https://doi.org/10.5194/nhess-2020-90
Preprint. Discussion started: 31 March 2020

Natural Hazards and Earth System Sciences
Open Access
Discussions

Review article: Towards a context-driven research: a state-of-the-art review of resilience research on climate change

Ringo Ossewaarde[1], Tatiana Filatova[2], Yola Georgiadou[3], Andreas Hartmann[4], Gül Özerol[5], Karin Pfeffer[6], Peter Stegmaier[7], Rene Torenvlied[8], Mascha van der Voort[9], Jord Warmink[10], Bas Borsje[11]

Correspondence to: Ringo Ossewaarde (m.r.r.ossewaarde@utwente.nl)

[1] Department of Public Administration, University of Twente, Enschede, Drienerlolaan 5, 7522NB, Netherlands

[2] Dept of Governance and Technology for Sustainability, University of Twente, Enschede, Drienerlolaan 5, 7522NB, Netherlands

[3] Department of Urban and Regional Planning and Geo-Information Management, University of Twente, Enschede, Hengelosestraat 99, 7514AE, Netherlands

[4] Department of Construction Management and Engineering, University of Twente, Enschede, Drienerlolaan 5, 7522NB, Netherlands.

[5] Dept of Governance and Technology for Sustainability, University of Twente, Enschede, Drienerlolaan 5, 7522NB, Netherlands

[6] Department of Urban and Regional Planning and Geo-Information Management, University of Twente, Enschede, Hengelosestraat 99, 7514AE, Netherlands.

[7] Department of Science, Technology and Policy Studies, University of Twente, Enschede, Drienerlolaan 5, 7522NB, Netherlands.

[8] Department of Public Administration, University of Twente, Enschede, Drienerlolaan 5, 7522NB, Netherlands.

[9] Department of Design Production and Management, University of Twente, Enschede, Drienerlolaan 5, 7522NB, Netherlands.

[10] Department of Water Engineering and Management, University of Twente, Enschede, Drienerlolaan 5, 7522NB, Netherlands.

[11] Department of Water Engineering and Management, University of Twente, Enschede, Drienerlolaan 5, 7522NB, Netherlands.

https://doi.org/10.5194/nhess-2020-90
Preprint. Discussion started: 31 March 2020

Natural Hazards and Earth System Sciences
Open Access
Discussions

Abstract

Since the 1970s, Holling's socio-ecological systems (SES) approach has been a most predominant theoretical force in resilience research in the context of the climate crisis. From Holling's approach, however, two contrasting scientific approaches to resilience have developed, namely, naturalism and constructivism. While naturalist resilience research takes SES as complex systems marked by non-linearity and evolutionary changes, constructivist resilience research focuses on the embeddedness of SES in heterogenous contexts. In naturalist resilience research resilience is defined as a system property, while in constructivist resilience research resilience is politically loaded and historically contingent. The aim of this paper is to review and structure current developments in resilience research in the field of climate change studies, in terms of the approaches, definitions, models and commitments that are typical for naturalism and constructivism; identify the key tension between naturalist and constructivist resilience research in terms of the widely discussed issue of adaptation and transformation, and discuss its implications for sustainable development; and propose a research agenda of topics distilled from the adaptation-transformation tension between naturalist and constructivist resilience research.

Keywords: adaptive resilience, climate change, constructivism, naturalism, SES, transformative resilience, transformational adaptation

1. Introduction

Since the publication of Crawford Stanley Holling's 'Resilience and Stability of Ecological Systems' (1973), the notion of resilience has become increasingly popular in a wide variety of scientific disciplines. Used as a concept, framework, style of thinking, metaphor or discourse, resilience appears

https://doi.org/10.5194/nhess-2020-90
Preprint. Discussion started: 31 March 2020

Natural Hazards and Earth System Sciences Discussions

attractive as a theme for interdisciplinary research, including the bridging of the social sciences and engineering (Thorén, 2014). For resilience research, Holling's socio-ecological systems (SES) approach has been widely adopted, and reinterpreted, as a lens that helps elucidate human-nature interactions (Ostrom, 2007). In the SES approach, which emerged in the 1970s, societies are thought to exist in continuous interaction with their surrounding natural, political, social, cultural, economic and technological environments. Hence, climate change is not merely ecological change, but is first of all a reformation of established modes of thought (including conceptualizations of 'nature' and 'society'), of lifestyles and consumer habits, of production patterns, of health issues, of law, economy, science, technology, governance and politics (the typical research topics for the social sciences) (cf. Douglous & Wildavsky, 1983; Blühdorn, 2013; Fischer, 2017; Dryzek & Pickering, 2019). The SES approach is adopted by the Resilience Alliance, whose flagship journal, *Ecology and Society* (established in 1995), provides a platform for SES-based resilience research. The SES approach has not only been popularized but also recast and incorporated in other theoretical approaches. In fact, in resilience research, SES is typically redefined as complex systems, that is, it is incorporated in the context of the complexity theory approaches. Since its development in the 1940s, complexity theory has been a widely adopted theoretical approach in the naturalist social sciences.

Since the Tsunami in 2004, Katrina (2005), the global economic crisis (2007-2008), Fukushima Daiichi (2011), and recent El Niño events, and increased urgencies of the climate crisis (and calls for climate action), the political, social, cultural, economic, scientific and technological contexts in which resilience research takes place have changed (Pizzo, 2015). Such climate disasters and crises have revealed that vulnerability is not a function solely of exposure to natural hazards, but it is a function of multiple dimensions of social, cultural, political and economic disadvantage (Tierney, 2015; Lockie, 2016). Since 2010, global governance actors and national and local governments – including the Rockefeller Foundation's 100 resilient cities program – have developed resilience discourses in which relationships between governments, citizens and denizens are being ideologically reconfigured. Such policy discourses of bouncing back after crises and catastrophes have triggered new resilience

https://doi.org/10.5194/nhess-2020-90
Preprint. Discussion started: 31 March 2020

Natural Hazards and Earth System Sciences
Discussions

practices, such 'resilience humanitarianism' based on the idea of crisis as a new normality (Hilhorst 2018). These policy discourses and practices have ignited new resilience research, new outlets (such as the interdisciplinary journal *Resilience* (established in 2013)), and the establishment of resilience research programs in universities around the world. With the increased scientific interest in resilience topics, scientific approaches to resilience rapidly diversify. Many publications of the past decade address the development of different definitions and understandings of resilience. Resilience research is no longer primarily naturalist. The naturalist approach to resilience is now balanced by constructivist scientific approaches that enrich resilience research. This is particularly so in the field of anthropogenic climate change, where fundamental changes in the governance of the earth system are urgently required, if extreme catastrophes and associated suffering and oppression are to be avoided (Redman, 2014; Yanarella & Levine, 2014; Lockie, 2016; Dryzek & Pickering, 2019).

The aim of this paper is to retrace the current directions of naturalist and constructivist resilience research – and thereby order contemporary debates in a diversified and rapidly changing field of resilience research –, ultimately to identify upcoming research themes for the coming years. First, current scientific approaches in resilience research are reconstructed in terms of the differences between naturalist and constructivist resilience research in the social sciences. While naturalist resilience research typically defines resilience to climate change as a physical property (like atoms, mass, molecules, cells, DNA, etc.) of complex systems, constructivist resilience research defines resilience as a political phenomenon that is historically embedded in a changing social, cultural, political, economic, scientific, technological environment. Naturalism and constructivism are presented as two scientific approaches with different epistemological and ontological assumptions, that, to advance resilience research to a next level, need to be bridged. Second, contemporary key issues of debate in naturalist and constructivist resilience research are identified. Ultimately, naturalist and constructivist resilience research clashes on the issue of system adaptation and transformation in a context of severe disturbances or shocks that come with climate change, such as hurricanes, floods, drought and heatwaves. The tension between adaptation and transformation has, amongst other things, implications for social scientific enquiry into the sustainable energy transformation, the relationship of resilience research to sustainability discourses, and the response of resilience research to new political and technological circumstances. Third, naturalist and constructivist directions for future resilience research are identified, including the bridging of naturalist and constructivist resilience research, with an emphasis on the likely impact of changing conditions – particularly in ecological, political and technological dimensions – on the questioning, theorizing, and modes of analysis in resilience research.

2. The diversification of resilience research

It has been widely noticed that resilience is a concept with various meanings. Resilience is a topic that, in European literature, is first encountered in one of Aesop's fables, with a tree bending to a strong wind and is thereby left unharmed. As an English word, resilience derives from Latin (*resilire*), which means rebounding. This Latin word can be found in Lucretius' *On the Nature of Things* and Cicero's *Orations* (Alexander, 2013; Pizzo, 2015). Up to the early nineteenth century, this is the predominant understanding of resilience in common language, until engineers come to employ the term to describe properties of materials and the capacity of materials to absorb stresses and release energy, and recover their original form, without breaking or disfiguring, after undergoing some external shock or disturbance, such as an extreme weather event (Estêvão, Calado & Capucha, 2017; Bergström, 2018; Davoudi, 2018). In the 1950s, psychologists turn to resilience to analyze the coping mechanisms of concentration camp survivors; later, the concept is used to study all sorts of trauma, misfortune, adversity, stress and mental recovery (Bourbeau, 2015; Estêvão, Calado & Capucha, 2017; Bergström, 2018; Schwartz, 2018). In the 1970s, the ecologist C.S. Holling (1973: 14) redefines resilience as 'a measure of the persistence of systems and their ability to absorb change and disturbance.' Holling

https://doi.org/10.5194/nhess-2020-90
Preprint. Discussion started: 31 March 2020

incorporates resilience in a socio-ecological systems (SES) approach to analyze the stability of ecological assemblages as conditioned by, and conditioning, societies. Hence, in Holling's work, resilience has a relational and systemic focus in scientific enquiries into how nature and society interact – a line of enquiry that brings the social sciences, the natural sciences and engineering together in an overarching SES framework (Alexander, 2013; Bergström, 2018; Béné et al, 2018; Hoekstra, Bredenhoff-Bijlsma & Krol, 2018). One could say today that a ubiquitous concept like resilience expresses a 'governmental philosophy of nature and society' (Walker & Cooper, 2011: 145), the ability par excellence to survive conflict and crisis.

