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

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Abstract

The twofold aim of this paper is to provide an overview of the current state of resilience research with regard to climate change in the social sciences and propose a research agenda. Resilience research among social scientists is characterized by much more diversity today than a few decades ago. Different definitions and understandings of resilience appear in publications during the last ten years. Resilience research increasingly bears the mark of social constructivism, a relative newcomer compared to the more long-standing tradition of naturalism. There are also approaches that are indebted to both "naturalism" and "constructivism", which, of course, come in many varieties. Based on our overview of recent scholarship, which is far from being exhaustive, we have identified six research avenues that arguably deserve continuing attention. They combine naturalist and constructivist insights and approaches so that human agency, reflexivity and considerations of justice and equity are incorporated into system thinking research or supplement such research. Ultimately, we believe that the overarching challenge for future research is to ensure that resilience to climate change does not compromise sustainability and considerations of justice (including, environmental, climate and energy justice).

Keywords: adaptive resilience, climate change, just resilience, transformative resilience, transformational adaptation, wicked resilience

1. Introduction

A brief and non-exhaustive overview of resilience scholarship published in the period 1970-2020 reveals a diversification of research foci and themes, approaches and methods, and theoretical frameworks. Resilience has been a prevalent research topic among ecologists for several decades and,

very soon after, among cyberneticists. Given the association of resilience with the natural sciences and engineering (cf. Indirli, 2019), it is perhaps not so surprising that most social scientists did not see the need to have recourse to the terminology or concept until much later. And if they did adopt the idea earlier, they were likely to embrace the naturalist theoretical framework that accompanied it (Holling, 1973; 2001; cf. Chandler, 2014). Other social scientists are still reluctant to accept resilience as a universal and unifying concept, pointing out that the core concepts and principles in resilience theory that create theoretical tensions and methodological barriers between the natural and social sciences (Olsson et al., 2015). This conceived opposition between the natural sciences and social sciences may not be experienced by all naturalists or social scientists. Even more importantly perhaps, such opposition – real or surmised – may hinder fruitful collaborations in the face of our ecological crisis. Yet, collaboration, integration or "transdisciplinarity" in the real worlds of universities and research institutes may not always reflect a genuine transcendence of disciplinary boundaries, but instead largely consists of natural sciences and engineering research in sustainability (Groß and Stauffacher, 2014). That said, there have been genuine attempts to transcend the limitations of both naturalism – in the strict, technical sense of the term (Andler, 2014) – and forms of social constructivism that border on relativism (Proctor, 1998a; 1998b; Popa et al., 2015). Such "transdisciplinary" research is typically problem-oriented (Groß and Stauffacher, 2014).

Crawford Stanley Holling's ecological notion of resilience (Holling, 1973) is considered by some as a bridge between the social sciences and engineering (Ostrom, 2007; Thorén, 2014). The appeal of Holling's socio-ecological systems (SES) approach among some social scientists may be due to its being a corrective to the tendency of Holling's fellow ecologists to unconditionally embrace the methods and premises inherited from classical physics (cf. Holling, 1973; Thorén, 2014; Estêvão, Calado and Capucha, 2017; Davoudi, 2018). Holling corrected what he considered to be a flawed view of the world and of ecosystems, namely, as closed or stable. Against the "equilibrium-centered" view, he emphasized the influence of random events (natural or human-caused) on ecological systems (Holling, 1973, 15). Yet, even this complex systems approach does not score very highly at the level of reflexivity, which is required to discover and "acknowledge overt or covert forms of dominance shaping public

discourse and participation (Popa et al., 2015). Slightly more positively framed, societal resilience to climate change also involves political and institutional factors, lifestyles and consumer habits, production patterns, and structures of power in general (cf. Douglas and Wildavsky, 1983; Blühdorn, 2013; Kolers, 2016; Fischer, 2017; Dryzek and Pickering, 2019). Resilience research that takes into account such social factors (which do not necessarily obey physical laws) can be broadly classified as belonging to "social constructivism".

The Tsunami in 2004 and Katrina in 2005 seem to have acted as catalysts for generating more resilience research among social scientists (Pizzo, 2015). This increasing interest for resilience on the part of certain social scientists (and other scholars from different disciplines) cannot be detached from the popularity that the terminology has started to gain among national governments and global governance actors, including the Rockefeller Foundation, for instance, at the beginning of the new century. Such tendency became stronger with the global financial crisis of 2007-2008. The widespread recourse to the language of resilience by powerful private and public actors has incited a series of scholarship critical of such discourse (Chandler, 2014; Pizzo, 2015; Lockie, 2016; Derickson, 2016; Hilhorst 2018). The latter, it is observed, easily hides vested political and economic interests, and distracts attention from structural and institutional defects by emphasizing resilience through technological innovations. Katrina and, even more recently, Covid-19, it is argued, reveal a vulnerability that is not simply an unavoidable fragility in the face of natural hazards, but is also the fruit of institutions and political decisions over a long period of time. Natural disasters tend to be perceived as indiscriminate and indifferent as to whom they affect. Yet, as Belkhir and Charlemaine (2007, p. 12) point out, "hurricanes may not single out victims by their race, or gender or class but neither do such disasters occur in historical, political, social, or economic vacuums". In other words, social, cultural, political, and economic conditions are conceived to be involved in the resilience or non-resilience of a nation or of particular groups to natural calamities (Henkel et al., 2006; Tierney, 2015; Lockie, 2016).

The aim of this paper is to provide an overview of the current state of resilience research with regard to climate change in the social sciences and propose a research agenda. Resilience research

among social scientists is characterized by much more diversity today than a few decades ago. Different definitions and understandings of resilience appear in publications during the last ten years (cf. Indirli, 2019). Resilience research increasingly bears the mark of social constructivism, a relative newcomer compared to the more long-standing tradition of naturalism. Given this history, it is hardly surprising that social scientists focusing on resilience to climate change should initially have borrowed the research methods common to natural and applied sciences. “Social constructivist” approaches gradually made their entrance, especially in reaction to both the perceived inadequacy of particular naturalistic approaches and the increasing normative use of resilience in policy agendas (Weichselgartner and Kelman, 2015). There are also approaches that are indebted to both “naturalism” and “constructivism” (which, of course, come in many varieties). “Ecological naturalism”, for instance, departing from ecological science, integrates constructivist insights about power and mastery, the diversity of human knowledge, and the politics of knowledge. It thereby resists the reductionistic tendencies of positivist empiricism (Code, 2005). “Critical realism” (Carolan, 2005) similarly wishes to avoid the danger of reductionism while profiting from the wealth of (applied) natural sciences.

Hence, though we acknowledge the many varieties of both “naturalism” and “constructivism” and the various endeavors to transcend the limitations of both naturalism and constructivism, we observe that most resilience research in the social sciences still takes place in the dialectical field constituted by these two approaches, in their strict, traditional senses (cf. Andler, 2014). This is the theme of the next section. But first we briefly examine how resilience research in the social sciences has undergone a thorough diversification. Such diversity, however, sometimes means that research takes place in parallel worlds and that there is little cross-fertilization between scholars. It is suggested that social scientific inquiry into resilience in the context of climate change could be raised to a next level if these two different approaches meet and interact. To this end, we reconstruct contemporary debates in that particular field of studies and distil recurrent research topics that divide social scientists. The issues of adaption and transformation in the context of severe disturbances or shocks that come with climate

change (such as hurricanes, floods, drought, and heatwaves) appear to be such divisive topics. Finally, naturalist and constructivist directions, as well as possible cross-fertilizations of these two currents, for future resilience research are identified. We point out that future resilience research in the social sciences – that is, the types of questions raised, theoretical frameworks and modes of analysis – will also be determined by changing conditions (ecological, political, and socioeconomic).

2. The diversification of resilience research in the social sciences

One of the earliest appearances of the term resilience – in European literature at least – seems to have been in one of Aesop's fables, namely, that of *The Oak Tree and the Reeds*. According to one of the versions of that story, the Oak Tree becomes uprooted during a storm while its fellow reeds survive it. In a conversation, the Oak Tree expresses its bewilderment that the fragile reeds were able to resist such a mighty storm while it succumbed. The reeds reply that it is precisely their non-resistance that saved them. Through their capacity to bend, they moved with the direction of the wind (which thus did not break them) and rose again when the storm was gone. They were flexible enough. The reeds "bounce" back and are thus "resilient". Indeed, the English word resilience derives from Latin (*resilire*), which generally meant rebounding. This Latin word can be found in the writings of Seneca the Elder, Pliny the Elder, Ovid, Cicero, and Livy; to rebound is also the sense in which *resilire* is used by Cicero in his *Orations* (Alexander, 2013). The term also appears in Lucretius" *On the Nature of Things*, where it denotes "being forced back by a resisting surface […] with reference to the action on Nature" (Pizzo, 2015, p. 133). Along this line, nature compels all things to "spring off".

