converts a strategy and how this conversion influences the strategy's effect on individual reactions. It thus re-conceptualizes shocks from mere policy windows to policy strategies evolve and function over time.

Keywords Adaptation · Mitigation · Recovery · Transformation · Critical event · Strategy development

1 Introduction

Various extreme events in recent years, such as the floods across Western Europe in 2021, heat waves in the United States in 2020, or wildfires in Greece in 2020, had severe impacts on our social, economic, and ecological systems. Typical government reactions to these events are to provide insurance, charity, and aid payments to affected households or businesses (Thaler and Fuchs 2020). Usually, these financial compensations strive for fast bounce-back and cater only to the short-term demands of those affected, without changing their underlying physical and social vulnerability, without using the momentum for a broader transformation towards climate neutrality and resilience (Slavikova et al. 2021;

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Osberghaus and Fugger 2022), and potentially creating undesired outcomes such as contradicting sustainability goals (Elmqvist et al. 2019; Muñoz-Erickson et al. 2021). Because of climate change, extreme weather events will most likely increase in the future (Dottori et al. 2018; Raymond et al. 2020), and may eventually overstretch the current adaptive capacities of households, businesses and entire societies (IPCC 2022). Persistent and interconnected issues such as social inequity and unsustainable resource use emphasize the need for profound changes that challenge existing structures and fundamentally transform the previous system (Rutting et al. 2023; Olsson et al. 2014; Feola 2015).

This raises the question of how to develop policy strategies that foster sustainability transitions (Rotmans et al. 2001; Meadowcroft 2009) in the aftermath of shocks such as extreme weather events. Sustainability transitions can be triggered by policy experiments and learning processes (Meadowcroft 2009; Voß et al. 2009). While transition processes are typically gradual and long-term (Rotmans et al. 2001), shock events and the reactions to these events can create ripple effects (Aldrich and Meyer 2014) and accelerate change processes of individual actors and of the socio-technical systems they live in (Madsen et al. 2022).

Policy strategies to encourage sustainability transitions and to provide more sophisticated responses to shocks should integrate climate change adaptation and mitigation "to reduce disruptions and enhance opportunities associated with climate change", so called climate resilient development pathways (IPCC 2022, p. 2917; note that climate resilience goes beyond the common narrow understanding of resilience as the capacity to accommodate damages and resume daily life, Aldrich and Meyer 2014). Generally, climate change adaptation and mitigation follow different strategies, institutional frameworks, and implementation actions. This does not only cause competing approaches to reaching divergent aims, but may also create conflicts or discrepancies (Landauer et al. 2019; Kondo et al. 2021). Actions in climate change adaptation may, however, encourage climate change mitigation activities and vice versa (Langlais 2009; Göpfert et al. 2019; IPCC 2022). Thus, since limited resources are available for coping with climate-related shocks and for combating climate change, climate resilience strives to develop policy strategies that integrate complementary approaches rather than only pushing a single solution to the most pressing problem.

Shocks can provide opportunities for building back better in order to withstand future climate change impacts and reduce carbon emissions. Even if formal structures of legitimation, domination and signification endure, shocks may motivate societal and institutional change and can encourage 'doing it differently' (O'Brien et al. 2007; Pelling and Manuel-Navarrete 2011). Shocks are often turning points that enable far-reaching changes in policy strategies (Thaler et al. 2020). Transition and transformation research typically addresses radical socio-political upheaval that destabilizes entire regimes such as a change from dictatorship to democracy (Herrfahrdt-Pähle et al. 2020; Otto et al. 2020). However, less extreme, more frequent and regional shocks such as natural hazards may instigate transition processes among individual actors while leaving the institutional and organizational structures of their current system unchanged. This kind of shocks can be anticipated and prepared for, and dedicated policy strategies may set the regulatory boundaries and the incentives within which households and businesses act when managing the shock. If these policy strategies are designed and implemented with a climate resilience perspective, it is more likely that households and businesses leverage their recovery after the shock to transition to more resilience and sustainability (Elmqvist et al. 2019; Muñoz-Erickson et al. 2021).

However, we claim that a conceptual framework bridging the design of policy strategies to their implementation after a shock and the following reactions of the affected individuals and businesses is still missing. To close this gap, we present the Strategy Shock Implementation Reaction framework (SSIR) as a conceptual framework for researching how individual climate resilience and ultimately, as the reactions of many individuals add up, societal resilience develops after a shock. The SSIR framework allows to trace the process when a policy problem (despite cursory remedies) culminates to a point where it can no longer be buffered by the individual coping capacities of those affected; a policy strategy is put forward to deal with the resulting shock; and, critically dependent on how it is implemented, the strategy fosters or undermines specific individual motivations and reactions.

Section 2 discusses how shocks are conceptualized in previous transition and resilience research. In Section 3, we present the phases and elements of the SSIR framework. Here we argue how this conceptual framework links three strands of research: (1) environmental governance theories on how policy strategies are developed and implemented (Section 3.1); (2) empirical studies on the role of shocks in opening policy windows (Section 3.2); and (3) psychological action theories on how households or businesses prepare for future shocks (Section 3.3). Section 4 details how the framework can be operationalized in empirical research, and Section 5 illustrates how the SSIR framework may manifest in the real world by specifying the framework's elements for two examples in the housing sector, planned relocation and building renovation. Section 6 discusses research directions but also limitations arising from the SSIR framework.

2 The role of shocks in socio-ecological transitions

Several approaches exist for conceptualizing transitions as well as the related concepts of resilience, transformations or sustainability pathways in the context of global environmental change (Olsson et al. 2014; Feola 2015; Patterson et al. 2017). These approaches entail different understandings of the effects of shocks. The terms transition and transformation are frequently used interchangeably, and many distinct and overlapping definitions exist for both, depending on the underlying concepts (Feola 2015; Rutting et al. 2023). We follow Patterson et al.'s (2017) use of sustainability transformations as "an umbrella term to encompass diverse perspectives on transitions and transformations in the global sustainability literature" (p 2). We distinguish three main research directions: (a) transition theory, (b) socio-ecological system framework, and (c) transformation pathways.

In transition theory, the multi-level perspective on socio-technical transitions (MLP) centers on socio-cultural landscapes, socio-technical regimes, and niches factors (Geels 2002; Raven et al. 2012). In the MLP, a transition occurs when dynamics at the different levels create a window of opportunity, such as landscape factors destabilizing regimes or niches gathering momentum (Lachman 2013). Rupture points may break ecological, economic, social, or technological lock-ins (Geels 2011). Disruptive events can destabilize dominant regimes from existing paths and open space for niche innovations to emerge and gain influence. However, rather than on shocks from natural hazards, the MLP focuses on disruptions or rupture points during the long-term evolution of a socio-technical landscape or regime over years to decades (e.g., World War II, the 1973 oil crisis, Chernobyl nuclear accident) (Johnstone and Schot 2022). In the social-ecological system framework, by contrast, crises, perturbations or disturbances are considered to trigger and drive transformations (Olsson et al. 2014). Social-ecological systems are characterized by their capacities "to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks" (Walker et al. 2004, p. 1). Social-ecological systems navigate and adapt to change and therein exhibit similar trajectories over time (Westley et al. 2011; Gunderson et al. 2017). However, only adapting to disturbances might not change the root causes of a system's vulnerability or might perpetuate lock-in, so that a system might undergo fundamental shifts only as late as when ecological, economic or social conditions become untenable, which means an undesired resilience outcome (Walker et al. 2004; Folke et al. 2010; Elmqivst et al. 2019). Resilience scholarship has picked up the importance of governance and individual agency in bringing about transformations for sustainability (Westley et al. 2013; Patterson et al. 2017).