In the social sciences, resilience research that has emerged from Holling's SES approach has developed in two contrasting directions. In resilience research, resilience to climate change can mean many different things – including a concept, metaphor, ideology, governing rationality, policy, etc. (Anderson, 2015) –, yet, the particular meaning of resilience that is enacted in resilience research is typically either naturalist or constructivist. Naturalism is a type of science that seeks to explain the world in the manner of the natural sciences, with the world being modelled as consisting of physical properties (Aiken, 2006; Floridi, 2017). Resilience is likewise defined as one of the system properties (Hoekstra, Bredenhoff-Bijlsma & Krol, 2018). In naturalist research, resilience is defined as a system property: resilience is an essential measure of the dynamic equilibrium or survivability of a socio-ecological system. By contrast, constructivism is a type of science that denaturalizes and historicizes, in the sense that it defines phenomena like resilience as a historically contingent social construct. It is focused on heterogenous contexts of natural and social science itself – contexts marked by diversity of (contested) knowledges, values, practices and meanings. It is more critical and politically sensitive. It typically expresses concern for issues of equity, domination, 'climate change gentrification' and 'climate apartheid' in resilience research. Its key concern and research focus is typically environmental and climate justice, which refer to (un)equal distribution of environmental burdens, struggles for recognition, claims to participation, and unequal impacts of anthropogenic climate change (Braun, 2014; Yanarella & Levine, 2014; Skillington, 2015; Sjöstedt, 2015; Weichselgartner & Kelman, 2015;

https://doi.org/10.5194/nhess-2020-90
Preprint. Discussion started: 31 March 2020

Pizzo, 2015; Lockie, 2016; Derickson, 2016; Lyster, 2017; Schlosberg, Collins & Niemeyer, 2017; Mummery & Mummery, 2019). Duffield (2016), for instance, refers to digital humanitarianism as a 'resilience of ruins'. Davoudi (2018: 5) introduces the notion of 'unjust resilience' (marked by the systematic neglect of marginalized people). And Glaser et al (2018: 3) refer to 'undesirable resilience', 'bad resilience' and 'wicked resilience'.

2.1. The naturalist view on resilience

Naturalist social research, which has its origins in the logical positivism of the Vienna Circle of the 1920s and 1930s, mainly developed in the context of the Cold War, with the development of cybernetics, computational power and automation (and automated decision making) (Simbirski, 2006; Floridi, 2017; 2018; Davoudi, 2018). Naturalist social studies are based on the cybernetic idea that machines, organisms and societies show considerable similarity in structure and function; and can be described in terms of (the metaphor of) systems. Since the 1940s, such studies have typically adopted complexity theory as their distinctive overarching theoretical outlook, within which other theories (for instance, on behavioral change, decision making under risk, or social institutions) are incorporated. In complexity theory, ecology and society are modelled as complex, non-linear, evolutionary systems. Such systems are composed of many components (properties, agents, resources, governance systems). And these components interact with each other, in response to ever-changing environments (Walsh-Dilley & Wolford, 2015; Juncos, 2017; 2018). Hence, resilience to climate change is a matter of evolution: in naturalist social science resilience is presented as 'evolutionary resilience' (Pizzo, 2015: 137; Davoudi, 2018: 4). When this type of science comes to embrace Holling's SES approach in the 1970s, it incorporates the notion of resilience within the context of its complexity theoretic orientation (Wiese, 2016; Bergström, 2018). The ability to cope with uncertainty and complexity is found in the capacities and relations between multiple agents that are able to interact and self-organize, learn and

https://doi.org/10.5194/nhess-2020-90
Preprint. Discussion started: 31 March 2020

Natural Hazards and Earth System Sciences
Open Access
EGU
Discussions

adapt (in an incremental or transformative way) making the system flexible in absorbing shocks and developing in face of changes (Jesse, Heinrichs & Kuchshinrichs, 2019).

Since the 1970s, when it emerged from mathematical sociology, agent-based modelling (ABM) is a much endorsed tool used in complexity-theoretic research for analyzing complex, non-linear interactions of autonomous yet interconnected (social and ecological) properties (Conte & Paolucci, 2014). ABM is a computational mode of analysis that simulates an artificial society of diverse agents – households, farmers, organizations, governments – making decisions, interact and learn in their ever-changing environment, according to programmable rules (Farmer & Foley, 2009). In naturalist resilience research, ABM is widely used for analyzing the interdependencies between agents, the nonlinear interactions between agents, and the emergent adaptive behavior that arises from these interactions (Hawes & Reed, 2006; Van Duinen et al, 2015; Martin & Schlüter, 2015; Sun, Stojadinovic & Sansavini, 2019). ABM computes, in probabilistic terms, the recovery process of complex non-linear systems under stress and tracks the emergence of new states (Filatova, Polhill & Van Ewijk, 2016). Resilience could be calculated at the system level as a system property using standard the resilience metrics (Pumpuni-Lenss, Blackburn & Garstenauer, 2017). Since ABM traces feedbacks between micro-macro scale explicitly, one could also estimate resilience of individual agents, communities or (sub)groups of agents.

2.2 The constructivist view on resilience

In constructivist social science, also inspired by Holling's approach, resilience to climate change presents itself as an object of scientific inquiry or guiding concept rather than as a system property (Walsh-Dilley & Wolford, 2015; Weichselgartner & Kelman, 2015; Kythreotis & Bristow, 2017). In constructivist resilience research, resilience is not researched within the framework of complexity theory. Instead, resilience, defined as a social construct, is studied from a variety of theoretical angles,

https://doi.org/10.5194/nhess-2020-90
Preprint. Discussion started: 31 March 2020

involving a variety of (typically phenomenological and discursive) ideational orientations. Constructivist resilience research focuses on the political context of resilience discourses, emphasizing that resilience to climate change is not so much technical as political and administrative in nature Alexander, 2013; Bourbeau, 2015; Boas & Rothe, 2016; Juncos, 2018; Wessel, 2019). Resilience is typically presented as a neoliberal construct of governments that fail to address the challenges that come with anthropogenic climate change and seek to shift responsibility (for pollution, safety, welfare, health, etc.) to individuals, limit legal entitlements (including human rights), and make individuals more self-reliant in coping with their own struggles in a market-dominated world (Braun, 2014; Pizzo, 2015; Tierney, 2015; Howell, 2015; Anderson, 2015; Ksenia et al, 2016; Schwartz, 2018; Davoudi, 2018). For instance, governments that fail to provide basic access to water to millions of rural citizens advocate for community-based water management schemes, the leading paradigm for rural water access in East Africa. Such schemes 'work' for the state (and donors) as a means of shifting (or offloading) responsibility for public service provision to the most vulnerable citizens for whom community management may not be a preferred option (Katomero & Georgiadou, 2018). From a critical constructivist viewpoint (typically inspired by the works of Michel Foucault), resilience as neoliberal discourse is analyzed as a phenomenon that reproduces power imbalances, domination, lawlessness, inadequate public services, and injustice. Evans and Reid (2013) accuse the perspective of resilience of the character of a doctrine, according to which the resilient subject must constantly adapt to a dangerous and changing world and is willing to accept this. Ecological and societal catastrophes like Katrina (2005) and Fukushima (2011) manifest such neo-liberalized resilience that is divorced from concerns of justice (Fainstein, 2014; Tierney, 2015; Ribault, 2019). Such costly catastrophes present themselves as 'anthropological shocks' (Beck (2015: 80), in the sense that they open up a new consciousness (Fazey et al, 2018). Katrina, for instance, is not only an ecological, economic and deadly disaster, but it is also a 'racial flood' that brings back colonial patterns of racism, slavery, vulnerability and abandonment; and it is an initiator of policy transformations.

https://doi.org/10.5194/nhess-2020-90
Preprint. Discussion started: 31 March 2020

Natural Hazards and Earth System Sciences
Discussions

Resilience to climate change is addressed in constructivist research as a problematic of governing (policy-making, regulating, administering, etc.) in a complex world that is marked by unequal power relationships and their neoliberal repercussions. In the past few years, various scholars have moved beyond the idea that resilience is a neoliberal construct marked. Chandler (2014), for instance, argues that resilience can be understood as a post-neoliberal construct. In resilience discourses, the art of governing is fundamentally reframed in recognition of the self-organization of systems – capacities of everyday democracy that are embedded in the relational, creative, reflexive and transformative capacities of stakeholders (Chandler, 2014; Boas & Rothe, 2016). In such self-organization, myth-making is key in constructing resilience, in the sense that a widely embraced narrative connects diverging ideologies, values, interests, worldviews and power relations. Resilience is one of those myths. The 'myth of resilience' (Kuhlicke, 2013) refers to the stories that stakeholders enact to make sense of the radically surprising discovery of something entirely unknown. As narrators, stakeholders interpret their own capacities to deal with stresses and shocks, such as extreme weather events in the form of floods, droughts and heatwaves. In many regions, these events occur with increasing frequency and intensity, exposing the stakeholders to unprecedented risks and uncertainties. It is in this context of sense-making process that stakeholders develop the capacity to adapt and transform. In other words, constructing resilience to climate change, as a form of self-organization, comes with myth-making, storytelling and narratives that unify diverse stakeholders. For instance, the increasing attention on "urban climate resilience" (Tyler and Moensch, 2012) resonates with the narrative that cities, or 'local governments', are to lead and shape climate change adaptation. This narrative and the associated process is conceptualized as 'responsibilization', the increasing legal and financial responsibility of local government, private companies and individual citizens in climate change adaptation (O'Hare et al., 2016; Klein et al., 2017).