Despite the various meanings attributed to the term, the connotation attached to *resilire* was commonly that of rebounding (cf. Indirli, 2019). Up to the early nineteenth century, this was the predominant understanding of resilience in common language and imagination. A slight shift appeared when engineers started to use the term to refer to the properties and capacities of materials to absorb tensions and release energy, and recover their original forms, without breaking or disfiguration after

137 undergoing some external shock or disturbance (such as extreme weather conditions) (Estêvão,
138 Calado and Capucha, 2017; Bergström, 2018; Davoudi, 2018). In the 1950s, psychologists re-adapted
139 the common sense of the term to mental health and used it to study the coping mechanisms of
140 concentration camp survivors. Later, the concept is used to study various kinds of trauma, misfortune,
141 adversity, stress, and mental recovery (Bourbeau, 2015; Estêvão, Calado and Capucha, 2017;
142 Bergström, 2018; Schwartz, 2018). In the 1970s, the ecologist C.S. Holling (1973, p. 14) redefines
143 resilience as "a measure of the persistence of systems and their ability to absorb change and
144 disturbance." Thus understood, resilience is widely conceived as the opposite of vulnerability, which is
145 defined as the inability to absorb change and disturbance (Gallopin, 2006; Miller et al., 2010). For
146 instance, a coastal system that is vulnerable to accelerated sea-level rise is not resilient enough (Smit,
147 Goosen and Hulsbergen, 1998). In such accounts, greater resilience means becoming less vulnerable
148 to change and shocks. That said, a system can still be vulnerable to other changes while being resilient
149 in other respects (Gallopin, 2006). Holling incorporates resilience in a socio-ecological systems (SES)
150 approach to analyze the stability and strength of ecological systems, which are constituted by the
151 interaction between natural ecosystems and human societies (Alexander, 2013; Bergström, 2018;
152 Béné et al., 2018; Hoekstra, Bredenhoff-Bijlsma and Krol, 2018). Ecosystems, as noted earlier, are
153 rarely closed systems, but are instead subjected to natural and human influences.

154 In the social sciences, resilience research has been influenced by these earlier studies. As a
155 result, some social scientists have recourse to mathematical and simulation models and consider
156 resilience as a property of a system, which can be (made) weak or strong. In these studies, society is
157 modelled as a social system that consists of parts (including agents and technologies) and physical
158 properties that can be objectively studied (Aiken, 2006; Floridi, 2017). Resilience as a system property
159 is an objective measure of the dynamic equilibrium, stability, strength, or survivability of a socio-
160 ecological system, including coastal systems, urban systems, forest systems, etc. (Hoekstra,
161 Bredenhoff-Bijlsma and Krol, 2018). Such approaches, indebted to applied natural sciences and the
162 complex systems theory, can be very useful, especially when both the problem and the solution are

primarily and solely of a technical nature. That said, even an apparently purely technical process such as water purification involves reckoning with various social factors (for instance, changing habits, medicine uses and particular surroundings of water collection systems).

The story becomes even more complicated when, for instance, attempts to make communities more resilient to climate change overlook the political and cultural reasons why particular groups living in particular areas are more vulnerable to the effects of climate change (such as tsunami, hurricane, heavy rainfall, drought, and heatwaves). These problems may not even get sufficient attention due to, for instance, "cultural racism and "institutional racism" (Henkel et al., 2006, p. 102). Social constructivism provides social scientists with the conceptual and analytical tools to understand social realities. Historically, constructivism in the social sciences has arisen in reaction to what was experienced as the narrowness of the naturalist approach (once again, in the technical/strict sense of the term, according to which "the social is part of nature, social processes are natural processes, with causal powers reducible to natural causation" (Andler, 2014, p. 286)). Most social constructivists do not believe that reality is objective in the naturalist sense (strictly defined) and can thus be fully grasped. Instead, it is conceived that natural and social phenomena can only understood by taking into account diverse factors that determine and influence human perceptions, experiences, meanings, interests, values, identities, patterns of domination, etc.

In resilience research, social constructivists typically model society as a historically embedded construct that is the result of particular understandings of nature, society and the person, of values, symbols and historical practices (which may not be very rational or just), and power relations. These social scientists tend to be more sensitive to the potential and actual abuse of power. When engaging with resilience issues in the context of climate change, they typically express concern for vulnerable communities. Research topics can thus include the(un)equal distribution of environmental burdens, struggles for recognition, claims to participation, and unequal impacts of anthropogenic climate change (Braun, 2014; Yanarella and Levine, 2014; Skillington, 2015; Sjöstedt, 2015; Weichselgartner and Kelman, 2015; Pizzo, 2015; Lockie, 2016; Derickson, 2016; Lyster, 2017; Schlosberg, Collins and

Niemeyer, 2017; Mummery and Mummery, 2019). Davoudi (2018, p. 5), for instance, problematize the very notion of "resilience", pointing out that there are "unjust resilience building programs" that do not only neglect disadvantaged communities, but also create "resilient enclaves" for privileged elites". Similarly, Glaser et al (2018, p. 3) observe that resilience can be "wicked" when an undesirable status quo is being maintained. Reflexivity is arguably an indispensable part of resilience research (cf. Popa et al., 2015).

2.1. The dialectic between naturalism and constructivism

Social scientists focusing on resilience to climate change have inherited an enormous body of scholarship on resilience stemming from the physical sciences and engineering, cybernetics, evolutionary biology and psychology, among others. In the 1970s, social scientists could thus have recourse to both closed-systems theories and complexity theory to think about resilience to climate change (Dahlberg, 2015; Davoudi, 2018). Some of them also merged the two models so that socio-ecological systems became conceptualized as adaptive complex systems (Wiese, 2016; Bergström, 2018). Holling's SES is an example of the integration of complexity theory in ecological science. According to the adaptive complex system line of thought, the resilience of a system depends on the capacity of individual agents to cope with uncertainty and complexity. They are able to interact and self-organize, learn and adapt (in an incremental or transformative way), thereby making the system flexible enough to absorb shocks and develop even in face of drastic changes (Jesse, Heinrichs and Kuchshinrichs, 2019).

Social scientists drawing on complexity theory and evolution-based models tend to emphasize a type of laissez-faireism, pointing out that adaptive complex systems have their own self-organizational structures that should not be interfered with (Adger et al., 2011). Bureaucratic interventions to address vulnerability and increase resilience to climate change are said to generate

unintended consequences that may well reduce a system's ability to absorb changes and disturbances. In 2001, Holling introduced the notion of "panarchy" as an alternative to hierarchy, to safeguard the self-organization of complex systems against the threat of bureaucratic intervention (Holling, 2001). Derived from the ancient Greek god of the woods, Pan, panarchy refers to the structure in which complex (ecological and social) systems are interlinked in an evolutionary process of adaptive cycles of growth, accumulation, restructuring, and renewal (Berkes and Ross, 2016). Accordingly, when confronted with shocks (like extreme weather events), adaptive systems stabilize with supporting self-organizing structures until those structures are overstretched and can no longer absorb changes and disturbances; this is when there is a transformation of the system (Allen et al., 2014). Resilience is therefore conceived as a primary system property that is measured by the magnitude of shocks that can be absorbed before the structures of system change (Boyer, 2020).

Some social scientists show a predilection for agent-based modelling (ABM) as their mode of analysis in resilience research (cf. Cote and Nightingale, 2012; Pumpuni-Lenss, Blackburn and Garstenauer, 2017; Patriarca et al., 2018; Mirchandani, 2020). They therefore aim at the constant refinement of simulation tools that can integrate complexity, uncertainty and multiplicity of agents and techniques of regulation in favor of adaptation. Since the 1970s, when it emerged from mathematical sociology, ABM has been used in complexity-theoretic research for analyzing complex systems (Conte and Paolucci, 2014). ABM is a computational mode of analysis that simulates complex (non-linear) systems that include diverse interacting agents that make decisions, interact and learn or adapt in their ever-changing environment, according to programmable rules (Hawes and Reed, 2006; Farmer and Foley, 2009; Van Duinen et al., 2015; Martin and Schlüter, 2015; Sun, Stojadinovic and Sansavini, 2019). ABM computes, in probabilistic terms, the recovery process of complex (non-linear) systems under stress and tracks the emergence of new stages, phases or entries into new adaptive cycles (Filatova, Polhill and Van Ewijk, 2016). Resilience to climate change, as a system property, can thus be calculated (Pumpuni-Lenss, Blackburn and Garstenauer, 2017). Since ABM traces feedbacks

240 between micro-macro scale explicitly, it also enables scholars to estimate the resilience of a system's
241 individual agents, communities or (sub)groups of agents.

242 The above approaches to resilience rely on what can be broadly defined as "natural" sciences
243 and their applied variants. Society and human persons are conceived according to the theories and
244 models common in these disciplines. The application of conceptual frameworks and models developed
245 to study allegedly objective and objectifiable things to the interaction between humans and their social
246 and natural environments is not without its challenges and dangers. Scientists, including social
247 scientists, may unwittingly serve political agendas if they are oblivious of their own political and
248 ideological commitments (Popa et al., 2014). The blurry line between science and politics is illustrated
249 by Holling's and Friedrich Hayek's re-appropriation of complexity theory to criticize government
250 intervention (Walker and Cooper, 2011; Davoudi, 2018). The historical context of both men, namely,
251 one marked by Keynesian policies, should arguably also be borne in mind. One of the possible
252 (side)effects of scientific models presuming resilient individual agents is that they can lend credence
253 to the idea of self-reliant and self-sufficient individuals and further the "neoliberal individualization of
254 responsibility" (Davoudi, 2018, p. 5). Such alliance, perhaps unwitting, between political agendas and
255 science is the great fear of those social constructivists whose primary commitment is to justice and the
256 protection of vulnerable individuals and groups (Fainstein, 2014; Derickson, 2016; Kolers, 2016;
257 Lockie, 2016; Lyster, 2017; Mummery and Mummery, 2019).