Other approaches like transformative pathways to sustainability (Leach et al. 2012; Stirling 2014) and transformative or transformational adaptation (Pelling 2011; O'Brien 2012) put similar emphasis on governance as enabling condition for adaptation planning and implementation (New et al. 2022). The former underscores the political nature of transformations and the intersection of research and governance perspectives in complex sustainability problems (Rutting et al. 2023), while the latter addresses how resilience and justice concerns arise from the interrelation between localized climate-related shocks and the systemic structures that produced societal inequalities in the first place (Patterson et al. 2017; Meerow et al. 2019).

As highlighted by the IPCC AR6 Special Reports, radical shifts and large systemic changes are required to accelerate the transition to climate resilient development (New et al. 2022). However, the role of disruptions, perturbations, or crises as turning points for far-reaching policy changes remains underdeveloped. Recent work analyzes the effects of exogenous shocks on governance for a transformation towards sustainability, but does not elaborate how the policy strategies designed to deal with the shock affect households and businesses (Herrfahrdt-Pähle et al. 2020; Johnstone and Schot 2022). Thus, we adopt a multiphase and multi-level view on the effects of shocks on governance, placing the impacts of shocks on policy strategies and consequently on individual reactions at the center.

3 The Strategy Shock Implementation Reaction (SSIR) framework

The Strategy Shock Implementation Reaction (SSIR) framework proposes a sequence how the prevalent policy strategy, such as improving community resilience, is filtered during and after a shock, directing households or businesses to specific individual reactions. For more accessible reading, the respective framework elements are highlighted in bold font when first mentioned in the text.

The framework is divided into three phases: In the **first phase of strategy development**, a policy problem appears, like climate-related hydro-meteorological extreme events, when actual risk management strategies no longer can cope with these events, and a dedicated strategy, such as the creation of a national compound climate-risk management strategy, is developed to respond to the problem. The **second phase of strategy application** begins when a shock occurs (e.g., devasting natural hazards events like Cyclone Chido in 2024,

the 2024 hurricane season in the United States, or the 2024 Spain flood event), necessitating the implementation of the strategy. In the policy window following the shock, strategies are either implemented as intended, are revised, or emerge. The phase ends when all relevant policy solutions of the strategy have been implemented. The **third phase of strategy impact** begins when emergency measures are completed, and households and businesses start considering long-term recovery and prevention of future shocks. It ends when these individual actors have taken specific reactions (or have remained inactive) regarding their well-being, properties, and assets.

The three phases build on the respective assumptions that (1) beliefs and narratives influence strategy development (Kahan et al. 2007; Davy 2008; Hartmann 2010); (2) shocks influence existing strategies (Grossman 2015); and (3) implemented strategies influence individual behavior (Babcicky and Seebauer 2019). Figure 1 shows the process from strategy to shock to reactions posited in the SSIR framework.

The definitions of framework elements are summarized in Table 1. The next sections deduce the elements' theoretical background: First, we reflect on how policy strategies are informed by narratives and beliefs stemming from actor coalitions and policy entrepreneurs (Section 3.1); then, we describe how shocks initiate the implementation, revision, or emergence of strategies (Section 3.2.); and finally, we discuss the drivers and forms of individual reactions (Section 3.3).

3.1 Strategy development: from problems to paper

The first phase of the SSIR framework maps out how policy strategies are developed. In the 1970 s, the strategy concept became popular in management studies, focusing on organizations (van Assche et al. 2021b). It is defined as a 'consciously intended course of action,' such as a plan or guideline to address a specific problem (Mintzberg 1987, p. 11). Strategies are found in all spheres of society, and the strategizing of individuals, organizations, communities, or states never stops (van Assche et al. 2020), such as the strategy 'living with



Fig. 1 The Strategy Shock Implementation Reaction (SSIR) framework

Table I Dellinti	on and operationalization of the SSIR framewor	K cicilients	
Element	Definition	Potential methods for operationalization	References
Policy beliefs	A set of values that follows a systematic pat- tern. Policy-relevant beliefs determine the preferences of a group regarding a specific problem; a group takes action based on the shared set of beliefs, such as technology- believers preferring technical mitigation measures to reduce the potential risk.	 Discourse analysis Frame analysis (Entman 1993; Win- slow 2017) Qualitative content analysis (Mayring 2015) 	Sabatier 2007; Zahariadis 2007; Biesbroek 2021; Kammermann and Angst 2021; Zhou et al. 2021
Policy narratives	Competing views that are produced, evolved, or shared in a discourse between the actors involved. Narratives include specific views about the nature and causes of a policy problem and the potential policy solutions, but also connect these specific views with the general ideology, identity, and policy beliefs of the involved actors, e.g., encourage a multi-actor risk manage- ment to also include non-state actors.	 Semi-structured interviews with actors who developed policy strategies Document analysis to track signature phrases in documents or audiovisual media 	Shanahan et al. 2013; Jones et al. 2014; Crow and Jones 2018; Lebel and Lebel 2018
Strategy	A pattern in a stream of decisions either intended or emergent that plans for the long-term and addresses a specific policy problem, like natural hazards. Intended strategy: A pattern of policy solutions developed purposefully from deliberations on how a policy problem will persist or worsen in the future. It explicitly addresses the stated goals/objectives, e.g., use of planned relocation to reduce exposed buildings in hazard-prone areas. Emergent strategy: A pattern of policy solutions that emerges in the absence of intentions but is consistently replicated or transferred. It may only implicitly address the stated goals/objectives. Unrealized strategy: Policy solutions that were debated within policy narratives, but did not become part of the strategy. Implemented strategy: A series of activities undertaken by government to achieve the stated goals/objectives, realizing the policy solutions prescribed by the strategy. The activities directly affect households and businesses. Revised strategy: A strategy that is substan- tially reoriented or expanded subsequent to a shock or to a policy development before being implemented. Unchanged strategy: A strategy implemented as originally prescribed, with only marginal amendments or omission of selected policy solutions. Failure: A strategy that substantially under-	• Document analysis of published strate- gies (Bowen 2009) • Semi-structured interviews with poli- cymakers (active and retired) to identify informal, unrealized, and failed strategies	Mintzberg and Waters 1985; Mintzberg 1987; Matheson 2009; Neugebauer et al. 2016; van Assche et al. 2020; Assche et al. 2021a, b