3. Bridging the naturalist and constructivist view on resilience

Given the two scientific approaches in resilience research, each based on contrasting premises, it has been widely questioned whether resilience can possibly operate as a theoretical model or unifying paradigm – and whether such a unifying paradigm would be desirable in the first place (Alexander, 2013; Thorén, 2014; Bourbeau, 2015; Fainstein, 2015; Pizzo, 2015). Although a unifying paradigm is neither possible nor desirable, naturalist and constructivist research approaches must be bridged to enrich and renew our understandings of resilience – an enrichment and renewal of resilience research that is much-needed for responding to the ecological and societal challenges of anthropogenic climate change. Naturalist resilience research has the great merit that it may help to increase complex system's robustness to system failure when faced with shocks and disturbances. ABM may be a valuable tool for developing procedural stability, environmental risk management under conditions of uncertainty, provision of planning security, and prevention of adverse consequences from disruptive shocks (Schilling, Wyss & Binder, 2018). Constructivist resilience research has the great merit of providing a critical and most penetrating understanding of resilience as a political phenomenon that contains political intention and direction. Its interpretation of resilience to climate change as a social (political, ideological, mythical, discursive) construct is useful for generating understanding of how resilience is mobilized, taken up in climate governance, and resisted by social movements, such as the Fridays for Future and Extinction Rebellion, that push for less unsustainable trajectories.

3.1 The debate on adaptive and transformative resilience

In recent years, the dialectic between naturalism and constructivism in resilience research has come to revolve around the issue of adaptation and transformation (Chandler, 2014; Redman, 2014; Fainstein, 2014; Dahlberg et al, 2015; Sjöstedt, 2015; Boas & Rothe, 2016; Duit, 2016; Clément & Rivera, 2017; Lyster, 2017; Schlosberg, Collins & Niemeyer, 2017; Fazey et al, 2018; Glaser et al, 2018;

https://doi.org/10.5194/nhess-2020-90
Preprint. Discussion started: 31 March 2020

Hoekstra, Bredenhoff-Bijlsma & Krol, 2018; Jesse, Heinrichs & Kuchshinrichs, 2019; Dryzek & Pickering, 2019). It is an urgent issue that emerges from an ambiguity in Holling's SES approach (Redman, 2014). In the 1970s, Holling (1973) reinterprets resilience as bouncing back in terms of SES adaptation. SES adaptation refers, on the one hand, to the capacity of agents to influence the socio-ecological system (and influence or strengthen resilience as a system property). And on the other hand, it alludes to adaptation to new (ecological and social) environments, as an evolutionary process (Boyd et al, 2015). Naturalist social science typically focusses on the constant refinement of simulation tools (that can cope with radical complexity, uncertainty and multiplicity of agents) and techniques of administrative regulation in favour of adaptation as evolutionary resilience (cf. Cote & Nightingale, 2012; Patriarca et al, 2018). Yet, the bouncing back of SES not only refers to a return to some previous (dynamic) equilibrium or to the persistence and endurance of systems. It also refers to socio-ecological transformation in an ongoing process of non-equilibrium and instability and reinvention in changing environments (Folke, 2006). Transformation refers to the capacity of agents to create a new system, particularly when conditions make the existing system untenable or illegitimate. Constructivist resilience research is primarily focused on transformation. Such research unsettles taken-for-granted assumptions and definitions of the situation and ignites new imaginations needed for realizing less unsustainable futures (Fazey et al, 2018). In the recent notion of 'transformational adaptations' (Mummery & Mummery, 2019: 920; Pelling, O'Brien & Matyas, 2015), adaptation and transformation are reconciled. Transformational adaptations refer to changes that are aligned to the scale of projected, possible and desirable changes that are informed by (ultimately constructivist) considerations of environmental and climate justice.

The naturalist emphasis on resilience to climate change as system adaptation to climate change means that resilience research focusses on the degree to which systems can build capacity for learning, as a way to respond to shocks or disturbances, embrace evolutionary change, and live with complexity and uncertainty (Thorén, 2014; Juncos, 2017; Warmink et al, 2017; Béné et al, 2018). Warmink et al (2017) point out that in Dutch river management, uncertainty analysis typically complicates decision making, with typical adaptation responses being conservative and within safety margins. This leads to over-dimensioning and high costs of water engineering works (like flood defences). Given unpredictability and uncontrollability, adaptive resilience comes with short-term planning, uncertainty reductions, incremental and path-dependent changes (Borsje et al, 2011; Haasnoot et al, 2013). Adaptive resilience – the system's re-stabilizer – is taken as inherently positive, while disturbances and shocks (de-stabilizers) are taken as negative (Duit, 2016; Lockie, 2016). As a consequence of the near flood events of 1993 and 1995 along the river Rhine in the Netherlands, the Dutch government responded by increasing the flood conveyance capacity of the large rivers, thereby decreasing flood water levels (Hamers et al, 2015). Since its completion in 2015, the Room for the River project is considered effective thus far, particularly as its secondary objective to increase ecosystem values in the river appears successful.

It is on the basis of the premise that adaptive resilience is good that naturalist resilience research ties up with climate risk management, as a way of managing ecosystem services (critical for survival), under conditions of ecological and societal shocks and disturbances (Boyd et al, 2015; Berbés-Blázquez et al, 2017). The constructivist emphasis on resilience to climate change as system transformation refers to the emergent transformation of systems into something new (Rothe, 2017; Béné et al, 2018). Transformative resilience is typically defined as the system's internal capacities, capabilities and relations that enables it to create a new condition in which responsibilities may be shifted. Flood protection, for instance, is typically a governmental responsibility, but with new storytelling stakeholders can transform an established situation and realize alternative scenario's in which responsibilities may be distributed among different stakeholders (Warmink et al., 2017). Adaptive resilience comes with evolutionary change (the definition of change that naturalist research typically endorses), whereas transformative resilience comes with 'metamorphosis', that is, a transfiguration of culture that is triggered by the shocks and disturbances that come with radical newness and reinventions, reassessments and rediscoveries (Beck, 2015; Fazey et al, 2018). Transformational adaptation bridges evolutionary change and metamorphosis, in the sense that such

https://doi.org/10.5194/nhess-2020-90
Preprint. Discussion started: 31 March 2020

Natural Hazards and Earth System Sciences
Open Access
Discussions

adaptation attends to broader socio-political processes of transformation. The argument for transformational adaptation is that the ecological and societal challenges of climate change are unprecedented in scale and intensity and come with new risks and locations of activities (Kates, Travis & Wilbanks, 2012). The notion of transformational adaptation picks up on and challenges the transformative logic of system transfiguration with simultaneous system adaptation, based on uncertainty regarding how fast and how far disruptions will go – or whether sustainable transformations will thrive as political projects at all.

Although constructivist social science manifests a higher degree of sensitivity to issues of environmental and climate justice in a current oppressive situation that is marked by high degrees of injustice, naturalist resilience research does not exclude considerations of justice. On the contrary, enhancing adaptive resilience to climate change may entail liberal principles of equity, fairness and access to resources and services, so as not to privilege or marginalize certain stakeholders (Redman, 2014; Thorén, 2014; Ksenia et al, 2016; Schlosberg, Collins & Niemeyer, 2017; Bergström, 2018). Yet, naturalist enquiry into adaptive resilience leaves the status quo of systems, including the problematic Global North-Global South relationship (marked by massive power inequality), typically unquestioned. It tends to treat adaptive resilience as a technical property that is devoid of political and moral substance (Swyngedouw, 2011; Pizzo, 2015; Clément & Rivera, 2017; Davoudi, 2018; Glaser et al, 2018; Dryzek & Pickering, 2019). In constructivist resilience research the justice question is placed in a context of broader socio-political processes of transformation: adaptive systems can be unjust and oppressive (Fainstein, 2014; Weichselgartner and Kelman, 2015; Huang, Boranbay-Akan and Huang, 2016; McGreavy, 2016; Ribault, 2019). Short-term, incremental, adaptive response to shocks and disturbances may blur long term sustainability vision, while dominant (or dominating) stakeholders typically reify existing climate policy efforts in their (standardized) adaptive responses (Lockie, 2016; Derickson, 2016; Rothe, 2017; Estêvão, Calado and Capucha, 2017; Ribault, 2019). Kythreotis & Bristow (2017) call this phenomenon the ‘resilience trap’ – the reinforcement of established power relations and contemporary resilience discourse (Blühdorn, 2013; Redman, 2014; Yanarella & Levine, 2014;

https://doi.org/10.5194/nhess-2020-90
Preprint. Discussion started: 31 March 2020

Lockie, 2016; VanderPlaat, 2016; Schilling, Wyss & Binder, 2018; Glaser et al, 2018; Ribault, 2019). Transformational adaptation, accordingly, must include a process of filtering out resilience traps that come with adaptive resilience. Transformational adaptation includes the constructivist understanding that adaptive resilience to climate change may well enforce a governance of unsustainability (cf. Van de Ven, 2017).

3.2 Transformative resilience and sustainability

In constructivist resilience research, the notion of sustainability is transformative. Sustainability is based on the idea that existing systems can be transformed – with respect to social, cultural, political, administrative, economic, technological and environmental factors –, with the right governance interventions and reconfigurations of the ecological and social underpinnings of SES (Pizzo, 2015; Weichselgartner & Kelman, 2015; VanderPlaat, 2016; Hughes, 2017; Jesse, Heinrichs & Kuchshinrichs, 2019). Currently, the sustainable energy transformation is no doubt the best example of such a reconfiguration (Park et al, 2012; De Haan & Rotmans, 2018). Fossil energy sources like coal, oil and gas are largely responsible for carbon dioxide emissions, which generate global warming. The sustainable energy transformation, accordingly, is, amongst other things, a response to climate change. From the (typically naturalist) perspective of strengthening 'energy resilience' (Béné et al, 2018: 120; Jesse, Heinrichs & Kuchshinrichs, 2019: 21) – energy systems must adapt to changing environments in which high levels of greenhouse gas emissions comes from burning fossil fuels for electricity, heat and transportation. Energy resilience means that energy systems can limit the risk of power outage and continue providing reliable energy supplies at stable costs, even in a turbulent ecological and political environment (Wiese, 2016). The notion of energy resilience, as a form of adaptive resilience to climate change, implies that the energy transition, including the use of renewables, can only go via incremental changes, to avoid system collapse (Berbés-Blázquez et al,

https://doi.org/10.5194/nhess-2020-90
Preprint. Discussion started: 31 March 2020

Natural Hazards and Earth System Sciences
Open Access
EGU
Discussions

2017; Schilling, Wyss & Binder, 2018). Transformational adaptation includes this notion of energy resilience, but aligns it to the scale of desirable ecological and societal changes that are informed by justice considerations and political direction towards less unsustainable futures.