258 One of the major points of contention between naturalism, in the strict sense, and social
259 constructivism is that most social constructivists are unwilling to conceive resilience to climate change
260 as a system property (an intellectual attitude that does not imply that all naturalistic approaches
261 actually conceive resilience as a system property) (cf. Andler, 2014). Instead, resilience is perceived as
262 a socio-political construct created by diverse stakeholders (Walsh-Dilley and Wolford, 2015;
263 Weichselgartner and Kelman, 2015; Kythreotis and Bristow, 2017). This means that it is not a neutral
264 or technical element and, accordingly, requires constant critical scrutiny to uncover its possible
265 ideological and mythical nature (Alexander, 2013; Bourbeau, 2015; Boas and Rothe, 2016; Juncos,

2018; Wessel, 2019). Some scholars have pointed out the neoliberal ideology underpinning both theories/models and policies that rely on the idea of adaptive cycles governed by invisible laws, which make intervention undesirable (Chandler, 2014; Tierney, 2015). It is thereby overlooked that the so-called self-organizing system is itself the result of political decisions over a long period of time. Governments are thus accused of shifting the responsibility for vulnerable systems (which are themselves the products of formal and informal institutions and political decisions, among other things), floods, pollution, safety, welfare, health, etc. onto "resilient" individuals or individuals who ought to be become more resilient, which is another word for self-reliant (Braun, 2014; Pizzo, 2015; Tierney, 2015; Howell, 2015; Anderson, 2015; Ksenia et al., 2016; Schwartz, 2018; Davoudi, 2018). In some cases, such resilience discourse enables governments to avoid their public responsibility. An instance of such "wicked" dynamics is governments" shifting the responsibility for the provision of access to water onto local "communities" while the latter might be absent due to strife or inadequate management capacities (Katomero and Georgiadou, 2018). In such situations, vulnerable individuals and groups are denied this basic human right, while other powerful groups claim sole access to water.

Social constructivists are generally critical of the very language of resilience. Those who point out the discursive or narrative nature of resilience-based political speeches and policies are usually indebted to Michel Foucault's idea of a discourse. The latter refers to systems of thoughts and beliefs expressed through language and practices that systematically construct subjects and societies of which they speak. In other words, both language and practices are creative acts. Through resilience discourses, a particular type of subject (like resilient or self-reliant) and a particular type of society (like a market-based "society") are discursively constructed and reinforced (Miller et al., 2010). Evans and Reid (2013) thus argue that resilience has the character of a doctrine, according to which the resilient subject must accept and constantly adapt to a dangerous and changing world. Given this doctrine, vulnerability is rejected as weakness, a moral flaw (very much like a lack of character or will power) (Cole, 2016). A problematic normativity is brought into existence when citizens are expected to adapt to ecological and societal catastrophes by becoming self-reliant (Fainstein, 2014; Tierney, 2015; Kolers,

2016; Ribault, 2019). In other words, some (or most) social constructivists do not merely try to answer the question of how to make societies and individuals resilient to climate change, but instead question the normativity of the concept "resilience". Such a critical approach is arguably problematic and counterproductive in some cases. The urgency of real problems (like rising water levels that threaten millions of people) makes a dialogue between different approaches highly desirable.

3 Bridging the naturalist and constructivist view on resilience

Given the different appraisals of the very concept resilience with respect to climate change among social scientists, 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). The question of whether such unifying paradigm is possible or desirable need not be answered here. It can still be argued that it is desirable to bring together the insights gained from naturalistic and constructivist approaches to enrich and renew understandings of resilience to climate change. Resilience to climate change research that relies on naturalist and naturalistic premises may be able to provide quick solutions to crises precisely because various unpredictable and apparently irrelevant elements are discounted. The focus on the obvious problem without taking into account the broader context – which may be problematic – has many advantages, certainly if the bigger picture is taken into account after recovery from an acute crisis. In the event of a flood, for instance, the first concerns should arguably be evacuation and preventing another flood. Once everyone is safe, the question as to why the flood has affected a particular group can be raised. The particular choices made with regard to urban and rural planning can be critically scrutinized. Answers to the various questions that a flood and its aftermath raise will require knowledge from many disciplines. "Resilience" to floods will mean much more than building dams. It will also involve criticism of particular social structures, institutions and

318 decisions that have rendered some people or areas more vulnerable to natural hazards or the effects
319 of climate change.
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322 **3.1 The debate on adaptive and transformative resilience**
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324 Resilience research in recent years reveals divergence between social scientists when it comes to the
325 issue of adaptation and transformation (Chandler, 2014; Redman, 2014; Fainstein, 2014; Dahlberg et
326 al., 2015; Sjöstedt, 2015; Boas and Rothe, 2016; Duit, 2016; Ziervogel, Cowen and Ziniades, 2016;
327 Clément and Rivera, 2017; Lyster, 2017; Schlosberg, Collins and Niemeyer, 2017; Fazey et al., 2018;
328 Glaser et al., 2018; Hoekstra, Bredenhoff-Bijlsma and Krol, 2018; Jesse, Heinrichs and Kuchshinrichs,
329 2019; Dryzek and Pickering, 2019). Such disagreement can partly be explained by a particular ambiguity
330 in Holling's SES approach (Redman, 2014). In the 1970s, Holling (1973) reinterpreted resilience as
331 bouncing back or forward in terms of SES adaptation. Adaptation refers, on the one hand, to the
332 capacity of agents to influence the system (and influence or strengthen resilience as a system
333 property). And on the other hand, it alludes to panarchical adaptation to new (ecological and social)
334 environments, as an evolutionary process towards a new stage, phase, or adaptation cycle (Boyd et
335 al., 2015).
336 Yet, as Holling emphasizes, the bouncing back and bouncing forward of a system not only refers
337 to a return to some previous (dynamic) equilibrium or to the persistence and endurance of systems. It
338 also refers to socio-ecological transformation in an ongoing process of non-equilibrium and instability
339 and reinvention of systems in changing environments marked by different adaptive cycles (growth,
340 accumulation, restructuring, and renewal) (Folke, 2006). Transformation means that agents are
341 capable of creating a new system and a new discourse, particularly when the existing system is
342 untenable or illegitimate. This focus on undesirable status quos and hence on transformation – after a
343 crisis, for example – is characteristic of many social constructivists, but may also be important to those

who have somehow combined the goods of several worlds (Carolan, 2005; Code, 2005). Scholars critical of resilience discourses propounded by national and international governance actors, therefore, do not try to find ways to increase resilience, but above all things, try to ignite new imaginations and counter-discourses necessary for realizing less unsustainable futures (Fazey et al., 2018). Recently, a middle ground between adaptation and transformation has been developed, in the form of "transformational adaptation" (Pelling, O'Brien and Matyas, 2015; Mummery and Mummery, 2019). Examples of transformational adaptations include green growth or the greening of present economies. These are changes that are aligned with the scale of projected, possible and desirable changes within systems that are informed by considerations of justice.

Resilience research that emphasizes system adaption to climate change focusses on the degree to which complex 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). Given unpredictability and uncontrollability, adaptive resilience is especially a matter of 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 conceived as inherently positive, while disturbances and shocks (de-stabilizers) are negative (Duit, 2016; Lockie, 2016). Research building on the premise that adaptive resilience is desirable thus partners well with climate risk management (Boyd et al., 2015; Berbés-Blázquez et al., 2017). The response of the government to the overflowing of the Meuse River in 1993 and 1995 illustrates research-based risk reduction through adaption that involves a break with the past. The government did not simply have recourse to building more dikes and strengthening existing barriers, which has been the traditional approach, but instead opted for river deepening and widening measures (Dijkman et al., 1997; 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 to be successful. However, a research completed in 2013 (Ward et al., 2013) points out that the risk of flooding is expected to increase in the future (two- to three-fold

increase by 2030 compared to 2010), and emphasizes the need for change at the level of land-use. Indeed, the researchers found out that the impact of land-use on flood risk is likely to be greater than climate change itself. This means that households, for instance, can help to reduce the risk of future floods through a change of behavior. But that's easier said than done. The authors of the report note that there are few means to move households to participate in such risk reduction and point out the need for further research on ways to implement new measures and motivate people to change their behavior (Ward et al., 2013: 45).

Research that prioritizes transformative resilience in the context of climate change looks at a system's internal capacities, capabilities and relations that enable it to create a new condition marked by new or different power relationships and different priorities. In such cases, constructivists typically point out the undesirability and injustice of status quos (Ziervogel, Cowen and Ziniades, 2016; Rothe, 2017; Béné et al., 2018). According to this perspective, anthropological shocks open up new horizons, reassessments (including of past ideas, beliefs and practices) and rediscoveries (Beck, 2015; Fazey et al., 2018). There is no going back to how it was before these shocks. According to these critical voices, adaptive resilience research and policies based on that research contribute to maintaining systems that are unjust (Skillington, 2015; Derickson, 2016; Fazey et al., 2018; Mummery and Mummery, 2019). This does not mean that adaptive resilience research – which usually draws on "naturalistic" methods – does not include justice in its models (Redman, 2014; Thorén, 2014; Ksenia et al., 2016; Schlosberg, Collins and Niemeyer, 2017; Bergström, 2018). Yet, such models are based on, and reflects, existing systems. They cannot take structures of power into account because that structural power – to influence production, consumption, knowledge, and so on – is not a measurable entity (Howell, 2015; Pizzo, 2015; Lockie, 2016; Derickson, 2016; Davoudi, 2018). This also means that they cannot possibly integrate thoroughly unequal power relationships – such as the Global North-Global South relationship – into their models (Pizzo, 2015; Clément and Rivera, 2017; Davoudi, 2018; Glaser et al., 2018; Dryzek and Pickering, 2019).

The limitations of models need not be a problem unless they become the political tools to implement adaptive measures (Fainstein, 2014; Weichselgartner and Kelman, 2015; Huang, Boranbay-Akan and Huang, 2016; McGreavy, 2016; Ziervogel, Cowen and Ziniades, 2016; Ribault, 2019). Adaptive responses to shocks and disturbances may blur long term sustainability visions and enable powerful stakeholders to maintain their positions(Lockie, 2016; Derickson, 2016; Rothe, 2017; Estêvão, Calado and Capucha, 2017; Ribault, 2019). Kythreotis and Bristow (2017) call this phenomenon the "resilience trap" – the reinforcement of established power relations and contemporary resilience discourses (Blühdorn, 2013; Redman, 2014; Yanarella and Levine, 2014; Lockie, 2016; VanderPlaat, 2016; Schilling, Wyss and Binder, 2018; Glaser et al., 2018; Ribault, 2019). Hence, some constructivist scholars reject Holling's panarchy concept, emphasizing that transformation towards more sustainable worlds is not an evolutionary process of adaptive cycles but a political-administrative phenomenon (cf. Boyer, 2020).