Table 1 Definition and operationalization of the SSIR framework elements

Element	Definition	Potential methods for	References
System performance	How the policy problem, that is, individual and societal risks, evolves over time and how well previous strategies managed the policy problem before the shock, such as the implementation of Nature-based Solutions for disaster risk reduction. How previous strategies were shaped by related policy domains.	• Document analysis of consecutive versions of policy strategies at different governance levels • Time series and spatial analysis of in- dicators of the policy problem	Farley et al. 2007; O'Donovan 2017
Shock	A sudden, rare, harmful, disruptive, and urgent event that (almost) overstretches current coping capacities, such as large-scale extreme weather events. It may return re- peatedly or persist as a background stressor.	 Workshops or semi- structured interviews with local scientists, affected households and businesses, or experts to reconstruct side-effects, informal aspects and barriers to policy implementa- tion during/after the shock Analysis of eco- nomic and psycho- social data of shock impacts and revealed vulnerabilities Spatial analysis of hot and cold spots 	Grossman 2015; Cairney and Jones 2016; Dolan 2021
Risk appraisal	How threatened a person feels by a certain risk. Risk appraisal is composed of a cogni- tive and an affective subcomponent.	• Qualitative, semi- structured interviews with individual actors • Quantitative, struc- tured surveys with individual actors	Grothmann and Reusswig 2006; Babcicky and Seebauer 2019; Kuhlicke et al. 2020
Coping appraisal	The cognitive process by which a person evaluates possible responses that may re- duce the perceived threat. Coping appraisal includes the three subcomponents response efficacy, self-efficacy, and response costs.	• Cognitive mapping (Kearney and Kaplan 1997; Kropf et al. 2021)	Grothmann and Reusswig 2006; Babcicky and Seebauer 2019; Kuhlicke et al. 2020
Non-protective responses	Responses aiming to avoid or suppress the emotional consequences of the threat or the allocation of responsibility for preventing the threat.		Grothmann and Reusswig 2006; Babcicky and Seebauer 2019; Kuhlicke et al. 2020
Individual reactions	Responses during recovery from the shock and prevention of recurring similar shocks.		Kuhlicke et al. 2020; Seebauer and Babcicky 2021; Noll et al. 2021

Element	Definition	Potential methods for operationalization	References
Actor coalitions	Actor coalitions are groups of individuals with decision power, such as elected offi- cials, policy makers, risk managers, individ- ual citizens, civil servants, or representatives of interest groups These groups coordinate to pursue congruent policy narratives.	 Actor mapping through professional networks, online search, snowball sampling Social network 	Sabatier 1988, 2007; Zahariadis 2007; Oborn et al. 2011; Candel and Biesbroek 2016
Policy entrepreneurs	Policy entrepreneurs are individuals who lobby for their favored policy narrative and form actor coalitions. Policy entrepreneurs need not have decision power.	analysis (Scott 2000; Borgatti et al. 2009, 2018; Scott and Car- rington 2011) • Process net maps (Sattler 2022)	Sabatier 1988, 2007; Zahariadis 2007; Oborn et al. 2011; Candel and Biesbroek 2016

Table 1 (continued)

floods' developed across the globe some decades ago or 'the behavioral turn' strategy in risk management (Sayers et al. 2015; Kuhlicke et al. 2020).

The strategy concept has gained more attention in recent years, particularly in the fields of sustainable development and environmental policy which require long-term policy solutions (Matheson 2009; Nilsson et al. 2016; Sachs et al. 2019; van Assche et al. 2020; Assche et al. 2021a, b). Strategies are described as "a vision for a desirable longer-term future" (van Assche et al. 2020, p. 696) of different public and private actors that is based on collectively binding decisions (e.g., consensus or a democratic majority) on how to get there. Examples of higher-level international strategies are the UN Sustainable Development Goals, the Sendai Framework on Disaster Risk Reduction and the COP21 Paris Agreement on climate change.

Strategies need not always result from a deliberate plan, however. While **intended** strategies are purposefully developed to address a policy problem (like the 'living with floods' strategy), strategies can also **emerge** in the absence of intentions as a "pattern in a stream of actions" (Mintzberg 1987, p. 12). Emergent strategies also result from unexpected opportunities or ad-hoc solutions to isolated cases of a policy problem that are consistently replicated and transferred to other similar contexts (Mintzberg and Waters 1985). Most strategies contain both intended and emergent elements, however (Neugebauer et al. 2016). Some strategies remain **unrealized** and are discarded; for instance, because they cannot compete with other strategies that are better aligned with the dominant policy narratives or better address the policy problem.

To operationalize the strategy concept, van Assche et al. (2020) introduce the institutional and the discursive dimensions of strategies. The institutional dimension proposes that strategies depend on and are shaped by institutions (e.g., a national or regional authority), which coordinate and integrate different discourses and actions of public and private actors in different policy domains. The discursive dimension describes a collective narrative, vision, or perspective about a desirable future and how to get there (van Assche et al. 2021b). At higher political levels and for cross-cutting and transboundary policy problems such as climate change, food security, or sustainable development, more coordination and integration towards a shared vision or goal is required (Candel and Biesbroek 2016; Peters 2018; Biesbroek and Candel 2019).

Policy narratives reflect worldviews of different actors, which structure and convey their understanding of the nature and causes of a policy problem and the potential policy

solutions that could be included in a strategy, but also connect these specific views with their general ideology, identity and policy beliefs (Jones et al. 2014). Narratives come to the fore under unfamiliar conditions (e.g., during a shock event) or when facing highly uncertain future developments (e.g., because of impending environmental or socio-economic changes); they may provide orientation and align strategic action by diverse actors (Constantino and Weber 2021). Policy narratives can create enduring collaboration following a vision and can be used for monitoring progress and achievements (Mintrom and Rogers 2022). In the case of natural hazards, policy narratives could appear in the mental models of experts (risk as the combination of hazard, exposure, and vulnerability; IPCC 2014) and laypeople (perception of risk as dreadful, unknown, or uncontrollable; Slovic 1987).

Policy narratives are rooted, inter alia, in **policy beliefs**, that is, a set of values that follows a systematic pattern (Sabatier 1988; Jones et al. 2014). Policy beliefs reflect core principles and commitments actors have based on their own norms, values, and ideas that determine their preferences regarding a specific problem (Sabatier 1988; Biesbroek 2021; Kammermann and Angst 2021). Policy actors take action based on the shared set of beliefs (Zhou et al. 2021). Policy beliefs and narratives tend to be more stable than policy strategies, which may constitute a challenge for policy coordination and integration if new policies run counter to established beliefs (Hall 1993; Pierson 1993); yet, there are examples of narratives changing over time, such as the adoption of fishery concerns within EU development cooperation policy which realized mutual synergies towards improving livelihoods and food security (Candel et al. 2015) or the implementation of Nature-based Solutions, which can provide multiple co-benefits such as risk reduction, improving biodiversity or carbon storage (Debele et al. 2023).