From the (typically constructivist) perspective of strengthening transformative resilience, energy resilience comes with the enactment of an energy political status quo. This is a status quo that includes powerful agents that have a vested interest in promoting fossil energy – and it uses all sorts of tactics (including sponsoring the climate change denial movement) – to secure its power position (Stegemann & Ossewaarde, 2018; Szablowski & Campbell, 2019). It is an energy political constellation that enacts a condition of 'energy injustice', particularly in the Global South. The notion of energy injustice refers to current energy systems that distribute the ecological and economic benefits and burdens of energy systems in unfair ways; dominate, degrade and devalue certain stakeholders; and exclude certain agents from processes that govern the benefits, burdens and recognitions (Jenkins et al, 2016; Heffron & McCauley, 2017). The transformative resilience of energy systems, which is tied up with the notion of 'energy justice', refers to agents' negation of a fossil-based energy system and its oligarchical power structure; and the creation of a renewable-based system, energy commons and collaboratives beyond the energy establishment (Acosta et al, 2018; Jesse, Heinrichs & Kuchshinrichs, 2019). In other words, the sustainable energy transformation comes with transformative resilience and energy justice that typically assumes the form of resistance to the most hegemonic powers (VanderPlaat, 2016; Bourbeau & Ryan, 2018; Juncos, 2018; Schwartz, 2018). Transformational adaptation includes the long-term vision of energy governance, but it searches for realizing such transformation through adaptations by the status quo. Transformational adaptation means that the sustainable energy transformation comes with the change of the energy establishment into agents of sustainability – a change that comes from within the power complex, for instance, via stakeholder participation.

Adaptive resilience to climate change comes with short-term systematic adjustments to a changing technological environment that is currently increasingly dominated by smart urbanism and

https://doi.org/10.5194/nhess-2020-90
Preprint. Discussion started: 31 March 2020

Natural Hazards and Earth System Sciences
Open Access
Discussions

artificial intelligence (AI) technologies. Such technologies reshape systems and their ecological and societal environments (cf. Taddeo & Floridi, 2018). Particularly in naturalist resilience research, AI is identified as a new systems property that permeates systems to generate productivity gains, improve efficiency, lower costs, predict climate change stress, track carbon emissions, monitor flood risks, etc. (Rajan & Saffiotti, 2017; Khakurel et al, 2018; Vahedifard, et al, 2019; Miller, 2019; Saravi et al, 2019). Strengthening adaptive resilience to climate change through AI primarily means that an integrated data system for circulating information among agents needs to be developed. In an AI technological environment, resilience implies close collaboration between agents (data stakeholders, community-level stakeholders, state-level institutions, etc.) (Vahedifard, et al, 2019). AI comes in both for converting datasets into usable information and as a monitoring method (like change detection algorithms). Identifying, harnessing, synthesizing, and communicating pertinent yet unstructured data (weather data, cell phone GPS data, social media feeds, traffic cameras, smart city sensors, images, videos, audio data, etc.) enables agents to better forecast, prepare for, respond to, and recover from disturbances and shocks (Rajan & Saffiotti, 2017; Vahedifard et al, 2019). By being able to predict (estimate or forecast) more accurately and learn from past disturbances and shocks, lessons can be learned and applied in building adaptive resilience against disturbances (Saravi et al, 2019). AI quantifies the probabilities of occurrence of extreme events, essential in predicting and preparing for future natural hazards, such as floods. For instance, with advances in machine learning, water availability, ice surfaces and melting rates, pollution, deforestation, etc. can be more precisely or smartly monitored so that changes over time can be tracked. Yet, with monitoring also learning of agents and organizations is needed.

More specifically, strengthened adaptive resilience typically weakens the transformative resilience that is needed for materializing sustainable transformations (Khakurel et al, 2018[illegible] constructivist resilience research, it is typically emphasized that AI, like resilience, not only has a positive impact on sustainable trajectories, but also enacts resilience traps (typically via adapting and rebadging existing short-term strategies) and enforces injustice and unsustainability (for instance, via

https://doi.org/10.5194/nhess-2020-90
Preprint. Discussion started: 31 March 2020

massive energy usage and the production of electronic waste). Big data and AI are typically in the hands of giant tech oligarchs like Google, Amazon, Apple, Microsoft, Facebook and Chinese forces (Miller, 2019), that, like the oil barons, are established powers that have a vested interest in the further acceleration and consumption of technological devices (Khakurel et al, 2018). Given such an oligarchical power structure, AI typically tends to obstruct transformative resilience exerting power beyond rule of law and democratic will and understanding (as found in the many recent privacy rights violations, scandals (like the Facebook-Cambridge Analytica data scandal (2018), the many Google scandals, etc.), and mistrust of new technologies). Given such problematic power structures, AI thereby weakens transformative resilience (cf. Taddeo & Floridi, 2018). In other words, from the critical angle of constructivist resilience research, AI typically comes with unjust resilience and tends to close down alternative futures. Transformative resilience to climate change, accordingly, comes with resistance to big tech firms and their handling of data and digital surveillance and domination of vulnerable people. Reconciling adaptive and transformative resilience – in the form transformational adaptation – comes with the change of big tech firms from within the oligarchical complex, with AI redesigned and politically (democratically or technocratically) controlled for the making of less unsustainable futures.

4. Six upcoming themes in diversified resilience research

The diversification of resilience research and the tension between, and the reconciliation of, naturalism and construction in theorizing (and, in their practical implications, pushing for) change as adaptation, transformation or transformational adaptation triggers new research themes for the study of anthropogenic climate change. Theorizing change has become the key issue in resilience research, in the wake of changing political, ecological and technological environments. In naturalist research, resilience to climate change is presented as 'evolutionary resilience' and as 'adaptive resilience', with

https://doi.org/10.5194/nhess-2020-90
Preprint. Discussion started: 31 March 2020

Natural Hazards and Earth System Sciences Discussions

the key issue of changing environments being the survivability of complex systems under stress. Change is, accordingly, evolutionary change. In constructivist research, resilience to climate change is presented as mythical (the 'myth of resilience') and as transformative resilience, with the key issue of change being the overcoming of 'resilience to change', 'resilience traps' and 'unjust resilience' or 'bad resilience'. Such overcoming is presented as an indispensable condition for enhancing change. Such change refers to metamorphosis and comes with transformative politics and governance. The reconciliation of naturalism and constructivism in terms of change can be found in the notion of transformational adaptation, which ties incrementalism to long term sustainability visions. It is a notion that comes with the search for the conditions and tempo of transformations in different ecological and societal contexts. Ultimately, the overarching challenge for future research is to ensure that resilience to climate change does not compromise sustainability and considerations of justice.

A first promising direction for future resilience research that emerges from the diversification of resilience research concerns the reconciliation of naturalism and constructivism. Resilience cannot operate as a theoretical model or unifying paradigm, given that naturalism and constructivism are grounded in contrasting epistemological and ontological assumptions; and reflect contrasting scientific universes and manifest different scientific and political commitments (Mummery & Mummery, 2019). Yet, as a metaphor resilience provides a sound basis for reconciling types of science, mainly because of its heterogeneity and high level of abstraction (Thorén, 2014). Intellectually, the reconciling of naturalism and constructivism implies an appreciation of diverse scientific vocabularies, many visions of what counts as scientific knowledge, other sciences' scientific worlds, a certain embracing (which includes making manifest) of the tensions between the contrasting types of science, and creating spaces for constructive contestation (Pfeffer & Georgiadou, 2019). Thereby, new resilience perspectives may develop. New questions may be posed (or new answers to long-standing questions may be provided). The resilience trap – typically marked by the promotion of adaptive strategies that reify responses and corresponding power structures in the short-term – may be avoided (via challenging current assumptions underpinning resilience research). Current adaptation and

https://doi.org/10.5194/nhess-2020-90
Preprint. Discussion started: 31 March 2020

transformation and transformational adaptation approaches may be further refined. And much-needed new ways of scientific thinking and possibilities may be opened up in resilience research, beyond old conceptualizations and modes of analyses (cf. Fazey et al, 2018). These developments ask for new collaboration frameworks and platforms that empower all types of stakeholders to bring both their resilience research questions and their assets to the table to collectively explore and define potential futures from the perspective of all present world views.

A second theme for future resilience research comes with a change in political environment, in which the legitimacy of adaptive, transformative and transformational adaptive responses to climate change is constantly contested. Anthropogenic climate change comes with a political-administrative crisis, which manifests itself in the form of a legitimacy crisis, authority crisis (including the crisis of scientific authority), crisis of democracy, a crisis of human rights, a crisis of modernity (Swyngedouw, 2011; Blühdorn, 2013; Fischer, 2017; Ossewaarde, 2018; Stegemann & Ossewaarde, 2018; Dryzek & Pickering, 2019). Crisis has been widely constructed as the new normal (Hilhorst, 2018). In an increasingly toxic political environment – marked by climate change denial, anti-immigration policies, and nationalist protectionism – adaptive and transformative resilience and transformational adaptation may be expressed and contested in manifold ways. For instance, on the one hand, environmental protest movements are stakeholders that develop a leverage required to change established systems (such as energy systems) and their governance arrangements, while on the other hand agents who gain power by such arrangements typically use tactics of repression and criminalization, particularly in the extractive sectors of the Global South (Szablowski & Campbell, 2019). New research questions emerge on the one hand from polarization and the exercise of (il)legitimate power in the governing of and for resilience to climate change. This is the question of how the adaptation and reconfiguration of systems under pressures of climate change comes with power inequalities, polarization, battle for resources, democratic deficits and post-democratic tendencies, climate change denial tactics, attacks on legal rights, climate injustice, and the resilient governance of unsustainability. To put it in more positive terms, urgent questions concern the

https://doi.org/10.5194/nhess-2020-90
Preprint. Discussion started: 31 March 2020

meanings of transformation, the theorization of transformation in terms of just resilience, the linkage of resilience to desirable futures, the development of a transformation agenda in participative, proactive and deliberative ways, and the comparison of different administrative capacities and new governance arrangements that explain differences in system adaptation and reconfiguration (cf. Blühdorn, 2013; Fischer, 2017; Davoudi, 2018; Köhler et al, 2019; Mummery & Mummery, 2019).