3.2 Transformative resilience and sustainability

For some constructivist scholars, genuine sustainability presupposes transformative resilience because inherently unsustainable systems cannot be made more wholesome by tweaking a few of their constituents. In cases of inherent or structural defects, resilience refers to the capacity to "use" a crisis to reappraise critically the social, cultural, and political choices underpinning SES, and if necessary, to make new choices (Pizzo, 2015; Weichselgartner and Kelman, 2015; VanderPlaat, 2016; Ziervogel, Cowen and Ziniades, 2016; Hughes, 2017; Jesse, Heinrichs and Kuchshinrichs, 2019). The reconfigurations of SES do require interventions by all governance actors. Transformative resilience used in this sense is thus a post-neoliberal concept. When applied to the energy transition, transformative resilience entails a more radical change than adaptive resilience does. In the former case, this means concrete plans to phase out fossil fuels and hence to reorganize economies, where

the old fossil fuel industry no longer holds the reins (Alexander and Yacoumis, 2018; Stegemann and Ossewaarde, 2018; Bergmann and Ossewaarde, 2020). Adaptive resilience is involved when the phasing out of fossil fuels is being delayed and when certain discourses ensure that the fossil industry is given carte blanche to carry on business as usual (Buschmann and Oels, 2019). Geels (2014, p. 24) explains how "the coal regime has so far resisted climate change pressures through a "clean coal" discourse and the innovation promise of carbon capture and storage (CCS)." It is widely agreed that non-renewable fossil energy sources like coal, oil and gas are largely responsible for landscape degradation, water pollution, as well as greenhouse gas emissions and other pollutants that have been causing global warming (Cook et al., 2016). The sustainable energy transformation, accordingly, is, amongst other things, a response to climate change. In a more robust sense, it is more than simply a response to climate change. Instead, the latter is a symptom of the inherent unsustainability of the present socioeconomic system and is therefore an additional, urgent reason to radically transform the latter (Alexander and Yacoumis, 2018). Hence, those who conceive an energy transition as an adaptive necessity are primarily concerned with what several scholars call "energy resilience" (Béné et al., 2018, p. 120; Jesse, Heinrichs and Kuchshinrichs, 2019, p. 21), that is, with the continuing supply of energy to support the prevailing socioeconomic system and prevention of power outage during the transition.

In other words, reliable energy supplies at stable costs must be kept going to support the present socioeconomic system (Wiese, 2016). Since system collapse is to be avoided at any cost, adaptive resilience to climate change means incremental changes and the increasing use of renewables without stopping the use of fossil fuels (Berbés-Blázquez et al., 2017; Schilling, Wyss and Binder, 2018; Stegemann and Ossewaarde, 2018). Adaptive resilience here means the gradual greening of energy and hence the gradual greening of the system through green technological without essentially changing the old system (Geels, 2014). In fact, important stakeholders of the "old regime" resist the transition to a new order (ibid). Such resistance takes, among other things, the form of continuing investments in fossil-fuel-based energy and greening measures – which create the impression of a transition (especially in the media) – thereby further anchoring the existing system (Alova, 2020;

447 Gençsü et al., 2020). The incentives to "destabilize" such a flourishing economic system are thus
448 weakened.

449 Scholars who challenge existing social structures therefore critically point out that the primary
450 and sole focus on "energy resilience" (that is to say, energy security) is more likely to maintain the
451 energy system's status quo, which further allows powerful stakeholders to promote fossil energy and
452 keep their established positions. As Simpson (2013, p. 249) notes, the "critical approach to energy
453 security challenges the existing economic, political and technical assumptions that underpin traditional
454 debates on energy production and consumption, but it also challenges traditional notions of security
455 that have the nation-state as their referent object". An uncritical adaptive energy resilience approach
456 can thus reinforce "energy injustice", that is, the "the unequal distribution of ills" throughout the
457 energy system, whereby that system is defined as "the entire energy chain, from mining, conversion,
458 production, transmission, and distribution, right through to energy consumption and waste" (Jenkins
459 et al., 2016, p. 179). Scholars who focus on the transformative resilience of energy systems are
460 therefore generally committed to energy justice and have a more critical approach to energy resilience
461 (or security) because the latter presumes the socioeconomic order and unequal structures of power
462 (Jenkins et al., 2016; Heffron and McCauley, 2017). They propose the creation of a renewable energy-
463 based system, energy commons and collaboratives beyond the energy establishment (VanderPlaat,
464 2016; Bourbeau and Ryan, 2018; Juncos, 2018; Schwartz, 2018; Acosta et al., 2018; Jesse, Heinrichs
465 and Kuchshinrichs, 2019).

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467

468 **4. Six upcoming themes in diversified resilience research**

469

470 Current research on resilience to climate change in the social sciences reflects a diversity of focusses
471 and commitments, ranging from climate-resilient infrastructure to issues of justice and power. Some
472 critical scholars question the very notion of resilience and point to the "wicked" dynamics involved as

473 “resilience” becomes a policy instrument to consolidate one particular, often established social reality
474 at the expense of other, fairer possible alternatives. Research that unwittingly supports such political
475 purpose has thus attracted the criticism of scholars who emphasize transformation towards new social
476 constellations, where power (to influence the course of things), responsibility, burdens, and benefits
477 are fairly distributed (Derickson, 2016; Jenkins et al., 2016; Heffron and McCauley, 2017; Alexander
478 and Yacoumis, 2018; Davoudi, 2018; Glaser et al., 2018; Stegemann and Ossewaarde, 2018).
479 Ultimately, the overarching challenge for future research is to ensure that resilience to climate change
480 does not compromise sustainability and considerations of justice (including, environmental, climate
481 and energy justice).Based on our overview of recent scholarship, which cannot possibly be exhaustive,
482 we have identified six research avenues that deserve continuing attention.

483 One of them is the further development of transdisciplinarity, which includes the collaboration
484 between constructivist and naturalistic approaches to resilience, not only at the institutional level, but
485 especially at the level of research itself. Such transdisciplinarity thus means that a scholar draws on
486 different scientific traditions to approach one particular problem. In other words, transdisciplinarity
487 does not restrict itself to “forced” collaboration between scholars from different disciplines, which is
488 a prevalent organization of inter, multi and trans -disciplinarity (cf. Pohl, 2001). It also does not mean
489 homogenization of science and the repression of the diversity of human thinking. It does entail an
490 appreciation of diverse scientific vocabularies, of the variety of scientific knowledge, and the
491 acknowledgement of clashes, which can be conducive to the advancement of human knowledge (cf.
492 Pfeffer and Georgiadou, 2019). Bringing together various perspectives of a complex reality arguably
493 fosters our understanding of that same reality.

494 There have been several attempts to “bridge” the disciplinary divide, some more successful than
495 others. Such attempts at integration are deemed even more desirable when it comes to environmental
496 issues (Pompe and Rinehart, 2002; Mooney et al., 2013). Edward O. Wilson’ famous consilience is a good
497 example of a failed attempt since he takes the natural sciences and their methods to be hegemonic. Wilson
498 (1998, p. 11) thus notes:

> Given that human action comprises events of physical causation, why should the social sciences and humanities be impervious to consilience with the natural sciences? […] Nothing fundamental separates the course of human history from the course of physical history, whether in the stars or in organic diversity.

Similarly, the allegedly transdisciplinary "Earth System Analysis" approach, developed at the Potsdam-Institute for Climate Impact Research (Germany), makes use of mathematical modelling in which the world is conceived as a cybernetic organism (Pohl, 2001, p. 40).

More successful integrative approaches do not allow the methodology and theoretical framework of one particular scientific tradition to dominate the other. We have mentioned "ecological naturalism" above as an example of such an approach. The "critical realist" (Proctor, 1998) is yet another way to benefit from the realism of the naturalist approach, thereby avoiding relativism, without falling into the trap of reification and determinism. With regard to energy, for instance, Jenkins et al (2016, p. 179) argue that a "combination of the social science account of energy (policy) with its natural science counterpart (systems)" helps us to determine where injustices lie, even more accurately than through social constructivist approaches alone. Conversely, evolutionary resilience approaches that draw on system thinking can be enriched by taking into account human agency, the issue "unequal power relations that can disrupt feedback loops and channels of communications" (Davoudi, 2018, p. 4), and more generally, the idea that we cannot simply wait for evolutionary change, or for systems to explode, but instead have to realize alternatives imagined by human imagination.

This brings us to the second theme, which could be dubbed "critical resilience" research. Critical thinking is arguably a precondition for, and characteristic of, science in general. This means that reservations with regard to the very concept "resilience", in policies and models, need to be taken seriously. Research that constantly analyses the dominant and new – and often, implicit – conceptions of resilience must thus be stimulated even if it does not seem to serve practical purposes. Critical

525 resilience research thus also includes the integration of reflexivity in transdisciplinary research, which
526 involves “a reflexive questioning of values, background assumptions and normative orientations”
527 (Popa et al., 2015, p. 46) of various approaches to resilience. Critical resilience research is expected to
528 pay attention to diverse conceptions of resilience and also to address the “question of outcomes and
529 who gets to define them as resilient or otherwise”, “the potential exclusions in determining system
530 “boundaries”, and “the question of the political—resilience from what, to what, and who gets to
531 decide?” (Porter and Davoudi, 2012, p. 331). Such critical resilience research can accompany other
532 resilience research, thereby preventing science from serving ideological goals.