In strategy development, different policy actors want their beliefs and worldviews reflected in policy outcomes at different levels (Zhou et al. 2021). Policy actors operate at multiple political levels in order to increase policy flexibility and efficiency (Marks and Hooghe 2000). Multi-level governance can be organized into two different types. The first type is characterized by shared power between governments representing clearly defined territories such as nation states and regional governments (Liesbet and Gary 2003). In this type, the development of policy strategies typically follows a nested approach such that lower-level strategies aim to be coherent with higher-level strategies. This type is common in the European Union, where policy reforms initiated and pushed at the supra-national level are to be transposed to national and regional levels (Cunha and Swinbank 2009), such as the Floods Directive or the Nature Restoration Law. The second type of multi-level governance starts from the policy problem, and power and decision-making are dispersed between multiple concerned levels. This type is characterized by low entry thresholds into the governance structure and highly flexible organization (Liesbet and Gary 2003). It results in problem-driven policy strategies that emerge from close collaboration between concerned actors, while external interactions are kept to a minimum. A prominent example of the second type is the governing of common property resources such as communal tenure in alpine meadows or water resources (Ostrom 2015).

However, policy actors rarely act alone. Actor coalitions are groups of policy actors from different institutions and backgrounds such as elected officials, individual citizens, civil servants, or representatives of interest groups, trade associations or corporations who share a set of policy beliefs and have decision power (Sabatier 2007). For instance, two actor coalitions formed in a recent reform of the Common Agricultural Policy conveying either

core agricultural or environmental policy narratives (Loacker et al. 2025). Some individuals or corporate actors – so-called **policy entrepreneurs** (Kingdon 1984), change agents (Mintrom and Rogers 2022) or catalyzing agents (New et al. 2022) – lobby for their favored policy narrative, build actor coalitions and networks, and seize the opportunity to initiate action after a policy window has opened (Zahariadis 2007; Oborn et al. 2011), like the implementation of planned relocation to adapt to extreme weather events (Thaler et al. 2020). While policy entrepreneurs do not have decision power themselves, they possess a variety of skills to collectively shift dominant beliefs and norms (Westley et al. 2013). Policy entrepreneurs play a crucial role in directing the development of policy strategies, providing a common vision, building social networks and trust, leveraging resources, capturing the attention of policymakers, and bridging local, narrow problems to broad, cross-cutting issues (Zahariadis 2007; Oborn et al. 2011; Westley et al. 2013; Candel and Biesbroek 2016).

Most policy problems do not appear entirely unexpectedly but evolve and are addressed over time. System performance reflects the history before the shock happens - how a widening discrepancy between revealed conditions and stated objectives grows into a policy problem, and how actions to deal with the problem are taken as long as profound shocks are absent (Farley et al. 2007; O'Donovan 2017). On a floodplain for instance, the system performance may keep up by expanding dams and pumps as riverside wetlands are drained to erect additional settlements; however, once a flood event exceeds these protective measures and delivers a shock, flood risk management turns into a policy problem that necessitates more extensive measures, like early-warning systems or planned relocations. System performance comprises the repeated occurrence or accumulation of small hazard events, as well as the incremental policy steps taken to cope with these small events. In addition, system performance includes processes of policy learning, if earlier policy decisions are revisited in the light of new information (O'Donovan 2017), policy integration, if strategies are shaped by related or adjacent policy domains (Solecki and Michaels 1994), and missionoriented policies (Mazzucato 2018), if strategies are expanded to span large societal challenges such as climate change.

3.2 Strategy application: from paper to action

The second phase of the SSIR framework describes how strategies are implemented after a shock. A **shock** is a sudden, rare, harmful, disruptive, and urgent event that (almost) overstretches current coping capacities (Grossman 2015; Dolan 2021). Shocks related to climate change are large-scale extreme weather events like hurricanes, floods, droughts or heatwaves. A shock originates outside the socio-political system under study (Cairney and Jones 2016; Hanger-Kopp et al. 2022); thus, routine events such as periodic elections or regular turnover in institutions do not qualify as shocks (Beland and Howlett 2016; Dolan 2021). A shock may be anticipated, e.g., with long-term monitoring systems, but its exact timing is random. A shock conveys urgency, as it speeds up the development and application of strategies (Grossman 2015). Shocks should not be overrated in their relevance; a shock alone rarely suffices to propel an issue to enduring prominence (Solecki and Michaels 1994).

Some policy problems do not culminate in singular shock events, however. Slow-onset issues like climate change persist as background stressors, incurring continuous degradation or system underperformance that amounts to a shock once the accumulated shortfalls become unbearable (Grossman 2015). The SSIR framework is tailored to rare and out-

standing events, however; slow-onset issues often give rise to reciprocal framing contests between system performance and policy narratives, which makes it hard to disentangle directional influences (Dolan 2021).

Shocks typically open policy windows for transforming governance regimes, creating new visions, enabling learning and innovation, or changing behavioral patterns (Broto et al. 2014; Herrfahrdt-Pähle et al. 2020; Kanda and Kivimaa 2020). A policy window is a temporary period of rapid policy implementation; during this period, existing policy arrangements become instable and fluid if they are designed only for managing routine fluctuations in system performance (Penning-Rowsell et al. 2006; Jones et al. 2014). For instance, key personnel may extend their daily working hours or introduce shortcuts in decision-making when managing a shock. During a policy window, the likelihood of developing new strategies is higher than usual as niche actors may step up and propose alternatives if the regime turns dysfunctional under the changed conditions (Solecki and Michaels 1994; Herrfahrdt-Pähle et al. 2020). For instance, insurance companies may use a recent flood to lobby for public co-financing of insurance schemes. Policy windows are considered particularly relevant for diffusion, acceleration and upscaling of innovations for sustainability transitions (Köhler et al. 2019). However, policy windows might also have negative implications, for instance if the shock doctrine encourages extensive privatization and deregulation after an event as it occurred after Hurricane Katrina in 2004 in the United States (Klein 2008).

When the window opens, public and policy attention turns to the policy problem and may challenge or reframe the dominant policy narratives (Bubeck et al. 2017; Rose et al. 2020). Actors strive for fast recovery and symptomatic relief and may draw on large resource inflows that become available after the shock, for instance, international aid funds or private donations (Penning-Rowsell et al. 2006; Birkmann et al. 2010; Brundiers and Eakin 2018). Once the most pressing issues have been resolved, actor engagement winds down because continued activity no longer yields significant returns and media attention decreases (although the problem may still be unresolved), and the policy window eventually closes (Solecki and Michaels 1994; Farley et al. 2007; Grossman 2015).

Radical and catalytic change that questions core beliefs and agendas happens rarely during the timespan from the opening to the closing of a policy window after a shock (Solecki and Michaels 1994). Instead, policy windows tend to accelerate or modify ongoing change, by amplifying existing ideas and pre-signals (e.g., by transferring policy instruments from other contexts; Johnson et al. 2005; Thaler et al. 2020), by instigating renegotiation of leadership and institutional roles (e.g., by speeding up administrative decision-making for permits and budgets; Birkmann et al. 2010), or by shifting policy narratives to favor a particular approach (e.g., by promoting a specific promising technology; Kulmer et al. 2022).