A third promising topic for future resilience research concerns the relationship between adaptive resilience and transformative resilience and transformational adaptation in the reactive and proactive governance responses to anthropogenic climate (Clément & Rivera, 2017). In the coming decade, questions like how adaptive and transformative resilience to climate change is strengthened or weakened; how the current performance of systems when it comes to responding to possible disturbance (for instance, through the use of monitoring systems) can be better understood; how unjust resilience can be disabled; and how transformational adaptation manifests itself (how multiple adaptations may lead to transformational adaptation and what are the tipping points for igniting transformation), become urgent ones for resilience research (Grove & Chandler, 2017; Glaser et al, 2018). The notion of 'tentative governance' appears particularly relevant in the context of transformational politics, when it comes to phasing out systems and weakening adaptive resilience. Tentative governance is marked by interventions that are designed as preliminary rather than as persistent, for purposes of probing and learning rather than for stipulating definite targets or fixating existing systems and their underlying assumptions (Kuhlmann, Stegmaier & Konrad, 2019). It is likely that stakeholder engagement in transformational politics and tentative governance varies, and manifests itself differently, across different policy fields. For instance, the sustainable energy transformation may include multi-layer governance challenges, many pro-active stakeholders, new investment opportunities and job opportunities. Given that multiple public and private actors are responsible for the performance of different parts of a system, tentative governance comes with transformational adaptations that must be arranged. Hence arises the question which adaptations allow for transformation? Sea level rise and the disruption and relocation of coastal cities, by contrast,

https://doi.org/10.5194/nhess-2020-90
Preprint. Discussion started: 31 March 2020

Natural Hazards and Earth System Sciences
Open Access
EGU
Discussions

may trigger a more limited transformative politics, despite inevitable transfiguration of systems due to shocks and disturbances (metamorphosis). Yet, in the coming decade, transformational politics and tentative governance – including anthropogenic topics like population displacement, privatization of climate adaptation, conflict organized around scarce resources (like water resources), intergenerational environmental conflict, and the closing of old infrastructures that are too costly to maintain – becomes a more urgent research topic.

A fourth topic for future resilience research concerns the relationship between phasing out of unsustainable systems and societal transformations. The sustainable energy transformation is a most obvious phasing out of old systems (like coal energy systems) and change of worldviews, middle class values, lifestyles, etc. towards new energy systems, given that burning fossil fuels has such a major impact on climate change. Adaptative and transformational responses to climate change are intermingled with responses to other societal and ecological developments. Hence, a response like investment in transportation systems that aims to address increasing transportation demand must accordingly include possible climate change impacts. In the Anthropocene epoch, systems typically face pressures to change, to establish new (less unsustainable) interactions between society and ecology. Pressures on existing systems – typically those that are marked by unjust resilience and resilience traps (like established energy systems) – not only emerge from ecological adversity, over-exploitation, resource depletion, etc., but particularly from new ways of thinking, new lifestyles, new contestations (like the Fridays for Future, the Anti-Mining, the Transition Towns and Degrowth movements), etc. At the same time, anthropogenic climate change comes with the development of a multi-trillion market of the emerging climate economy, which proves new climate investment opportunities. Given such societal pressures and opportunities, new research topics include the governing and accelerating of the decline of existing systems (Stegmaier, Visser & Kuhlmann, 2014; Hoffmann, Weyer & Longen, 2017; Stegmaier, Visser & Kuhlmann, 2020); the particular circumstances in which accelerations can manifest themselves; the identification of, and coping with, uncertainties in processes of adaptation and transfiguration and transformational adaptation; and the construction of new incentive structures, for accelerating sustainable transformation (cf. Clément & Rivera, 2017; Warmink et al, 2017; Köhler et al, 2019). This branch of discontinuation research assumes that socio-technical systems influence socio-ecological systems, so that some technologies threaten resilience while others enhance it (Smith & Stirling 2010). Such research informs that political objectives like drastic reduction of CO2 emissions will hardly be achieved by using single cleaner technologies alone, but structural SES transformations are needed to qualitatively alter established systems (Vögele, Kunz, Rübbelke & Stahlke 2018; Rogge & Johnston, 2017; Stegmaier 2019). One of the challenges for the coming decade is to reverse the negative image of climate change: transformational adaptation comes with stakeholders taking a pro-active view on climate change, with new opportunities emerging from responses to climate change. How can climate change be regarded as an opportunity rather than as a risk in the governance of transformational adaptation to climate change?

A fifth theme for future resilience research concerns the role of environmental, energy and climate justice in theorizing, modeling, interpreting and explaining resilience to climate change (cf. Skillington, 2015; Fazey et al, 2018; Mummery & Mummery, 2019). For future research, theories of environmental justice, energy justice and climate justice, that is, theoretical insights on (un)equal distribution of environmental and social burdens, struggles for recognition, claims to participation, and unequal impacts of climate change, can be conducive to helping furthering comprehension of adaptive and transformative resilience and transformational adaptation. How can justice claims be made more responsive to newly unfolding ecological and societal circumstances and uncertainties? How can principles of equity, fairness and access to resources and services be secured in a toxic political environment? And how can – in the problematic context of climate-induced migration and a political environment marked by anti-immigration policies – the wellbeing of migrants be ensured? Theories of environmental, energy and climate justice are also highly relevant for developing understanding of how adaptive and transformative resilience and transformational adaptation are perceived and experienced in everyday life by different stakeholders that face anthropogenic challenges. Constructivist enquiry into perceptions, experiences and prioritizations of resilience is a promising

https://doi.org/10.5194/nhess-2020-90
Preprint. Discussion started: 31 March 2020

Natural Hazards and Earth System Sciences
Open Access
EGU
Discussions

topic for future resilience research. In this regard, insurance decisions of citizens against the risks associated with climate extremes can gain further research attention. As addressed by O'Hare et al. (2016), citizens are faced with an increasing responsibility to make decisions to 'insure' themselves and their assets against the possible damages of climate change. Such decisions can have diverse justice implications in different political and economic contexts that influence how citizens perceive, experience and prioritize climate risks. Similarly, the cross-sectional dimensions of justice, particularly gender relations, is becoming increasingly relevant and yet challenging to understand and integrate into climate justice (Terry, 2009), and energy justice (Feenstra and Özerol, 2018) frameworks. And in the Global South, addressing issues of corruption, violence, poverty and lack of access to resources (and violent battles for resources) and services (like education and sanitation), and treatment of nature as a sacred entity (rather than as an economic resource), may have a higher priority than global environmental considerations (Köhler et al, 2019).

A sixth theme for future resilience research comes with a changing (geo)technological environment, that is, the so-called 'AI revolution' in the making. Given worldwide investments and top-down AI strategies that global governance actors and national governments have recently published, AI will most plausibly become a major force that shapes adaptive and transformative resilience to climate change by means of monitoring and learning. A relevant example of big data is the G-Earth Engine, which opens up an unprecedented dataset of satellite images for scientific research. Such extensive datasets, marked by high temporal resolution, are essential for monitoring a changing earth system. In the past decade, resilience discourses have increasingly incorporated phenomena like big data, AI, cybersecurity and smart city; in the coming decade, resilience discourses may increasingly become technology discourses. New interplays between automation, (un)sustainability, and adapting and transforming systems trigger new questions for future resilience research (cf. Köhler et al, 2019). For instance, in the near future, not only the number of climate disasters is expected to rise but also the data – satellite data, drone data, sensor data, social media data, volunteer geographic information (VGI) data, Internet of Things data, etc. – available on such disasters is expected to increase in size,

https://doi.org/10.5194/nhess-2020-90
Preprint. Discussion started: 31 March 2020

amounting to vast volumes of climate disaster data. However, AI, due to the unstructured nature of input data, may omit those phenomena, places and social groups that are not present in the data (Hoefsloot et al. 2019). Alternative ways of knowing can refine or contribute complementary insights to the precise measurements and data gaps (Pfeffer and Georgiadou 2019). New research questions for naturalist and constructivist research emerge from challenges of organizing big data and how to make it available and usable, given the variety of public and private stakeholders, workflows and incentive structures involved in the (social) construction of big data (Wright, 2016). How can AI be augmented with alternative ways of knowing to strengthen adaptive/transformative resilience? How to incorporate the socio-spatial dimension in resilience research, in order to pronounce the different capabilities of different groups and places? And what role can AI play in creating a dialogue between the naturalist and constructivist resilience research? In the coming years, AI tools – mainly tracking (for instance, tracking of deforestation tracking or energy/water consumption) and machine learning techniques – are expected to be widely used, among other things, for detecting and predicting how climate disasters probably develop, for locating areas or communities at risk, for analyzing the consequences of climate disasters, and for assisting in climate disaster responses. Working with AI for purposes of learning from data – for instance, via the use of data mining or deep learning techniques for dissecting patterns in satellite images – comes with the design of procedures for data analytics, forecasting and intervention (Rodríguez-González, Zanin & Menasalvas-Ruiz, 2019) and requires domain and local knowledge as well as a dialogue between naturalist and constructivist researchers. In contrast to the official national statistics of the past, which diffused societal controversies, big data analytics create a myriad parallel realities, stand in the way of achieving a minimal consensus about basic facts and amplify controversies. In sum, next to technologization of resilience discourses, social processes of big data construction, the inclusion and exclusion of diverse stakeholders, the embeddedness of AI in everyday practices, the various uses of AI in the exploitation of data as well as the integration and inclusion of alternative knowledges are promising fields of resilience research.

https://doi.org/10.5194/nhess-2020-90
Preprint. Discussion started: 31 March 2020