533 A third research avenue, somewhat related to the second theme, consists in the
534 contextualization of resilience research and discourse, that is, in embedding it in its political and
535 cultural context. By understanding the bigger picture in which both the ecological crisis and the
536 responses to it arise, it may be possible to govern resilience research towards sustainability and justice,
537 and to identify the factors – which may be institutional, cultural or political – that stimulate or deter
538 such change (cf. Bahadur and Tanner, 2014). In a system thinking language, such research can identity
539 the various agents that maintain or disrupt the system. For instance, on the one hand, environmental
540 protest movements are stakeholders that develop a leverage required to transform established
541 systems (such as energy systems) and their governance arrangements. On the other hand, agents who
542 hold power thanks to such arrangements typically use tactics of repression and criminalization,
543 particularly in the extractive sectors of the Global South (Szablowski and Campbell, 2019). Research
544 focusing on the different fields of forces in various political contexts may discover how differences in
545 system adaptation and reconfiguration relate to particular administrative capacities and governance
546 arrangements (cf. Blühdorn, 2013; Fischer, 2017; Davoudi, 2018; Köhler et al., 2019; Mummery and
547 Mummery, 2019). It can also generate insights into the (possible) connection between particular
548 resilience policies and models, on the one hand, and new forms of power inequalities, polarization,
549 injustice, and democratic deficits, on the other hand. Bierbaum and Stults (2013, p. 18) point to the
550 “growing recognition of the need for a new model of deep and long-term stakeholder engagement”.

551 Such a model ensure that all (local) stakeholders are involved in determining a "vision of resilience,
552 impediments to achieving that vision, and contextually relevant actions for achieving that vision"
553 (Bierbaum and Stults, 2013, p. 30). It can safeguard both the effectiveness and equitability of solutions.

554 A fourth promising topic for future resilience research is the interplay between adaptive
555 resilience and transformative resilience and transformational adaptation (Clément and Rivera, 2017).
556 The focus can be on the ways in which transformational adaptation manifests itself, how multiple
557 adaptations may lead to transformational adaptation and the tipping points for igniting
558 transformation (Grove and Chandler, 2017; Glaser et al., 2018). The notion of "tentative governance"
559 appears particularly relevant in the context of transformational politics, when it comes to phasing out
560 systems and weakening adaptive resilience. Tentative governance is marked by interventions that are
561 designed as preliminary rather than as persistent, for purposes of probing and learning rather than for
562 stipulating definite targets or fixating existing systems and their underlying assumptions (Kuhlmann,
563 Stegmaier and Konrad, 2019). It is likely that stakeholder engagement (including resistance) in
564 transformational politics and tentative governance varies, and manifests itself differently, across
565 different policy fields. For instance, the sustainable energy transformation may include multi-layer
566 governance challenges, many pro-active stakeholders, new investment opportunities and job
567 opportunities. In contrast with the sustainable energy transformation, sea level rise and the disruption
568 and relocation of coastal cities may trigger a more limited transformative politics, despite inevitable
569 transformation of systems due to shocks and disturbances (metamorphosis). Yet, in the coming
570 decade, transformational politics and tentative governance – including anthropogenic topics like
571 population displacement, privatization of climate adaptation, conflict organized around scarce
572 resources (like water resources), intergenerational environmental conflict, and the closing of old
573 infrastructures that are too costly to maintain – becomes a more urgent research topic.

574 The fifth research theme concerns the relationship between the phasing out of unsustainable
575 systems and societal transformations. In other words, what are the implications of the disintegration
576 of old systems for societies, that is, for their cultures, collective identities, traditions, economies,

political-administrative power constellations, class structures, etc.?; and which societal transformations promote such disintegration? Research topics encompass the governing and accelerating of the decline of existing systems and their adaptive cycles (Stegmaier, Visser and Kuhlmann, 2014; Hoffmann, Weyer and Longen, 2017; Stegmaier, Visser and Kuhlmann, 2020); the particular circumstances in which accelerations can manifest themselves; the identification of, and coping with, uncertainties in processes of adaptation and transformation and transformational adaptation; and the construction of new incentive structures, for accelerating sustainable transformation (cf. Clément and Rivera, 2017; Warmink et al., 2017; Köhler et al., 2019). This branch of discontinuation research assumes that technologies influence socio-ecological systems. Some technologies threaten resilience to climate change, while others enhance it (Smith and Stirling 2010), which brings us to another, related research topic, namely, the implications of the so-called "AI Revolution" and the (top down and politically steered) making of the alleged "Age of Artificial Intelligence" for resilience research and SES (Berendt, 2019).

Given worldwide investments in AI technologies and top-down AI strategies that global governance actors and national governments have recently published (Ossewaarde and Gülenç, 2020), AI will most plausibly become a major force that shapes or undermines resilience to climate change. New interplays between automation, (un)sustainability, and adapting and transforming systems trigger new questions for future resilience research (cf. Köhler et al., 2019). Hoefsloot et al (2019) have expressed the concern that the total and unconditional reliance on the data generated by AI technology may lead to a flawed prediction of climate disasters. For instance, the coverage of climate disasters – satellite data, drone data, sensor data, social media data, volunteer geographic information (VGI) data, among others – may be incomplete and leave out certain geographical areas and even certain social groups (Hoefsloot et al., 2019). Other sources of information are necessary to ensure more accurate measurements (and predictions), complement data gaps and identify the needs of local communities (Bierbaum and Stults, 2013; Pfeffer and Georgiadou 2019). A recent example of the integration of different sources of knowledge is the resilient settlement program led by UN

603 HABITAT, which brought together a multitude of actors (policy, private, academic, community
604 organizations) and data and algorithms and local knowledges to identify settlements at risks
605 (unhabitat.org, 2019). This example illustrates the importance of embedding AI technologies in
606 particular contexts so that the needs of particular communities, for instance, are served, and fairness
607 and transparency are safeguarded. Resilience research and models must therefore include an
608 evaluation of AI technologies: how has data been acquired and by whom?; what are the implications
609 of particular AI technologies for the SES in question?; which new power relations are established
610 through the reliance on AI technologies?; which stakeholders are being included and which ones
611 excluded during the whole process beginning with the problem definition to the formulation of
612 solutions that involve an intensive application of AI? (Rajan and Saffiotti, 2017; Taddeo and Floridi,
613 2018; Khakurel et al., 2018; Vahedifard, et al., 2019; Miller, 2019; Saravi et al., 2019).

614 A sixth theme for future resilience research concerns the role of environmental, energy and
615 climate justice in theorizing, modeling, interpreting, and explaining resilience to climate change (cf.
616 Skillington, 2015; Fazey et al., 2018; Mummery and Mummery, 2019). What kind of research results
617 from the integration of theories of environmental justice, energy justice and climate justice into
618 adaptive and transformative resilience and transformational adaptation models? Future resilience
619 research will somehow have to confront wicked problems: given unstable political contexts, scarcity
620 of "resources" and struggles for survival and power, how can principles of equity, fairness and access
621 to resources and services be secured?; In the problematic context of climate-induced migration and a
622 political environment marked by anti-immigration policies, how can the wellbeing of migrants be
623 ensured and, in general, human rights be safeguarded?; how can the disparity and inequality in the
624 distribution of risks, locally and globally, be tackled? Equity in this regard will mean much more than
625 equality. Other challenges include the incorporation of cross-sectional dimensions of justice,
626 particularly gender and racial relations, into climate justice (Terry, 2009), and energy justice (Feenstra
627 and Özerol, 2018) frameworks. And in the Global South, addressing issues of corruption, violence,
628 poverty and lack of access to resources (and violent battles for resources) and services (like education

629 and sanitation) may have a higher priority than global environmental considerations (Köhler et al.,
630 2019).
631
632 **5. Conclusion**
633
634 In the social sciences, resilience to climate change is a concept that is incorporated in different
635 theoretical approaches that are linked to contrasting scientific approaches. Holling originally
636 reinterpreted and incorporated the notion of resilience in his SES approach, which was then picked up
637 by naturalist scientists and embedded in cybernetic complexity theory, for instance. The complexity
638 theory was for a very long time the preferred approach to resilience to climate change in the social
639 sciences. This situation changed as resilience increasingly became the theme of political discourses
640 and policies some decade ago, especially in the wake of socio-ecological catastrophes, financial crises,
641 and pandemics. The instrumentalization and decontextualization of resilience by local and global
642 governance actors invited the critical response of scholars who often had recourse to constructivist
643 approached. The diversification of resilience research and expansion of the social scientific jargon
644 resulted from this development. The question of whether resilience should operate as a unifying
645 paradigm is not yet settled. However, it may well facilitate interdisciplinary dialogue and even
646 transdisciplinarity. Such cooperation or dialogue is arguably necessary given the extremely complex
647 nature of our socio-ecological predicaments. New light may be shed on how new political-
648 administrative institutions (including panarchical self-organization) and practices can respond in
649 legitimate ways (taking justice and vulnerability considerations into account) to the challenges of
650 climate change, in different ecological, political and technological contexts (cf. Johnsson et al., 2018).
651 The six themes for future resilience research that we have identified combine naturalist and
652 constructivist insights and approaches so that human agency, reflexivity and considerations of justice
653 and equity are incorporated into research that predominantly involves system thinking. In fact, further
654 cooperation is the first identified research theme. Interdisciplinary and multidisciplinarity between

naturalist and constructivist approaches and the many varieties of these approaches can prove to be challenging, not only because of clashing methodologies and conceptual frameworks, but also because of institutional factors. Yet, there have been attempts to reduce the gap between these approaches, without destroying a fruitful tension. The second research area could be called "critical resilience" research. It includes questioning the very concept of resilience and proposing alternatives or supplementary concepts. Such critical resilience research will most probably be a complement to, or necessary component of, other resilience research. The third theme consists in the contextualization of resilience research, which serves the multiple purposes of effectiveness (of measures), sustainability and justice. The interaction between, as well as the blurry line, between adaption (adaptive resilience) and transformation (transformative resilience) is the fourth research area. Related to the latter topic is research focusing on the two-way relationship between the phasing out of unsustainable systems and societal transformations. Given the increasing incorporation of AI technologies in resilience research and policies, a fifth research topic pertains to the implications of AI technologies for societies, and more specifically, for sustainability and justice. The final theme is the integration of various forms of justice (such as inter-racial) and theories of justice into resilience research.