Once a shock has occurred, policy actors must act (Mintzberg 1987) as we can see on different examples of extreme weather events across the globe. An **implemented strategy** includes a series of activities undertaken by the government to tackle the policy problem revealed by the shock, realizing the policy solutions prescribed by the strategy. Implemented strategies include land use plans, laws, or government subsidies and directly affect households or businesses. The implemented strategy is either **unchanged** with only marginal amendments or omission of selected policy solutions; **revised** with substantial reorientation or expansion; or newly **emerging** due to a shock. A strategy can also **fail** and not be implemented, for instance, if it is expected to underperform when applied to the current shock.

Policy strategies can be implemented at multiple governance levels. Coordination and integration between and across levels are important to avoid redundancies, fragmentation, incoherence, or inconsistency (Peters 1998; Candel and Biesbroek 2016). National governments need to coordinate to align efforts, prioritize risk management, and implement measures that enhance resilience and address systemic vulnerabilities (Lal et al. 2012). Coordination and integration are achieved by either restricting the number of involved actors (in the first type of organization in multi-level governance) or limiting the engagement with unconcerned actors (in the second type; Scharpf 1994; Liesbet and Gary 2003; see Section 3.1). In both types, competencies are distributed such that the costs of heterogeneity are balanced by economic benefits of scale. Transaction costs of gathering and disclosing information, reaching consensus and decisions, and maintaining infrastructure should be kept low (Marks and Hooghe 2000). To some extent, however, redundancies ensure the reliability and flexibility of an implemented strategy (Landau 1969; Peters 2018).

3.3 Strategy impact: from action to reaction

The third phase addresses how an implemented strategy translates into reactions of households and businesses to the problem. The SSIR framework posits an indirect relationship: implementing the strategy does not directly incur individual reactions, but changes the underlying motivations and perceptions, which subsequently lead to specific individual reactions. The SSIR framework draws on Protection Motivation Theory (PMT; Rogers 1983) to describe how individual reactions result from motivations and perceptions. The PMT has been applied to a range of natural hazards, including droughts (Truelove et al. 2015), landslides (Mertens et al. 2018), tornados (Weinstein et al. 2000), volcanic hazards (Covey et al. 2019), wildfires (Martin et al. 2008) and most prominently floods (Grothmann and Reusswig 2006; Kuhlicke et al. 2020). The PMT may explain reactions from diverse individual actors such as households (Babcicky and Seebauer 2019), farmers (Mitter et al. 2019; Kropf et al. 2024), or local authorities (Grothmann et al. 2013).

According to the PMT, individual reactions arise from the interaction between risk appraisal, coping appraisal, and non-protective responses. Risk appraisal indicates how threatened a household or business feels by a certain risk. It is composed of a cognitive (risk perception as the expectancy value of probability and severity of negative outcomes) and an affective (feelings of fear and worry) subcomponent. An implemented strategy may influence risk appraisal, for instance, by countering misperceptions how likely and how severely the shock may return, or by contextualizing individual shock experiences. Coping appraisal indicates how an actor evaluates possible responses to reduce the perceived risk. Coping appraisal includes the three subcomponents response efficacy, self-efficacy, and response costs. Response efficacy describes how effective a reaction is considered in reducing the expected negative outcome; for instance, whether investing in irrigation infrastructure reduces damages of recurring droughts. Self-efficacy refers to the perceived ability to carry out this reaction; for instance whether the farmer has the expertise and capacity to carry out the entire investment process. Response costs include the required financial resources, time, and effort for the planned reaction, including investment and operating costs. An implemented strategy may influence the efficacy and costs of individual reactions by means of financial schemes (e.g., subsidies for energy-efficient investments), voluntary or mandatory guidelines (e.g., energy-efficiency standards), counselling, or other instruments.

The risk and coping appraisal processes interact: Without a significant risk appraisal, actors would not see any need to take action. If high risk appraisal coincides with high coping appraisal, protective reactions are initiated. If high risk appraisal meets low coping appraisal, actors may feel overwhelmed and instead turn to non-protective responses. Non-protective responses are avoidant or suppressing reactions in order to downplay the risk (e.g., denial, wishful thinking) or to shift responsibility (e.g., fatalism, overreaching reliance on external support; Bubeck et al. 2013; Babcicky and Seebauer 2019). For instance, if farmers recognize the drought risk but cannot imagine an effective response they could take themselves, they may instead consider the government responsible for compensating drought-related yield losses. An implemented strategy that takes comprehensive governmental steps to mitigate the shock impacts may make people disregard their personal contribution, or policies of promise and appeasement may encourage denial and wishful thinking.

The PMT is well suited to explain reactions that include a subjective balancing of costs and benefits (Kuhlicke et al. 2020); however, the PMT should not be misconstrued as covering all motivational determinants of individual reactions. In the example of floods, further relevant factors are past experiences of hazard events (Osberghaus 2017; Thistlethwaite et al. 2018), role models and normative expectations conveyed by the social environment (Poussin et al. 2014; Bubeck et al. 2018), or social capital when informal community networks provide emergency assistance or facilitate access to external charity and support (Aldrich and Meyer 2014). The SSIR framework focuses on risk appraisal, coping appraisal, and non-protective responses, though, because these factors are well confirmed in the pertinent literature and can be directly targeted in an implemented strategy.

The PMT is open to being applied to any kind of **individual reaction**; however, the strength of influence of risk appraisal, coping appraisal, and non-protective responses may vary between individual reactions. For instance, in the case of flood preparedness, the impact of risk appraisal is small (Bubeck et al. 2012; Bamberg et al. 2017), whereas coping appraisal is essential (van Valkengoed and Steg 2019; Noll et al. 2021). While risk appraisal refers to the general, overarching threat, the impact of coping appraisal depends on the specific reaction considered (Babcicky and Seebauer 2019; Noll et al. 2021).

The SSIR framework does not specify which particular individual reactions stand at the endpoint of the framework's three phases; however, for the purpose of applying the SSIR framework in climate resilience research, we propose transformation, maladaptation, back-fire, and inaction as prototypical individual reactions. These four prototypical reactions may illustrate possible (mis)directions in integrating climate change adaptation and mitigation.

Transformation ('build back better') aims to improve an actor's resilience to withstand shocks (Folke et al. 2016) or fundamentally change their capacities that are no longer adequate (Walker et al. 2004; Park et al. 2012). Transformation is also characterized by catering to previously underrepresented goals such as climate resilience or sustainability transition (Elmqvist et al. 2019). It expands the scope of action to indirect consequences of the shock and to possible overlaps with other domains by considering an actor's double exposure (O'Brien and Leichenko 2000). Examples of transformation reactions are modifications of production systems or income diversification.