In the coming decade, several AI challenges are most likely to increasingly come to the fore in resilience research. First, monitoring systems (for instance, monitoring the status and behavior of infrastructure or human settlement dynamics) that incorporate machine learning make that systems are automatically checked rather than regularly inspected by experts. When AI is integrated with knowledge of how systems work, expertise is outsourced to AI, which implies that expert knowledge may get lost or become obsolete. Moreover, AI classifications may have unintended consequences for certain places or communities. For example, by labelling areas at risks, property prices may go down or insurance agencies are not willing to provide an insurance certificate. Second, the digitalization of SES makes systems vulnerable to, for instance, breakdowns, power outages and cyberattacks – hence resilience strategies and digital strategies are intertwined (Wessel, 2019). 'Digital resilience' has recently become a key concept in resilience research that refers to strengthening resilience of digital systems to potential cyberattacks, including the adaptive capacity to respond to such attacks (Wright, 2016). The making of digital resilience typically implies bringing in tech firms for the protection of SES, whose algorithms are typically opaque. Third, because of the reliance on AI and associated data, other realities are neglected, excluding certain places or communities from digital resilience strategies. Fourth, AI systems facilitate governing at a distance, with governing becoming more invisible and possibly unaccountable. For instance, when disaster management (for instance, in the context of an extreme weather event) becomes 'digital humanitarianism', the distance between the saviors and survivors becomes big, with survivors becoming reified abstract entities that inspire limited empathy. In fact, survivors are confronted with the risks of AI systems, in terms of privacy breaches and identity frauds. In other words, while AI is expected to become a key theme in resilience research, a promising topic for future resilience research concerns the challenge of uncovering resilience traps and neutralizing the ecological and societal damage and injustice done through the reinforcement of AI technologies in governance processes like digitally-based service provision or humanitarian interventions in the Global South.

https://doi.org/10.5194/nhess-2020-90
Preprint. Discussion started: 31 March 2020

5. Conclusion

In the social sciences, resilience to climate change is a concept that is incorporated in different theoretical approaches that are linked to contrasting types of science. Holling originally reinterpreted and incorporated resilience in a SES approach, which was then picked up by naturalist scientists who incorporated Holling's reinterpretation of resilience in cybernetic complexity theory. The naturalist complexity theoretic approach to resilience as system adaption was dominant in the social sciences, until the ecological and political context of resilience research changed. When actors at global, national and local governance levels drafted their resilience policies in the wake of socio-ecological catastrophes, financial crises, climate crises, governance failures and the breakdown of infrastructures, constructivist approach developed to take resilience research far beyond complexity theory. And it introduced a variety of new concepts for resilience research, such as the myth of resilience, just resilience, resilience trap, transformative resilience and transformational adaptation. Resilience cannot operate as a unifying paradigm, given that naturalism and constructivism are grounded in different epistemological and ontological assumptions, definitions of what counts as scientific knowledge, and definitions of change (evolutionary change and metamorphosis). But resilience can facilitate the reconciliation of naturalism and constructivism, so that the two types of science can provide a liberating perspective on each other (without the one repressing the other) and brought into a theory-energizing tension with each other. The urgent challenges that come with anthropogenic climate change – which may potentially cause extreme degrees of human misery in the coming decades –, necessitate the reconciliation of naturalist and constructivist resilience research. Such reconciling – igniting theory-energizing tension – is needed for reimagining resilience to climate change which is needed for specifying how new political-administrative institutions and practices can respond

https://doi.org/10.5194/nhess-2020-90
Preprint. Discussion started: 31 March 2020

in legitimate ways (taken justice considerations into account) to the challenges of climate change, in different ecological, political and technological contexts (cf. Johnsson et al., 2018).

Given the development of resilience research in the past decade, with the rise of constructivist resilience research and its reconciliation with naturalism, the key issue in resilience research concerns the political response in the form of adaptation, transformation and transformational adaptation in newly unfolding environments. The six resilience themes for the coming decade that this paper has identified are all connected to the issue of the political-administrative response to the challenges that come with anthropogenic climate change. A first theme concerns the reconciliation of naturalism and constructivism, to be able to move beyond established assumptions, theories, concepts and modes of analysis; and to trigger new imaginations to be able to create new, theory-rich, resilience perspectives. A second theme is the legitimacy of the political response in a toxic political environment, in which top-down and bottom up responses, including new governance arrangements and system reconfigurations, may suffer from legitimacy deficits. A third theme is how, in a toxic political environment, adaptation, transformation and transformational adaptation can be materialized; and under which conditions are such governance responses enough for addressing climate change challenges. A fourth theme is how systems are under pressure due to climate change, ultimately igniting a phasing out of systems and a departure from consumerist lifestyles, values and assumptions. A fifth theme is how governance responses can be made legitimate, by incorporating considerations of environmental and climate and energy justice – thereby strictly connecting resilience to justice considerations. A sixth theme is how AI comes to intermingle with resilience: what is its role in political-administrative responses to challenges that come with climate change? And, correspondingly, what are the undesired consequences that come with AI, when it comes to responding to climate change. How does AI enact existing power structures, thereby reinforcing resilience traps?

https://doi.org/10.5194/nhess-2020-90
Preprint. Discussion started: 31 March 2020

References

Aiken, S.F. (2006) 'Pragmatism, Naturalism, and Phenomenology', *Human Studies* 29: 317-340.

Acosta, C., M. Ortega, T. Bunsen, B.P. Koirala & A. Ghorbani (2018) 'Facilitating energy transition through energy commons: an application of socio-ecological systems framework for integrated community energy systems', *Sustainability* 10: 366.

Alexander, D.E. (2013) 'Resilience and disaster risk reduction: an etymological journey', *Natural Hazards and Earth System Sciences* 13, 2707-2716.

Anderson, B. (2015) 'What Kind of Thing is Resilience?', *Politics* 35(1): 60-66.

Beck, U. (2015) 'Emancipatory catastrophism: What does it mean to climate change and risk society?', *Current Sociology* 63(1): 75-88.

Béné, C, L. Mehta, G. McGranahan, T. Cannon, J. Gupte & T. Tanner (2018) 'Resilience as a policy narrative: potentials and limits in the context of urban planning', *Climate and Development* 10(2): 116-133.

Berbés-Blázquez, M., C.L. Mitchell, S.L Burch & J. Wandel (2017) 'Understanding climate change and resilience: assessing strengths and opportunities for adaptation in the Global South', *Climatic Change* 141: 227-241.

Berendt, B. (2019) 'AI for the Common Good?! Pitfalls, challenges, and ethics pen-testing', *Paladyn: Journal of Behavioral Robotics* 10 (1): 44–65.

Bergström, J. (2018) 'An archaeology of societal resilience', *Safety Science* 110: 32-38.

Blühdorn, I. (2013) 'The governance of unsustainability: ecology and democracy after the post-democratic turn', *Environmental Politics* 22(1): 16-36.

Boas, I. & D. Rothe (2016) 'From conflict to resilience? Explaining recent changes in climate security discourse and practice', *Environmental Politics* 25(4): 613-632.

Borsje, B.W., van Wesenbeeck, B., Dekker, F., Paalvast, P., Bouma, T.J., de Vries, M.B. (2011) 'How ecological engineering can serve in coastal protection – a review', Ecological Engineering 37: 113-122.

https://doi.org/10.5194/nhess-2020-90
Preprint. Discussion started: 31 March 2020

Natural Hazards and Earth System Sciences
Open Access
Discussions

Bourbeau, P. (2015) 'Resilience and International Politics: Premises, Debates, Agenda', *International Studies Review* 17: 374-395.

Bourbeau, P. and C. Ryan (2018) 'Resilience, resistance, infrapolitics and enmeshment', *European Journal of International Relations* 24(1): 221-239.

Boyd, E., B. Nykvist, S. Borgström & I.A. Stacewicz (2015) 'Anticipatory governance for social-ecological resilience', *Ambio* 44 (supplement 1): 149-161.

Bracking, S. (2019) 'Financialisation, Climate Finance, and the Calculative Challenges of Managing Environmental Change', Antipode 51(3): 709-729.

Braun, B.P. (2014) 'A new urban dispositif? Governing life in an age of climate change', *Environment and Planning D: Society and Space* 32: 49-64.

Chandler, D. (2014) 'Beyond neoliberalism: resilience, the new art of governing complexity', *Resilience* 2(1): 47-63.

Ching, L. (2016) 'Resilience to climate change events: The paradox of water (In)-security', *Sustainable Cities and Society* 27: 439-447.

Clément, V. & J. Rivera (2017) 'From Adaptation to Transformation: An Extended Research Agenda for Organizational Resilience to Adversity in the Natural Environment', *Organization & Environment* 30(4): 346-365.

Conte, R. and M. Paolucci (2014) 'On agent-based modeling and computational social science', *Frontiers in Psychology* 5: 668.

Cote, M. & A.J. Nightingale (2012) 'Resilience thinking meets social theory: Situating social change in socio-ecological systems (SES) research', *Progress in Human Geography* 36(4): 475-489.

Dahlberg, R.. C.T. Johannessen-Henry, E. Raju & S. Tulsiani (2015) 'Resilience in disaster research: three versions', *Civil Engineering and Environmental Systems* 32(1-2): 44-54.

Davoudi, S. (2018) 'Just resilience', *City & Community* 17(1): 3-7.

Derickson, K.D. (2016) 'Resilience is not enough', *City* 20(1): 161-166.

https://doi.org/10.5194/nhess-2020-90
Preprint. Discussion started: 31 March 2020

Douglas, M. & A. Wildavsky (1983) *Risk and Culture. An Essay on the Selection of Technological and Environmental Dangers*. Berkeley: University of California Press.

Dryzek, J.S. & J. Pickering (2019) *The Politics of the Anthropocene.* Oxford: Oxford University Press.

Duffield, M. (2016) 'The resilience of the ruins: towards a critique of digital humanitarianism', *Resilience* 4(3): 147-165.

Duit, A. (2016) 'Resilience thinking: Lessons for public administration', *Public Administration* 94(2): 364-380.

Estêvão, P., A. Calado and L. Capucha (2017) 'Resilience: Moving from a "heroic" notion to a sociological concept', *Sociologia, Problemas E Práticas* 85: 9-25.

Evans, B. & J. Reid (2013) 'Dangerously exposed: the life and death of the resilient subject', *Resilience,* 1(2): 83-98.

Fainstein, S. (2014) 'Resilience and justice', *International Journal of Urban and Regional Research*, 157-167.

Farmer, J.D. & D. Foley (2009) 'The economy needs agent-based modelling', *Nature* 460: 685-686.

Fazey, I., P. Moug, S. Allen, K. Beckmann, D. Blackwood, M. Bonaventura, K. Burnett, M. Danson, R. Falconer, A.S. Gagnon, R. Harkness, A. Hodgson, L. Holm, K.N. Irvine, R. Low, C. Lyon, A. Moss, C. Moran, L. Naylor, K. O'Brien, S. Russell, S. Skerratt, J. Rao-Williams & R. Wolstenholme (2018) 'Transformation in a changing climate: a research agenda', *Climate and Development* 10(3): 197-217.