References

Acosta, C., Ortega, M., Bunsen, T. Koirala, B.P., and Ghorbani, A.: Facilitating energy transition through energy commons: an application of socio-ecological systems framework for integrated community energy systems, Sustainability, 10, 366, 2018.

Adger, W.N., Brown, K., Nelson, D.R., Berkes, F., Eakin, H. , Folke, C., Galvin, K., Gunderson, L., Goulden, M., O'Brien, M., Ruitenbeek, J., and Tompkins, E.L.: Resilience implications of policy responses to climate change, WIRE's Climate Change, 2, 5, 757-766, 2011.

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

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

Alexander, S. and Yacoumis, P.: Degrowth, energy descent, and “low-tech” living: Potential pathways for increased resilience in times of crisis**,** Journal of Cleaner Production, 197, 1840-1848, 2018.

Allen, C.R, Angeler, D.G., Germestani, A.S., Gunderson, L.H., and Holling, C.S.: Panarchy: Theory and Application, Ecosystems 17, 578-589, 2014.

Alova, G.: A global analysis of the progress and failure of electric utilities to adapt their portfolios of power-generation assets to the energy transition, Nature Energy, 5: 1-8, 2020.

Anderson, B.: What kind of thing is resilience?”*,* Politics, 35, , 60-66, 2015.

Andler D.: Is social constructivism soluble in critical naturalism?, in Galavotti M., Dieks D., Gonzalez W., Hartmann S., Uebel T., and Weber M. (eds) New Directions in the Philosophy of Science. The Philosophy of Science in a European Perspective, 5. Springer, 2014.

Bahadur A. and Tanner T.: Transformational resilience thinking: putting people, power and politics at the heart of urban climate resilience, Environment and Urbanization, 26, 1, 200-214, 2014.

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

Belkhir, J.A. and Charlemaine, C.: Race, Gender and Class Lessons from Hurricane Katrina, Race, Gender and Class, 14, 1, 120-152, 2007.

Béné, C, Mehta, L., McGranahan, G., Cannon, T. Gupte, J., and Tanner, T.: Resilience as a policy narrative: potentials and limits in the context of urban planning, Climate and Development, 10, 2, 116-133, 2018.

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

Berendt, B.: AI for the common good?! Pitfalls, challenges, and ethics pen-testing, Paladyn: Journal of Behavioral Robotics, 10, 1, 44–65, 2019.

Bergmann, Z. and Ossewaarde, R.: Youth climate activists meet environmental governance: Ageist depictions of the FFF movement and Greta Thunberg in German newspaper coverage, Journal of Multicultural Discourses, 2020.

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

Berkes, F. and Ross, H.: Panarchy and community resilience: Sustainability science and policy implications", Environmental Science and Policy, 61, 185-193, 2016.

Bierbaum, R. and Stults, M.: Adaptation to climate change: Context matters, *Michigan Journal of Sustainability,* 1, 15-30, 2013.

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

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

Boyer, J.: Toward an Evolutionary and Sustainability Perspective of the Innovation Ecosystem: Revisiting the Panarchy Model, Sustainability, 12, 8, 3232, 2020.

Borsje, B.W., van Wesenbeeck, B., Dekker, F., Paalvast, P., Bouma, T.J., and De Vries, M.B.: How ecological engineering can serve in coastal protection – a review, Ecological Engineering, 37, 113-122, 2011.

Bourbeau, P.: Resilience and international politics: Premises, debates, agenda, International Studies Review, 17, 374-395, 2015.

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

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

Bracking, S.: Financialisation, climate finance, and the calculative challenges of managing environmental change, Antipode, 51, 3, 709-729, 2019.

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

Buschmann, P., and Oels, A.: The overlooked role of discourse in breaking carbon lock-in: The case of the German energy transition, Wiley Interdisciplinary Reviews: Climate Change, 10, 3, 1-14, 2019.

Carolan, M. S.: Realism without reductionism: toward an ecologically embedded sociology, Human Ecology Review, 12, 1, : 1-20, 2005.

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

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

Clément, V. and Rivera, J.: From adaptation to transformation: An extended research agenda for organizational resilience to adversity in the natural environment, Organization and Environment, 30, 4, 346-365, 2017.

Code, L.: Ecological naturalism: Epistemic responsibility and the politics of knowledge, Dialogue and Universalism, 15, 5, 87-101, 2005.

Cole, A.: All of us are vulnerable, but some are more vulnerable than others: The political ambiguity of vulnerability studies, an ambivalent critique, Critical Horizons, 17, 2, 260-277, 2016.

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

Cook, J., Oreskes, N., Doran, P. T., Anderegg, W. R., Verheggen, B., Maibach, E. W., and Nuccitelli, D.: Consensus on consensus: a synthesis of consensus estimates on human-caused global warming, Environmental Research Letters, 11, 4, 048002, 2016.

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

Dahlberg, R.: Resilience and complexity: Conjoining the discourses of two contested concepts, Culture Unbound, 7, 541-557, 2015.

758 Dahlberg, R., Johannessen-Henry, C.T., Raju, E., and Tulsiani, S.: Resilience in disaster research: Three
759 versions, Civil Engineering and Environmental Systems, 32, 1-2: 44-54, 2015.
760 Davoudi, S.: Just resilience, City and Community, 17, 1, 3-7, 2018.
761 Derickson, K.D., Resilience is not enough, City, 20, 1, 161-166, 2016.
762 Dijkman, J., Klomp, R., and Villars, M.: Flood management strategies for the Rivers Rhine and Meuse in
763 The Netherlands, IAHS Publications-Series of Proceedings and Reports-Intern Assoc Hydrological
764 Sciences, 239, 371-382, 1997.
765 Douglas, M. and Wildavsky, A.: Risk and Culture. An Essay on the Selection of Technological and
766 Environmental Dangers, Berkeley: University of California Press, 1983.
767 Dryzek, J.S. and Pickering, J.: *The Politics of the Anthropocene*, Oxford: Oxford University Press, 2019.
768 Duffield, M.: The resilience of the ruins: Towards a critique of digital humanitarianism, Resilience, 4, 3,
769 147-165, 2016.
770 Duit, A.: Resilience thinking: Lessons for public administration, Public Administration, 94, 2, 364-380,
771 2016.
772 Estêvão, P., Calado, A., and Capucha, L.: Resilience: Moving from a “heroic” notion to a sociological
773 concept, Sociologia, Problemas E Práticas, 85, 9-25, 2017.
774 Evans, B. and Reid, J.: Dangerously exposed: the life and death of the resilient subject, Resilience, 1, 2,
775 83-98, 2013.
776 Fainstein, S.: Resilience and justice, International Journal of Urban and Regional Research, 157-167,
777 2014.
778 Farmer, J.D. and Foley, D.: The economy needs agent-based modelling, Nature, 460, 685-686, 2009.
779 Fazey, I., P. Moug, S. Allen, K. Beckmann, D. Blackwood, M. Bonaventura, K. Burnett, M. Danson, R.
780 Falconer, A.S. Gagnon, R. Harkness, A. Hodgson, L. Holm, K.N. Irvine, R. Low, C. Lyon, A. Moss, C. Moran,
781 L. Naylor, K. O”Brien, S. Russell, S. Skerratt, J. Rao-Williams, and Wolstenholme, R.: Transformation in
782 a changing climate: a research agenda, Climate and Development, 10, 3, 197-217, 2018.

783 Feenstra, M. and Özerol, G.: Using energy justice as a search light for gender and energy policy
784 research: a systematic review, 12th ECPR General Conference, Hamburg, Germany, August 2018.
785 Filatova, T., Polhill, J.G., and Van Ewijk, S.: *Regime shifts in coupled socio-environmental systems:*
786 *Review of modelling challenges and approaches,* **Environmental Modelling and Software***,* 75, 333-347,
787 2016.
788 Fischer, F.: Climate crisis and the democratic prospect: participatory governance in sustainable
789 communities, Oxford: Oxford University Press, 2017.
790 Floridi, L.: A plea for non-naturalism as constructionism, Minds and Machines, 27, 269-285, 2017.
791 Folke, C.: *Resilience: The emergence of a perspective for social–ecological systems analyses, Global*
792 *Environmental Change, 16, 3, 253-267, 2006.*
793 Frost, T.: The *dispositif* between Foucault and Agamben, Law, Culture and the Humanities*,* 15, 1, 151-
794 171, 2019.
795 Gallopin, G.C.: Linkages between vulnerability, resilience, and adaptive capacity, Global Environmental
796 Change*,* 16, 293–303, 2006.
797 Geels, F. W., and Schot, J.: Typology of sociotechnical transition pathways, Research Policy, 36, 3, 399-
798 417, 2007.
799 Geels, F. W.: Regime resistance against low-carbon transitions: introducing politics and power into the
800 multi-level perspective, Theory, Culture and Society, 31,5, 21-40, 2014.
801 Gençsü, I., Whitley, S., Trilling, M., van der Burg, L., McLynn, M., and Worrall, L.: Phasing out public
802 financial flows to fossil fuel production in Europe, Climate Policy, 20, 8, 1010-1023, 2020.
803 Gim, C., Miller, C.A., and Hirt, P.W.: The resilience work of institutions, Environmental Science and
804 Policy, 97, 36-43, 2019.
805 Glaser, M., Plass-Johnson, J.G., Ferse, S.C.A., Neil, M., Satari, D.Y., Teichberg, M., and Reuter, H.:
806 Breaking resilience for a sustainable future: Thoughts for the Anthropocene, Frontiers in Marine
807 Science, 5, 34, 2018.