Maladaptation ('build back short-sighted') can be defined as intended actions that restrict their scope to the direct, short-term consequences of the shock and increase vulnerability or deteriorate the conditions for sustainability transition (Juhola et al. 2016). It includes quick end-of-pipe fixes to remedy the most pressing problems as well as implementing corrections that cannot counter ongoing degradation. An example of a maladaptation reaction is business operations focused on optimizing gross margin and gaining competitive advantage in narrow market segments at the expense of overall resilience.

Backfire ('build back worse') refers to reactions that are not just insufficient to accommodate future shocks, as maladaptation does, but that make the system worse off than it was before the shock. These reactions undermine instead of reconcile climate change adaptation and mitigation, or increase negative environmental or social externalities. Examples of backfire reactions are expansions in business operations to compensate for losses, resulting in additional greenhouse gas emissions or higher assets at risk. Backfire also manifests as rebound effect, when savings from more efficient provision of services by technology modernization are (over)compensated by subsequent increases in consumption (Sorrell 2007; Gomez and Perez-Blanco 2014).

Inaction ('build back as before') refers to the active or implicit decision to not perform actions (or to postpone actions indefinitely) that go beyond those already agreed upon before the shock happened. Uncertainties are often used as an excuse for remaining inactive (Howden et al. 2007; Gifford 2011). Inaction is characterized by restoring an actor's pre-shock status, by depreciating damages or ignoring sunk costs, by remaining in inertia or with entrenched habits, and by continuing business-as-usual despite evidence that shocks will return in the future.

4 Operationalizing the SSIR framework

The SSIR framework is generic such that it can be applied to different socio-technical systems and shocks, while considering multiple actors and governance levels. It may structure ex-post, retrospective, historical research that aims to reconstruct why individual reactions occurred against the background of a historically grown policy environment, or may be employed for comparative analysis of regions where the same or different policy strategies were implemented after shock events. The framework may also guide ex-ante, prospective, forward-looking studies that aim to anticipate how current policy strategies will perform when put to the test by a shock in order to manage future risk. Prospective and retrospective research could be combined, for instance, if an intended strategy is designed to prevent or cope with specific shock scenarios defined by impact modeling, and the viability of both strategy and scenarios are evaluated once a shock occurs.

Table 1 provides a detailed mixed-method portfolio to operationalize the SSIR elements within the framework's three phases. Please note that we describe the phases in a linear way, though they may be iterative in research practice.

Phase 1 Strategy development. Tracing how policy strategies evolve from policy beliefs and narratives and are negotiated between policy actors mainly relies on document and interview sources. Policy strategies may be distinguished into regulations (e.g., proscriptions, commands, standards), incentive-based instruments (e.g., investment subsidies, interest rate cuts, tax increases or reductions, quotas), and voluntary agreements (e.g., peer role models, moral persuasion; Tol 2019; Mitter and Schmid 2021). It may be useful to visualize pre-shock developments in a historical timeline leading up to the status quo, allocating in

annual steps the publication dates of (draft) policy documents, time series data of indicators for the policy problem, and influential socio-economic events (such as elections or policy cycles), assigning each entry to a governance level (local, regional, national, international) and indicating critical events as reference points in this timeline. System performance can be monitored with specific indicators that track policy objectives over time. These indicators should not, however, be mistaken for neutral criteria; since indicators monitor objectives that are derived from policy narratives, indicators are also colored by what is deemed important in the dominant narratives (Dolan 2021).

Phase 2 Strategy application. Unless already specified when assessing system performance, the operationalization of the shock needs to define the boundaries of investigation (e.g., spatially, temporally, by governance levels, by economic sectors). Shocks tend to undermine regular documentation and data collection procedures; we therefore recommend to employ methods suitable for reconstructing what happened on the ground in order to capture informal and ad-hoc developments.

Phase 3 Strategy impact. Qualitative interviews and quantitative surveys may explore individuals' risk and coping appraisals, non-protective responses and reactions to implemented strategies (Mitter et al. 2019; Seebauer and Babcicky 2021). We suggest to build on the extensive corpus of previous research (Kuhlicke et al. 2020) and to use established interview guidelines and questionnaire items that are already confirmed as reliable and valid. Individual reactions can be analyzed at household or business level. These levels may intersect in smaller family-owned businesses, as they resemble households in characteristics such as the important role of family support or the spatial proximity of residential building and business location. However, businesses feature different vulnerabilities to natural hazards compared to households (e.g. physical damage to production facilities or storage; Winter et al. 2004; Marshall et al. 2015).

Cross-phase actor assessment. Policy actors from different governance levels may be categorized according to their interest, influence and power, the economic sector or institution they represent, and which shock impacts they have experienced. Participating actors may live and work in the study area or may contribute an external view. Researchers should be sensitive to involve actors that typically do not have a voice or are hard to engage, such as marginalized groups with limited resources. Social network analysis and process net maps may reveal interactions and relationships between actors and events that can be integrated and visualized with the above-mentioned historical timeline.

5 Two examples for applying the SSIR framework

We illustrate how phases and elements of the SSIR framework link to each other in two examples that describe how shocks influence individual reactions for sustainability transition and climate resilience in the housing sector. The first example, planned relocation from flood hazard zones, is intended to reduce flood risk and may also promote rebuilding in an energy-efficient manner. The second example, building renovation, pursues reductions in heating energy demand and carbon emissions, and may also support keeping homes cool during urban heat waves. These examples should be read as descriptive narratives that demonstrate how the SSIR framework can be applied to real-world cases in climate change adaptation and mitigation.

5.1 Planned relocation

Planned relocation is usually organized between different political-administrative levels (Schindelegger 2019): National and regional authorities design and the local level implements the strategy. Policy entrepreneurs may play a core role if they show transformative leadership by encouraging and managing local agents such as affected households, neighborhoods, or grassroots organizations (Thaler et al. 2020).

During **phase 1** of the SSIR framework, the policy problem manifested in an increasing number of buildings constructed in floodplains, indicating insufficient system performance. Moving buildings from high-risk flood hazard zones to no-risk zones was considered a policy strategy for adapting to this risk (Schindelegger 2019). Planned relocation is used across the globe, for example, in Austria, the United States of America, Australia, Vietnam, Japan, and Mozambique (Correa et al. 2011; de Sherbinin et al. 2011; Sipe and Vella 2014; UNHCR 2014; Kloos and Baumert 2015; Bukvic and Owen 2017; Barnett and McMichael 2018; Seebauer and Winkler 2020). Most communities resist this radical strategy, though, and instead turn towards other, less contested risk reduction measures (Thaler et al. 2020). The dominant **policy narrative** in flood risk management centered on cost-benefit assessments (Slavikova et al. 2021). Planned relocation adhered to this narrative because the one-time investment for removing old and constructing new buildings clearly pays off by precluding any repeated flood damages in the future. Planned relocation also matched with the narrative of shifting responsibility to homeowners as the state is no longer willing to provide comprehensive protection for everyone (Kuhlicke et al. 2020), and with the narrative of 'room for the rivers' and 'making space for water' (Warner and van Buuren 2011). The narrative in flood risk management was based on hierarchical **policy beliefs**, where the voluntary relocation of individual residents was combined with centralized technical engineering solutions (Thaler et al. 2020).