Feenstra, M. & G. Özerol (2018) 'Using energy justice as a search light for gender and energy policy research: a systematic review', 12th ECPR General Conference, Hamburg, Germany, August 2018.

Filatova, T., J.G. Polhill & S. van Ewijk (2016) 'Regime shifts in coupled socio-environmental systems: Review of modelling challenges and approaches', *Environmental Modelling & Software* 75: 333-347.

Fischer, F. (2017) *Climate crisis and the democratic prospect: participatory governance in sustainable communities*. Oxford: Oxford University Press.

Floridi, L. (2017) 'A plea for non-naturalism as constructionism', *Minds & Machines* 27: 269-285.

https://doi.org/10.5194/nhess-2020-90
Preprint. Discussion started: 31 March 2020

Folke, C. (2006) ‘Resilience: The emergence of a perspective for social–ecological systems analyses’, *Global Environmental Change* 16(3): 253-267.

Frost, T. (2019) ‘The *Dispositif* between Foucault and Agamben’, *Law, Culture and the Humanities* 15(1): 151-171.

Geels, F. W., & J. Schot (2007) ‘Typology of sociotechnical transition pathways’, *Research Policy*, 36(3), 399-417.

Gim, C., C.A. Miller and P.W. Hirt (2019) ‘The resilience work of institutions’, *Environmental Science and Policy* 97: 36-43.

Glaser, M., J.G. Plass-Johnson, S.C.A. Ferse, M. Neil, D.Y. Satari, M. Teichberg & H. Reuter (2018) ‘Breaking Resilience for a Sustainable Future: Thoughts for the Anthropocene’, *Frontiers in Marine Science* 5: 34.

Grove, K. & D. Chandler (2017) ‘Introduction: resilience and the Anthropocene: the stakes of ‘renaturalising’ politics’, *Resilience* 5(2): 79-91.

Haan, F.J. de & J. Rotmans (2018) ‘A proposed theoretical framework for actors in transformative change’, *Technological Forecasting and Social Change* 128: 275-286.

Haasnoot, M., J.H., Kwakkel, W.E. Walker & J. ter Maat (2013) ‘ Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world’, *Global Environmental Change* 23(2): 485-498.

Hamers, T., J.J. Kamstra, J. van Gils, M.C. Kotte-Albertus & G.M. van Hattum (2015) ‘The influence of extreme river discharge conditions on the quality of suspended particulate matter in Rivers Meuse and Rhine (The Netherlands)’*, Environmental Research* 143 A: 241-255.

Hawes C. & C. Reed (2006) ‘Theoretical Steps Towards Modelling Resilience in Complex Systems’. In: Gavrilova M. et al. (eds) *Computational Science and Its Applications*. ICCSA 2006. Lecture Notes in Computer Science, vol 3980. Berlin: Springer.

Heffron, R.J. & D. McCauley (2017) ‘The concept of energy justice across the disciplines’, *Energy Policy* 105: 658-667.

https://doi.org/10.5194/nhess-2020-90
Preprint. Discussion started: 31 March 2020

Hilhorst, D. (2018) ‘Classical humanitarianism and resilience humanitarianism: making sense of two brands of humanitarian action’, *International Journal of Humanitarian Action* 3: 15.

Hoefsloot, F. I., Pfeffer, K., & Richter, C. (2019). *People and Places Uncounted: Legibility in the Water Infrastructure of Lima, Peru*. 1-17. Paper presented at City Futures 2019, Dublin, Ireland.

Hoekstra, A.Y., R. Bredenhoff-Bijlsma & M.S. Krol (2018) ‘The control versus resilience rationale for managing systems under uncertainty’, *Environmental Research Letters* 13: 103002.

Hoffmann, S., Weyer, J., & J. Longen, (2017) ‘Discontinuation of the automobility regime. An integrated approach to multi-level governance’, *Transportation Research*, Part A 103, 391-408.

Holling, C.S. (1973) ‘Resilience and Stability of Ecological Systems’, *Annual Review of Ecology and Systematics* 4: 1-23.

Howell, A. (2015) ‘Resilience as Enhancement: Governmentality and Political Economy beyond “Responsibilisation”’, *Politics* 35(1): 67-71.

Huang, H., S. Boranbay-Akan and L. Huang (2016) ‘Media, Protest Diffusion, and Authoritarian Resilience’, *Political Science Research and Methods* 7(1): 23-42.

Hughes, S. (2017) ‘The Politics of Urban Climate Change Policy: Towards a Research Agenda’, *Urban Affairs Review* 53(2): 362-380.

Jenkins, K. D. McCauley, R. Heffron, H. Stephan & R. Rehner (2016) ‘Energy justice: A conceptual review’, *Energy Research & Social Science* 11: 174-182.

Jesse, B-J., H.U. Heinrichs & W. Kuchshinrichs (2019) ‘Adapting the theory of resilience to energy systems: a review and outlook’, *Energy, Sustainability and Society* 9: 27.

Johnson J.L. et al. (2018) ‘Interplays of Sustainability, Resilience, Adaptation and Transformation’. In: W. Leal Filho, R. Marans & J. Callewaert (eds) *Handbook of Sustainability and Social Science Research*. World Sustainability Series. Springer, Cham.

Johnston, P., & A. Stirling (2018) ‘Comparing nuclear trajectories in Germany and the United Kingdom: From regimes to democracies in sociotechnical transitions and discontinuities’, *Energy Research and Social Science*, 59, 101245.

Juncos, A.E. (2017) 'Resilience as the new EU foreign policy paradigm: a pragmatist turn?', *European Security* 26(1): 1-18.

Juncos, A.E. (2018) 'Resilience in peacebuilding: Contesting uncertainty, ambiguity, and complexity', *Contemporary Security Policy* 39 (4): 559-574.

Kates, R.W., W.R. Travis & T.J. Wilbanks (2012) 'Transformational adaptation when incremental adaptations to climate change are insufficient', *Proceedings of the National Academy of Sciences of the United States of America* 109 (19): 7156-7161.

Katomero, J. & Y. Georgiadou (2018) 'The Elephant in the Room: Informality in Tanzania's Rural Waterscape',. *ISPRS International Journal of Geo-Information 7:* 437.

Khakurel, J., B. Penzenstadler, J. Porras, A. Knutas & W. Zhang (2018) 'The Rise of Artificial Intelligence under the Lens of Sustainability', *Technologies* 6, 100.

Klein, J., S. Juhola & M. Landauer (2017) 'Local authorities and the engagement of private actors in climate change adaptation', *Environment and Planning C: Politics and Space 35*(6): 1055-1074.

Köhler, J., F.W. Geels, F. Kernc, J. Markard, E. Onsongo, A. Wieczorek, F. Alkemade, F. Avelino, A. Bergek, F. Boons, L. Fünfschilling, D. Hess, G. Holtz, S. Hyysalok, K. Jenkins, P. Kivimaa, M. Martiskainen, A. McMeekin, M.S. Muhlemeier, B. Nykvist, B. Pel, R. Raven, H. Rohracher, B. Sandén, J. Schot, B. Sovacool, B. Turnheim, D. Welch & P. Wells (2019) 'An agenda for sustainability transitions research: State of the art and future directions', *Environmental Innovation and Societal Transitions* 31: 1-32.

Kolers, A. (2016) 'Resilience as a Political Ideal', *Ethics, Policy & Environment* 19(1): 91-107.

Ksenia, C., G. Lizarralde, A. Dainty and L. Bosher (2016) 'Unpacking resilience policy discourse', *Cities* 58: 70-79.

Kuhlicke, C. (2013) 'Resilience: a capacity and a myth: findings from an in-depth case study in disaster management research', *Natural Hazards* 67: 61-76.

Kuhlmann, S., P. Stegmaier & K. Konrad (2019) 'The tentative governance of emerging science and technology—A conceptual introduction', *Research Policy* 48(5): 1091-1097.

https://doi.org/10.5194/nhess-2020-90
Preprint. Discussion started: 31 March 2020

Natural Hazards and Earth System Sciences
Open Access
EGU
Discussions

Kythreotis, A.P. & G.I. Bristow (2017) 'The 'resilience trap': exploring the practical utility of resilience for climate change adaptation in UK city-regions, *Regional Studies* 51 (10): 1530-1541.

Lockie, S. (2016) 'Beyond resilience and systems theory: reclaiming justice in sustainability discourse, *Environmental Sociology* 2(2): 115-117.

Lund, J.R. (2015) 'Integrating social and physical sciences in water management', *Water Resources Research* 51: 5905–5918.

Lyster, R. (2017) 'Climate justice, adaptation and the Paris Agreement: a recipe for disasters?', *Environmental Politics* 26(3): 438-458.

Martin, R. and M. Schlüter (2015) 'Combining system dynamics and agent-based modeling to analyze social-ecological interactions—an example from modeling restoration of a shallow lake', *Frontiers in Environmental Science* 3: 66.

Marvin, S., Luque-Ayala, A., & McFarlane, C. (2016). *Smart urbanism: Utopian vision or false dawn*. New York, NY: Routledge.

McGreavy, B. (2016) 'Resilience as Discourse', *Environmental Communication* 10(1): 104-121.

Miller, T. (2019) 'Explanation in artificial intelligence: Insights from the social sciences', *Artificial Intelligence* 267: 1-38.

Mummery, J. & J. Mummery (2019) 'Transformative climate change adaptation: bridging existing approaches with post-foundational insights on justice', *Local Environment* 24(10): 919-930.

Ogunbode, C.A., G. Böhm, S.B Capstick, C. Demski, A. Spence & N. Tausch (2019) 'The resilience paradox: flooding experience, coping and climate change mitigation intentions', *Climate Policy* 19(6): 703-715.

O'Hare, P., I. White & A. Connelly (2016) 'Insurance as maladaptation: Resilience and the 'business as usual' paradox', *Environment and Planning C: Government and Policy* 34(6): 1175-1193.