Groß, M. and Stauffacher, M.: Transdisciplinary environmental science: problem-oriented projects and strategic research programs, Interdisciplinary Science Reviews, 39, 4, 299-306, 2014.

Grove, K. and Chandler, D.: Introduction: Resilience and the Anthropocene: The stakes of "renaturalising" politics", Resilience, 5, 2: 79-91, 2017.

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

Haasnoot, M., Kwakkel, J.H., Walker, W.E., and Ter Maat, J.: Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world, Global Environmental Change, 23, 2, 485-498, 2013.

Hamers, T., Kamstra, J.J., Van Gils, J. Kotte-Albertus, M.C., and Van Hattum, G.M.: T*he 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, 2015.*

Hawes C. and Reed, C.: 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, 2006.

Heffron, R.J. and McCauley, D.: The concept of energy justice across the disciplines, Energy Policy, 105, 658-667, 2017.

Henkel, K.E., Dovidio, J.F., and Gaertner, S.L.: Institutional discrimination, individual racism, and Hurricane Katrina, Analyses of social issues and public policy, 6, 1, 99-124, 2006.

Hoefsloot, F. I., Pfeffer, K., and Richter, C.: *People and places uncounted: Legibility in the water infrastructure of Lima, Peru, 1*-17, Paper presented at City Futures 2019, Dublin, Ireland, 2018.

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

Hoffmann, S., Weyer, J., and Longen, J.: Discontinuation of the automobility regime. An integrated approach to multi-level governance, Transportation Research, Part A, 103, 391-408, 2017.

833 Holling, C.S.: Resilience and stability of ecological systems, Annual Review of Ecology and Systematics,
834 4, 1-23, 1973.
835 Holling, C.S.: Understanding the complexity of economic, ecological, and social systems, Ecosystems,
836 4: 390-405, 2001.
837 Howell, A.: Resilience as enhancement: Governmentality and political economy beyond
838 “responsibilisation”, Politics, 35, 1, 67-71, 2015.
839 Huang, H., Boranbay-Akan, S. and Huang, L.: Media, protest diffusion, and authoritarian resilience,
840 Political Science Research and Methods, 7, 1, 23-42, 2016.
841 Hughes, S.: The politics of urban climate change policy: Towards a research agenda, Urban Affairs
842 Review, 53, 2, 362-380, 2017.
843 Indirli, M.: An historical flight and some open questions towards a pluralistic but holistic view of
844 resilience, Geographies of the Anthropocene 2, 2, 194-248, 2019.
845 Jenkins, K., McCauley, D., Heffron, R., Stephan, H., and Rehner, R.: Energy justice: A conceptual review,
846 Energy Research and Social Science, 11, 174-182, 2016.
847 Jesse, B-J., Heinrichs, H.U., and Kuchshinrichs, W.: Adapting the theory of resilience to energy systems:
848 a review and outlook, Energy, Sustainability and Society, 9, 27, 2019.
849 Johnson, J.L., Zanotti, L, Ma, Z., Yu, D.J., Johnson, D.R., Kirkham, A., and Carothers, C.: Interplays of
850 Sustainability, Resilience, Adaptation and Transformation, in: W. Leal Filho, R. Marans and J. Callewaert
851 (eds) Handbook of Sustainability and Social Science Research, World Sustainability Series. Springer,
852 Cham, 2018.
853 Johnston, P. and Stirling, A.: Comparing nuclear trajectories in Germany and the United Kingdom: From
854 regimes to democracies in sociotechnical transitions and discontinuities, Energy Research and Social
855 Science, 59, 101245, 2018.
856 Juncos, A.E.: Resilience as the new EU foreign policy paradigm: a pragmatist turn?, European Security,
857 26, 1, 1-18, 2017.

858 Juncos, A.E.: Resilience in peacebuilding: Contesting uncertainty, ambiguity, and complexity,
859 Contemporary Security Policy, 39, 4, 559-574, 2018.
860 Kates, R.W., Travis, W.R., and Wilbanks, T.J.: Transformational adaptation when incremental
861 adaptations to climate change are insufficient, Proceedings of the National Academy of Sciences of the
862 United States of America, 109, 19, 7156-7161, 2012.
863 Katomero, J. and Georgiadou, Y.: The elephant in the room: Informality in Tanzania's rural waterscape,
864 *ISPRS International Journal of Geo-Information*, 7, 437, 2018.
865 Khakurel, J., Penzenstadler, B., Porras, J., Knutas, A., and Zhang, W.: The rise of artificial intelligence
866 under the lens of sustainability, Technologies*,* 6, 100, 2018.
867 Kitchen, R.: Steering the real-time city through urban big data and city dashboards?, 2018.
868 https://urbact.eu/steering-real-time-city-through-urban-big-data-and-city-dashboards-0
869 Klein, J., Juhola, S., and Landauer, M.: Local authorities and the engagement of private actors in climate
870 change adaptation, Environment and Planning C: Politics and Space, *35,* 6, 1055-1074, 2017.
871 Köhler, J., F.W. Geels, F. Kernc, J. Markard, E. Onsongo, A. Wieczorek, F. Alkemade, F. Avelino, A.
872 Bergek, F. Boons, L. Fünfschilling, D. Hess, G. Holtz, S. Hyysalok, K. Jenkins, P. Kivimaa, M. Martiskainen,
873 A. McMeekin, M.S. Muhlemeier, B. Nykvist, B. Pel, R. Raven, H. Rohracher, B. Sandén, J. Schot, B.
874 Sovacool, B. Turnheim, D. Welch and Wells, P.: An agenda for sustainability transitions research: State
875 of the art and future directions, Environmental Innovation and Societal Transitions, 31, 1-32, 2019.
876 Kolers, A.: Resilience as a political ideal. Ethics, Policy and Environment, 19, 1, 91-107, 2016.
877 Ksenia, C., Lizarralde, G., Dainty, A., and Bosher, L.: Unpacking resilience policy discourse, Cities, 58,
878 70-79, 2016.
879 Kuhlicke, C.: Resilience: a capacity and a myth: findings from an in-depth case study in disaster
880 management research, Natural Hazards, 67, 61-76, 2013.
881 Kuhlmann, S., Stegmaier, P. and Konrad, K.: The tentative governance of emerging science and
882 technology— A conceptual introduction**,** Research Policy, 48, 5, 1091-1097.

883 Kythreotis, A.P. and Bristow, G.I.: The “resilience trap”: exploring the practical utility of resilience for
884 climate change adaptation in UK city-regions, Regional Studies, 51, 10, 1530-1541, 2017.
885 Lockie, S.: Beyond resilience and systems theory: reclaiming justice in sustainability discourse,
886 Environmental Sociology, 2, 2, 115-117, 2016.
887 Lund, J.R.: Integrating social and physical sciences in water management, Water Resources Research,
888 51, 5905–5918, 2015.
889 Lyster, R.: Climate justice, adaptation and the Paris Agreement: A recipe for disasters?, Environmental
890 Politics, 26, 3, 438-458, 2017.
891 Martin, R. and Schlüter, M.: Combining system dynamics and agent-based modeling to analyze social-
892 ecological interactions—an example from modeling restoration of a shallow lake, Frontiers in
893 Environmental Science, 3, 66, 2015.
894 Marvin, S., Luque-Ayala, A., and McFarlane, C.: *Smart urbanism: Utopian vision or false dawn*, New
895 York, NY: Routledge, 2016.
896 McGreavy, B.: Resilience as discourse, Environmental Communication, 10, 1, 104-121, 2016.
897 Miller, F., H. Osbahr, E. Boyd, F. Thomalla, S. Bharwani, G. Ziervogel, B. Walker, J. Birkmann, S. Van der
898 Leeuw, J. Rockström, J. Hinkel, T. Downing, C. Folke, and Nelson, D.: Resilience and vulnerability:
899 Complementary or conflicting concepts?, Ecology and Society, 15, 3, 11, 2010.
900 Miller, T.: Explanation in artificial intelligence: Insights from the social sciences, Artificial Intelligence,
901 267, 1-38, 2018.
902 Mirchandani, C.: Resilience Modeling in Complex Systems, *Procedia Computer Science*, 168, 232-240,
903 2020.
904 Mooney, H.A., Duraiappah, A., and Larigauderie, A.: Evolution of natural and social science interactions
905 in global change research programs, Proceedings of the National Academy of Sciences, 110,
906 Supplement 1, 3665-3672, 2013.
907 Mummery, J. and Mummery, J.: Transformative climate change adaptation: Bridging existing
908 approaches with post-foundational insights on justice, Local Environment, 24, 10, 919-930, 2019.

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

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

Olsson, L,: Why resilience is unappealing to social science: Theoretical and empirical investigations of the scientific use of resilience, Science Advances**,** 1, 4, 2015.

Ossewaarde, M. and Gülenç, E.: National varieties of AI discourses: Myth, utopianism and solutionism in West European policy expectations, Computer, 53, 11, 53-61, 2020.

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

Popa, F., Guillermin, M., Dedeurwaerdere, T.: A pragmatist approach to transdisciplinarity in sustainability research: From complex systems theory to reflexive science, Futures, 65, 45-56, 2015.

Paradiso, M.: Information geography: A bridge between engineering and the social sciences, Journal of Urban Technology, 13, 3, 77-92, 2006.

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

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

Pelling, M., O'Brien, K., and Matyas, D.: Adaptation and transformation, Climatic Change, 133, 1, 113-127, 2015.

Pfeffer, K. and Georgiadou, Y.: Global ambitions, local contexts: Alternative ways of knowing the world, *ISPRS International Journal of Geo-Information*, 8, 516, 2019.