In line with **phase 2**, planned relocation was usually implemented after a **shock**, such as the floods in Austria in 2002 or 2013, New Orleans in 2005, Germany in 2016, or posttsunami in Japan in 2011 (Iuchi 2014; Mayr et al. 2020; Thaler et al. 2020). In Austria, policymakers used the 2013 flood event as a policy window to **implement the strategy** as a financial compensation scheme (Schindelegger 2019; Thaler et al. 2020). The Austrian government offered all residents in the relocated Danube community up to 80% of the value of the old building and the demolition costs (Thaler et al. 2020). The strategy used in Austria in 2013 was mostly **unchanged** as it had already been implemented in adjacent downstream areas in 2002. By contrast, in Simbach in Germany in 2016, households were relocated as an **emergent** strategy as no previous plans had existed but the public administration used the momentum after the flood (Mayr et al. 2020). In Abruzzi in Italy, planned relocation was **revised** to also increase biodiversity in the abandoned areas, improve individual wellbeing, and decrease carbon emissions (Knobloch 2005; Micangeli et al. 2013).

In **phase 3**, relocation programs met the individual considerations of flood-prone households. In Austria, the **risk** and **coping appraisal** in the decision to leave or remain in the flood risk zone centered on emotional reasons on the one hand, such as traumatic flood memories and a personal bond to the place, and financial restrictions on the other hand, such as uncertain income and family prospects (Seebauer and Winkler 2020). **Non-protective responses** appeared as feeling helpless and impotent against an uncertain yet overwhelming flood threat and against powerful state actors (Thaler et al. 2020). The potential **individual** reactions span all four prototypical reactions mentioned in Section 3.3. As a transformation reaction, the new building could be constructed as a zero- or low-emission building that is also hardened to natural hazard events, for example in the sustainable energy supply system of the relocated L'Aquila municipality (Italy; Micangeli et al. 2013). Individuals may act in a maladaptive way when rebuilding their homes with only piecemeal adaptation measures or at the fringe of, or even inside the flood risk zone (Nalau and Handmer 2018). Backfire occurred in the Austrian case when new buildings were developed at a larger size, including swimming pools or other energy and carbon-intensive amenities (Thaler and Fuchs 2020). Both maladaptation and backfire reactions could be avoided by mandating flood-proof, energy-efficient rebuilding standards in the relocation strategy, or by linking financial compensations not just with risk reduction but also with energy efficiency. Most voluntary relocation programs result in partial inaction if some residents refuse to relocate, thus remaining at risk, raising public costs for maintaining infrastructure for the few who stay in the floodplain, and blocking the use of the floodplain for water retention. Restoring a building destroyed by flooding to its previous state without any improvements towards climate change adaptation or mitigation would also represent an inaction reaction.

5.2 Building renovation

Building renovation is typically promoted by national policy-makers, but implementing the strategy by paying out refurbishment subsidies or by enforcing building standards and the phasing-out of fossil fuel heating systems is allocated at the local governance level. Craftspeople for construction, plumbing and electrical systems are important intermediate actors who translate government guidelines into specific products and services they market to individual residents (Hecher et al. 2017).

According to **phase 1** of the SSIR framework, the system performance clearly highlighted the policy problem that the thermal performance of the existing housing stock was insufficient and that widespread refurbishment was necessary, including insulating walls and roofs, installing double- or triple-glazed windows or retrofitting fossil-fuel heating systems. National climate monitoring continued to report that current efforts did not comply with carbon emission reduction targets (Umweltbundesamt 2021). In parallel, repeated heat waves increased heat stress and morbidity, in particular among vulnerable groups such as the elderly or people with cardiovascular and respiratory diseases (Kjellstrom et al. 2016). Well-insulated residential housing provides the double benefit of reducing heating demand in winter and keeping the building interior cool in summer. Consequently, policy strategies in Austria, the focus country of this example, called for extended efforts in building renovation, in climate and energy strategies (BMWFJ and BMLFUW 2010, Bundeskanzleramt 2013) as well as in heat protection plans (BMLFUW 2012; City of Vienna 2015). The dominant **policy narrative** was that the public sector should incentivize the renovation of privately-owned buildings. In contrast to the construction of new buildings, where strict energy standards were mandated (OIB 2019), renovating existing buildings was voluntary. This stemmed from **policy beliefs** in market forces, on the one hand, arguing that the role of policy just lies in providing subsidies to shorten the amortization period of efficiency investments, and in the sanctity of private property, on the other hand, arguing that policy should not impose restrictions on private possessions that had already been taxed and approved.

Phase 2 commenced with the shock of the 2008 global financial crisis. This shock was sudden and disruptive, as most market actors had not anticipated when and how hard the crisis would hit across all economic sectors. The Austrian government implemented a subsidy program for building retrofitting, mainly to support the construction industry (Amann et al. 2014); thus, as the economy recovered, subsidy budgets were cut substantially after 2014 (Seebauer et al. 2019). The original strategy remained basically **unchanged**: Because of voluntary participation and funding rates of ca. 30% of total renovation costs, the implemented strategy mainly reached mid- to high-income homeowners who could afford upfront investment costs (Schleich 2019). Despite continued subsidy provision, the retrofitting rate is still below policy targets (Umweltbundesamt 2021). In 2021, the program was revised by offering a 100% funding rate to low-income households to provide equal access to the program; however, it is still only homeowners who may apply, even though most low-income households are tenants (Seebauer et al. 2021). A similar renovation subsidy program in Italy even offered a 110% funding rate (Governo Italiano 2020). A possible future emergent strategy could be the inclusion of innovations in building technology in the funding criteria, for instance offering higher subsidies if recyclable and locally produced insulation materials made from straw are used.

In Phase 3, the renovation subsidy program intersected with the motivations and perceptions of households and thereby induced specific individual reactions. The risk appraisal was low: At this time, heating costs did not heavily burden household incomes, and energy poverty rates were lower than in other European countries (Statistik Austria & E-Control 2021); heat waves were not considered a severe threat (Babcicky and Seebauer 2016). The coping appraisal for renovating one's home depended on available capital for covering upfront investment costs, ownership status, and replacement opportunities when the old fossil heating system broke down (Hecher et al. 2017). Thus, a frequent non-protective response was to shift the responsibility for renovation to landlords or housing associations. The implemented strategy may have led to different individual reactions which advance or hinder climate resilient outcomes: A transformation reaction would be retrofitting the entire building envelope, combined with a heat pump that also cools in summer and with façade greening or shading. Linking the renovation subsidy program with funding schemes for urban greening could incentivize this transformation reaction. A maladaptation reaction would be quick and partial insulation while retaining the old heating system, which is then overdimensioned for the reduced heating demand; since 2011, the Austrian subsidy program also funds partial retrofits, which may have unintentionally promoted this reaction. Other possible maladaptation reactions are installing a more fuel-efficient burner but still heating with oil or natural gas. Backfire reactions would be heating to warmer room temperatures because it is cheaper after the retrofit (Sorrell 2007), or taking the subsidy as a windfall profit when the home would have been remodeled anyway because of changed domestic needs (Wilson et al. 2015; Seebauer et al. 2019). Inaction reactions would be refraining from any structural improvement of the building and bearing the full brunt of climate change, heat waves, and energy prices. Another inaction reaction would be adopting only everyday behaviors for energy saving (e.g. dressing warmer rather than turning up the heating) or heat-adapted routines (e.g., shifting leisure activities to cooler daytimes); however, everyday behaviors are much less enduring and effective than structural modifications. Moreover, self-imposed austerity such as cutting heating to a bare minimum may hit vulnerable and marginalized households disproportionally (Eisfeld and Seebauer 2022).