Ostrom, E. (2007) 'A diagnostic approach for going beyond panaceas', *Proceedings of the National Academy of Sciences 104*(39): 15181–15187.

https://doi.org/10.5194/nhess-2020-90
Preprint. Discussion started: 31 March 2020

Natural Hazards and Earth System Sciences
Open Access
Discussions

Paradiso, M. (2006) ‘Information Geography: A Bridge between Engineering and the Social Sciences’, *Journal of Urban Technology* 13(3): 77-92.

Park, S.E., N.A. Marshall, E. Jakku, A.M. Dowd, S.M. Howden, E. Mendham & A. Fleming (2012) ‘Informing adaptation responses to climate change through theories of transformation’, *Global Environmental Change* 22: 115-126.

Patriarca, R., J. Bergström, G. Di Gravio and F. Costantino (2018) ‘Resilience engineering: Current status of the research and future challenges’, *Safety Science* 102: 79-100.

Pelling, M., K. O’Brien & D. Matyas (2015) ‘Adaptation and transformation’, *Climatic Change* 133(1): 113-127.

Pfeffer, K. & Y. Georgiadou (2019) ‘Global Ambitions, Local Contexts: Alternative Ways of Knowing the World’, *ISPRS International Journal of Geo-Information 8*, 516.

Pietrapertosa, F., M. Salvia, S. De Gregorio Hurtado, V. D'Alonzo, J.M. Church, D. Geneletti, F. Musco & D. Reckien (2019) ‘Urban climate change mitigation and adaptation planning: Are Italian cities ready?’, *Cities* 91: 93-105.

Pizzo, B. (2015) ‘Problematizing resilience: implications for planning theory and practice’, *Cities* 43: 133-140.

Pumpuni-Lenss, G., T. Blackburn and A. Garstenauer (2017) ‘Resilience in complex systems: An agent-based approach’, *Systems Engineering* 20(2): 158-172.

Rajan, A. and A. Saffiotti (2017) ‘Towards a science of integrated AI and robotics’, *Artificial Intelligence* 247: 1-9.

Redman, C. L. (2014) ‘Should sustainability and resilience be combined or remain distinct pursuits?’, *Ecology and Society* 19(2): 37.

Ribault, T. (2019) ‘Resilience in Fukushima: Contribution to a Political Economy of Consent’, *Alternatives: Global, Local, Political* 44 (2-4) 94-118.

Rodríguez-González, A., M. Zanin & E. Menasalvas-Ruiz (2019) ‘Public Health and Epidemiology Informatics: Can Artificial Intelligence Help Future Global Challenges? An Overview of Antimicrobial

https://doi.org/10.5194/nhess-2020-90
Preprint. Discussion started: 31 March 2020

Resistance and Impact of Climate Change in Disease Epidemiology', *IMIA Yearbook of Medical Informatics*: 224-231.

Rogge, K. S., & P. Johnston (2017) 'Exploring the role of phase-out policies for low-carbon energy transitions: The case of the German Energiewende', *Energy Research & Social Science*, 33, 128-137.

Rogge, K. S., Kern, F., & M. Howlett (2017) 'Conceptual and empirical advances in analysing policy mixes for energy transitions', *Energy Research & Social Science*, 33, 1-10.

Rothe, D. (2017) 'Gendering Resilience: Myths and Stereotypes in the Discourse on Climate-induced Migration', *Global Policy* 8: 40-46.

Ruinen, R. van, T. Filatova, W. Jager & A. van der Veen (2015) 'Going beyond perfect rationality: drought risk, economic choices and the influence of social networks', *The Annals of Regional Science* 57(2-3): 335-369.

Samarakoon, S. (2019) 'A justice and wellbeing centered framework for analysing energy poverty in the Global South', *Ecological Economics* 65(C), 106385.

Saravi, S., R. Kalawsky, D. Joannou, M. Rivas Casado, G. Fu & F. Meng (2019) 'Use of Artificial Intelligence to Improve Resilience and Preparedness Against Adverse Flood Events', *Water* 11, 973.

Schilling, T., R. Wyss and C.R. Binder (2018) 'The Resilience of Sustainability Transitions', *Sustainability* 10, 4593.

Schlosberg, D., L.B. Collins & S. Niemeyer (2017) 'Adaptation policy and community discourse: risk, vulnerability, and just transformation', *Environmental Politics* 26(3): 413-437.

Schwartz, S. (2018) 'Resilience in psychology: A critical analysis of the concept', *Theory and Psychology* 28(4): 528-541.

Sjöstedt, M. (2015) 'Resilience revisited: taking institutional theory seriously', *Ecology and Society* 20(4): 23.

Simbirski, B. (2006) 'Cybernetic Muse: Hannah Arendt on Automation, 1951-1958', *Journal of the History of Ideas* 77(4): 589-613.

https://doi.org/10.5194/nhess-2020-90
Preprint. Discussion started: 31 March 2020

Skillington, T. (2015) ‘Climate justice without freedom: Assessing legal and political responses to climate change and forced migration’, *European Journal of Social Theory* 18(3): 288-307.

Stegmaier, P., Visser, V. R., & S. Kuhlmann (2020) ‘The incandescent light bulb phase-out. Exploring patterns of framing the governance of discontinuing a socio-technical regime’ (under review).

Stegmaier, P. (2019) ‘Killing the Coal. On governing the discontinuation of coal energy production’, Paper presented at the Nordic STS Conference; Session: How do technologies die?, Tampere.

Stegmaier, P., Kuhlmann, S., & V.R. Visser (2014) ‘The Discontinuation of Socio-Technical Systems as Governance Problem’. In: Borrás, S. & J. Edler (eds.) *Governance of Systems Change* (pp. 111-131). Cheltenham: Edward Elgar.

Strunz, S. (2014) ‘The German energy transition as a regime shift’, *Ecological Economics*, 100, 150-158.

Szablowski, D. & B. Campbell (2019) ‘Struggles over extractive governance: Power, discourse, violence, and legality’, *The Extractive Industries and Society* 6 (2019) 635–641.

Stegemann, L. and M. Ossewaarde (2018) ‘A Sustainable Myth: A Neo-Gramscian Perspective on the Populist and Post-Truth Tendencies of the European Green Growth Discourse‘, *Energy Research & Social Science* 43: 25-32.

Swyngedouw, E. (2010) ‘Apocalypse forever? Post-political populism and the spectre of climate change’, *Theory Culture & Society* 27 (2-3): 213-232.

Swyngedouw, E. (2011) ‘Depoliticized environments: the end of nature, climate change and the post-political condition’, *Royal Institute of Philosophy Supplement* 69: 253-274.

Sun, L., B. Stojadinovic and G. Sansavini (2019) ‘Agent-Based Recovery Model for Seismic Resilience Evaluation of Electrified Communities’, *Risk Analysis* 39(7): 1597-1614.

Taddeo, M. & L. Floridi (2018) ‘How AI can be a force for good’, *Science* 361 (6404): 751-752.

Terry, G. (2009) ‘No climate justice without gender justice: an overview of the issues’, *Gender & Development 17*(1): 5-18.

https://doi.org/10.5194/nhess-2020-90
Preprint. Discussion started: 31 March 2020

Thorén, H. (2014) ‘Resilience as a Unifying Concept’, *International Studies in the Philosophy of Science* 28 (3): 303-324.

Tierney, K. (2015) ‘Resilience and the Neoliberal Project: Discourses, Critiques, Practices—And Katrina’, *American Behavioral Scientist* 59(10): 1327-1342.

Tyler, S. & M. Moench (2012) ‘A framework for urban climate resilience’, *Climate and Development*, 4(4): 311-326.

Ungar, M. (2018) ‘Systemic resilience: principles and processes for a science of change in contexts of adversity’, *Ecology and Society* 23(4): 34.

Vahedifard, F., A. Ermagun, K. Mortezaei and A. AghaKouchak (2019) ‘Integrated data could augment resilience’, *Science* 363 (6423), 134.

VanderPlaat, M. (2016) ‘Activating the sociological imagination to explore the boundaries of resilience research and practice’, *School Psychology International* 37(2): 189-203.

Ven, A. van de (2017) ‘The innovation journey: you can’t control it, but you can learn to maneuver it’, *Innovation* 19(1), 39-42.

Verrest, H. & K. Pfeffer (2019) ‘Elaborating the urbanism in smart urbanism: distilling relevant dimensions for a comprehensive analysis of Smart City approaches’, *Information, Communication & Society* 22 (9): 1328-1342.

Vögele, S., Kunz, P., Rübbelke, D. & T. Stahlke (2018) ‘Transformation pathways of phasing out coal-fired power plants in Germany’, *Energy, Sustainability and Society*, 8(25): 1-18.

Walker, J. & M. Cooper (2011) ‘Genealogies of resilience: from systems ecology to the political economy of crisis adaptation’, *Security Dialogue*, 42(2): 143-160.

Walsh-Dilley, M. & W. Wolford (2015) ‘(Un)Defining resilience: subjective understandings of ‘resilience’ from the field’, *Resilience* 3(3): 173-182.

Warmink, J.J., M. Brugnach, J. Vinke-de Kruijf, R. M. J. Schielen & D. C. M. Augustijn (2017) ‘Coping with Uncertainty in River Management: Challenges and Ways Forward’, *Water Resources Management* 31: 4587-4600.

https://doi.org/10.5194/nhess-2020-90
Preprint. Discussion started: 31 March 2020

Natural Hazards and Earth System Sciences
Discussions

Weichselgartner, J. and I. Kelman (2015) ‘Geographies of resilience: Challenges and opportunities of a descriptive concept’, *Progress in Human Geography* 39(3): 249-267.

Wessel, R.A. (2019) ‘Cybersecurity in the European Union: Resilience through Regulation’, in E. Conde Pérez, Z. Yaneva & M. Scopelliti (eds.), *Routledge Handbook of EU Security Law and Policy*. London: Routledge, pp. 283-300.

Wiese, F. (2016) ‘Resilience Thinking as an Interdisciplinary Guiding Principle for Energy System Transitions’, *Resources* 5, 30.

Wright, D.J. (2016) ‘Towards a *digital* resilience’, *Elementa: Science of the Anthropocene* 4: 000082.

Yanarella, E.J. & R.S. Levine (2014) ‘From Sustainability to Resilience: Advance or Retreat?’, *Sustainability* 7(4): 197-208.