933 Pietrapertosa, F., Salvia, M., De Gregorio Hurtado, S., D'Alonzo, V., Church, J.M., Geneletti, D., Musco,
934 F., and Reckien, D.: Urban climate change mitigation and adaptation planning: Are Italian cities ready?,
935 Cities, 91, 93-105, 2019.
936 Pizzo, B.: Problematizing resilience: Implications for planning theory and practice, Cities, 43, 133-140,
937 2015.
938 Pohl, C.: How to bridge between natural and social sciences? An analysis of three approaches to
939 transdisciplinary from the Swiss and German field of environmental research, Nature Sciences
940 Sociétés, 9, 3, 37-46, 2001.
941 Pompe, J.J, and Rinehart, J.R.: Environmental conflict: In search of common ground, Albany NY, State
942 University of New York Press, 2002.
943 Porter, L. and Davoudi, S.: The politics of resilience for planning: A cautionary note. Planning Theory
944 and Practice, 13, 329-333, 2012.
945 Proctor, J.D.: Expanding the scope of science and ethics, Annals of the Association of American
946 Geographers, 88, 2, 290-296, 1998.
947 Proctor, J.D: The social construction of nature: Relativist accusations, pragmatist and critical realist
948 responses, Annals of the Association of American Geographers, 88, 3, 352-376, 1998.
949 Pumpuni-Lenss, G., Blackburn, T. and Garstenauer, A.: Resilience in complex systems: An agent-based
950 approach, Systems Engineering, 20, 2, 158-172, 2017.
951 Rajan, A. and Saffiotti, A.: Towards a science of integrated AI and robotics, Artificial Intelligence, 247,
952 1-9, 2017.
953 Redman, C. L.: Should sustainability and resilience be combined or remain distinct pursuits?, Ecology
954 and Society, 19, 2: 37, 2014.
955 Ribault, T.: Resilience in Fukushima: Contribution to a political economy of consent, Alternatives:
956 Global, Local, Political, 44, 2-4, 94-118, 2019.
957 Rodríguez-González, A., Zanin, M. and Menasalvas-Ruiz, E.: Public Health and Epidemiology
958 Informatics: Can Artificial Intelligence Help Future Global Challenges? An Overview of Antimicrobial

959 Resistance and Impact of Climate Change in Disease Epidemiology, IMIA Yearbook of Medical
960 Informatics, 224-231, 2019.
961 Rogge, K. S., and Johnston, P.: Exploring the role of phase-out policies for low-carbon energy
962 transitions: The case of the German Energiewende, Energy Research and Social Science, 33, 128-137,
963 2017.
964 Rogge, K. S., Kern, F., and Howlett, M.: Conceptual and empirical advances in analysing policy mixes
965 for energy transitions, Energy Research and Social Science, 33, 1-10, 2017.
966 Rothe, D.: Gendering resilience: Myths and stereotypes in the discourse on climate-induced migration,
967 Global Policy, 8, 40-46, 2017.
968 Ruinen, R. van, Filatova, T., Jager, W. and Van der Veen, A.: Going beyond perfect rationality: Drought
969 risk, economic choices and the influence of social networks, The Annals of Regional Science, 57, 2-3,
970 335-369, 2015.
971 Samarakoon, S.: A justice and wellbeing centered framework for analysing energy poverty in the Global
972 South, Ecological Economics, 65(C), 106385, 2019.
973 Saravi, S., Kalawsky, R., Joannou, D., Rivas Casado, M., Fu, G., and Meng, F.: Use of artificial intelligence
974 to improve resilience and preparedness against adverse flood events, Water, 11, 973, 2019.
975 Schilling, T., Wyss, R., and Binder, C.R.: The resilience of sustainability transitions, Sustainability, 10,
976 4593, 2018.
977 Schlosberg, D., Collins, L.B., and Niemeyer, S.: Adaptation policy and community discourse: risk,
978 vulnerability, and just transformation, Environmental Politics, 26, 3, 413-437, 2017.
979 Schwartz, S.: Resilience in psychology: A critical analysis of the concept, Theory and Psychology, 28, 4,
980 528-541, 2018.
981 Sjöstedt, M.: Resilience revisited: Taking institutional theory seriously, Ecology and Society, 20, 4, 23,
982 2015.

983 Simpson, A.: Challenging inequality and injustice: A critical approach to energy security, in Floyd, R.
984 and Matthew, R.A., Environmental Security: Approaches and Issues, London, Routledge, 248-263,
985 2013.
986 Skillington, T.: Climate justice without freedom: Assessing legal and political responses to climate
987 change and forced migration, European Journal of Social Theory, 18, 3, 288-307, 2015.
988 Smit, M.J., Goosen, H., and Hulsbergen, C.H.: Resilience and vulnerability: Coastal dynamics or Dutch
989 dikes?, The Geographical Journal, 164, 3, 259-268, 1998.
990 Stegemann, L. and Ossewaarde, M.: A sustainable myth: A neo-Gramscian perspective on the populist
991 and post-truth tendencies of the European green growth discourse, Energy Research and Social
992 Science, 43, 25-32, 2018.
993 Stegmaier, P., Visser, V. R., and Kuhlmann, S.: The incandescent light bulb phase-out: Exploring
994 patterns of framing the governance of discontinuing a socio-technical regime, 2020 (under review).
995 Stegmaier, P. (2019): Killing the coal: On governing the discontinuation of coal energy production,
996 Paper presented at the Nordic STS Conference; Session: How do technologies die?, Tampere, 2019.
997 Stegmaier, P., Kuhlmann, S., and Visser, V.R.: The discontinuation of socio-technical systems as
998 governance problem, in: Borrás, S. and Edler, J. (eds.) Governance of Systems Change, 111-131,
999 Cheltenham: Edward Elgar, 2014.
1000 Strunz, S.: The German energy transition as a regime shift, Ecological Economics, 100, 150-158, 2014.
1001 Sun, L., Stojadinovic, B., and Sansavini, G. Agent-based recovery model for seismic resilience evaluation
1002 of electrified communities, Risk Analysis, 39, 7, 1597-1614, 2019.
1003 Szablowski, D. and Campbell, B.: Struggles over extractive governance: Power, discourse, violence, and
1004 legality, The Extractive Industries and Society, 6, 635–641, 2019.
1005 Taddeo, M. and Floridi, L.: How AI can be a force for good, Science, 361 (6404), 751-752, 2018.
1006 Terry, G.: No climate justice without gender justice: an overview of the issues, Gender and
1007 Development, *17,* 1, 5-18, 2009.

1008 Thorén, H.: Resilience as a unifying concept, International Studies in the Philosophy of Science, 28, 3,
1009 303-324, 2014.
1010 Tierney, K.: Resilience and the neoliberal project: Discourses, critiques, practices – And Katrina,
1011 American Behavioral Scientist, 59, 10, 1327-1342, 2015.
1012 Tyler, S. and Moench, M.: A framework for urban climate resilience, Climate and Development, 4, 4,
1013 311-326, 2012.
1014 Ungar, M.: Systemic resilience: Principles and processes for a science of change in contexts of adversity,
1015 Ecology and Society, 23, 4: 34, 2018.
1016 UN-Habitat: Un-habitat-unveils-new-chinese-partnership-to-explore-the-use-of-artificial-intelligence-
1017 in-cities, 2019. https://unhabitat.org/un-habitat-unveils-new-chinese-partnership-to-explore-the-
1018 use-of-artificial-intelligence-in-cities
1019 Vahedifard, F., Ermagun, A., Mortezaei, K., and AghaKouchak, A.: Integrated data could augment
1020 resilience, Science, 363, 6423, 134, 2019.
1021 VanderPlaat, M.: Activating the sociological imagination to explore the boundaries of resilience
1022 research and practice, School Psychology International, 37, 2: 189-203, 2016.
1023 Ven, A. van de: The innovation journey: You can't control it, but you can learn to maneuver it,
1024 Innovation, 19, 1, 39-42, 2017.
1025 Verrest, H. and Pfeffer, K.: Elaborating the urbanism in smart urbanism: distilling relevant dimensions
1026 for a comprehensive analysis of Smart City approaches, Information, Communication and Society, 22,
1027 9, 1328-1342, 2019.
1028 Vögele, S., Kunz, P., Rübbelke, D., and Stahlke, T.: Transformation pathways of phasing out coal-fired
1029 power plants in Germany, Energy, Sustainability and Society, 8, 25, 1-18, 2018.
1030 Walker, J. and Cooper, M.: Genealogies of resilience: From systems ecology to the political economy
1031 of crisis adaptation, Security Dialogue, 42(2): 143-160, 2011.
1032 Walsh-Dilley, M. and Wolford, W.: (Un)Defining resilience: Subjective understandings of "resilience"
1033 from the field, Resilience, 3, 3, 173-182, 2015.

Ward, P. J., Aerts, J. C. J. H., De Keizer, O., and Poussin, J. K.: Adaptation to Meuse flood risk, Knowledge for Climate Report, Kfc 93/2013, 2013. **https://edepot.wur.nl/254248**

Warmink, J.J., Brugnach, M., Vinke-de Kruijf, J., Schielen, R. M. J., and Augustijn, D. C. M.: Coping with uncertainty in river management: Challenges and ways forward, Water Resources Management, 31, 4587-4600, 2017.

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

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

Wiese, F.: Resilience thinking as an interdisciplinary guiding principle for energy system transitions, *Resources*, 5, 30, 2016.

Wilson, D.S.: Evolutionary social constructivism, In *The literary animal: Evolution and the nature of narrative*, ed. J. Gottschall and D.S. Wilson, 20–37, Evanston: Northwestern University Press, 2005.

Wilson, E.O.: Consilience: The unity of knowledge, New York, Vintage, 1998.

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

Yanarella, E.J. and Levine, R.S.: From sustainability to resilience: Advance or retreat?, Sustainability*,* 7, 4, 197-208, 2014.

Ziervogel, G., Cowen, A., and Ziniades, J.: Moving from adaptive to transformative capacity: Building foundations for inclusive, thriving, and regenerative urban settlements, *Sustainability*, *8*, 9, 955, 2016.