6 Discussion and conclusions

The SSIR framework's added value is twofold: First, it highlights that governmental action can indeed shape and guide individual reactions, but only if strategies are designed to hold under different conditions and shocks. Second, it re-conceptualizes the role of shocks from mere policy windows to policy filters; in other words, that shocks do not just enable and accelerate, but create and modify actions by governments and households or businesses. The SSIR framework's target audience are researchers but also governance actors who strive to understand the factors that enable or prevent effective policy strategies for climate resilience of households and businesses when navigating the aftermath of shocks, for instance in exante or ex-post assessments of policy implementation, or when comparing case studies.

As the SSIR framework tracks policy strategies over the three phases of development, application, and impact, it raises research questions about how policy strategies evolve and function over time. First, the framework proposes that policy narratives persist throughout the process of deploying policy strategies and that these narratives continue to shape a strategy once it has been implemented. Research in this direction could retrace which narratives come to the fore at which critical points in a strategy's evolution (intended, emergent, unchanged, revised), why some narratives prevail over others, whether the predominant narratives affect the governance level responsible for the strategy, and whether traces of narratives are still recognizable once a strategy has been implemented and its activities and instruments have been adopted by households and businesses.

Second, the framework points to shocks as moments of change that convert intended strategies into implemented strategies, instigate revision, or introduce emergent aspects to the strategy. Shocks can affect intended strategies substantially, especially if the activities and instruments originally envisaged in the strategy cannot deliver an effective response and have to be amended on the fly. Research in this direction could disassemble policy strategies and analyze which of their functional parts are reframed and reoriented when they meet the harsh reality of managing the consequences of a shock. This research could detail whether the scope of a shock determines the governance level at which a strategy is implemented; for instance, lower governance levels could be expected to react faster because of lower coordination efforts.

A particular type of shock of interest in the SSIR framework could be 'run-up' shocks which are anticipated long before they happen and yet an adequate intended strategy is absent. Examples of run-up shocks in Western Europe are the widening discrepancies between trained workforce and demand in elderly care, between the employed adding to and the retired withdrawing from pension funds, or between teacher shortage and education needs. In these examples, reliable demographic data indicate when the system will eventually collapse, yet with only minimal intended strategies in place, in the moment of actual system collapse, a radical strategy will have to emerge. Research in this direction could compare the formation of emergent strategies in run-up versus unexpected shocks.

Third, the framework depicts individual reactions as the endpoint of the strategy process. How households or businesses cope with current and prepare for future shocks depends, inter alia, on the policy environment they live in. Policy strategies trickle down to individual reactions, past the filters of shock and implementation. Research in this direction could reconstruct how early policy beliefs and narratives remain as residue in implemented strategies and eventually guide individual reactions to a shock.

Due to its nature as a conceptual abstraction, the SSIR framework is inherently limited in representing the complex reality. For parsimony, the framework assumes a unidirectional causal sequence centered on a single policy problem, a single strategy, a single shock, and the motivations and reactions of a single group of individuals. In reality, however, there are continuous feedback loops between the different elements and between governance levels. Sustainability transitions involve multiple actors along multi-dimensional processes consisting of interdependent developments that happen (and even propagate each other) at a different pace and at niche, regime or landscape levels of socio-technical systems (Köhler et al. 2019; Herrfahrdt-Pähle et al. 2020). For instance, strategy implementation may boost or devalue specific policy narratives; policy evaluation after a shock may inform strategy development; social learning from coping with impacts and navigating institutional arrangements may lead to more sophisticated appraisals of and reactions to subsequent shocks; or widespread maladaptive reactions by individuals may degrade system performance. In practice, policy strategies do not stand alone but give overarching directions for a set of related problems and are parallel, complementary, or competing with other strategies on other governance levels in related policy domains. For instance, households and businesses may build political leverage already in the strategy development phase by means of grassroots initiatives and lobbying to push their preferred policy narratives and shape intended strategies. The impact of a shock on strategy implementation or the influence of an implemented strategy on individual reactions may be moderated by other sources of resilience that help households and businesses in dealing with the consequences of the shock, such as social cohesion and networks during and after a natural hazard event (Aldrich and Meyer 2014). Ongoing and recurrent events in system performance may be hard to disentangle from accumulated small shocks and make it difficult to define the onset, severity, and end of shocks.

Nevertheless, the SSIR framework may help in bringing the concept of climate resilient development pathways (CRDPs) into policy practice. Entering CRDPs requires transformational change in the policy narratives, policy beliefs and coalitions of the involved actors, the inclusion of currently underrepresented actors and contexts, and the provision of enabling governance conditions (Singh and Chudasama 2021; Stringer et al. 2022; IPCC 2022). Despite this grand scope, IPCC (2022), where CRDPs are most prominently discussed, emphasizes that there is no blueprint for how sustainability transformations are generated and remains vague how this fundamental change can be reached. However, IPCC (2022) highlights that CRDPs evolve from the process of actions and choices made by multiple actors. Here, the SSIR framework may step in as it argues for a process of strategy development that prepares policy solutions in anticipation of shocks, so that the recovery process, once the shock has occurred, reorients the system towards climate resilient development. However, IPCC (2022) is rather reluctant whether shocks may accelerate change faster than gradual shifts in everyday decisions and actions could. By contrast, the SSIR framework argues that shocks may allow switching to a more sustainable CRDP, but only if the necessary policy strategies have been prepared beforehand and are adapted accordingly during their implementation.

Thus, the SSIR framework may provide structure and directions for empirical research in the complexity of real-world climate resilient development and sustainability transitions. We would welcome empirical applications and theoretical amendments of the SSIR framework to expand on the aspect of policy coordination and integration. Cross-cutting policy problems, such as climate resilience at local to international levels, require more coordination and integration, but the policy strategies to be integrated need not move in a concerted manner but may develop at different paces or even in opposite directions (Candel and Biesbroek 2016). (Un)successful strategies could be assessed with regards to their degree of coordination – vertically by facilitating interactions between higher and lower governance levels (e.g., information flows, resource allocation), horizontally by producing agreements between actors at the same governance level who deal with specific aspects of the policy problem or are differently affected by the shock. Tracking how interrelated strategies evolve in parallel at multiple governance levels and to what extent they intersect when encountering specific shocks, could deepen our understanding of the dynamic development of policy strategies to reach transformative recovery.

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