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

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

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

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

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

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

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

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

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

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

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

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

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

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

Abstract

Since the 1970s, Holling's socio-ecological systems (SES) approach has been the most predominant theoretical force in resilience research with regard to the climate crisis. An overview of the scholarship in the social sciences during the past five decades reveals two different re-appropriations of Holling's legacy, which can broadly be classified as naturalist and constructivist, respectively. Characteristic for naturalist resilience research is its indebtedness to the concepts, methods, and assumptions of the so-called 'life sciences'. This has resulted in the recasting of Holling's SES into complex systems that are marked by non-linearity and evolutionary changes. Constructivist resilience research, on the other hand, relies on the concepts, methods and assumptions that are common in the 'human sciences'. Accordingly, resilience is studied and critically appraised in its historical, social, and political context. In this paper, recent developments in resilience research in the social sciences are reviewed to the end of proposing new research questions. The focus is on the different approaches, models and commitments that underpin these two approaches to resilience in the context of the ecological crisis. Particular attention is thereby paid to the naturalist emphasis on adaptation and the constructivist emphasis on transformation.

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

1. Introduction

Crawford Stanley Holling's ecological notion of resilience (Holling, 1973) has become part and parcel of the social sciences, particularly in the field of social studies of climate change. Some social scientists

have recast and integrated it in their theoretical frameworks. Others accept the terminology and conceptualization of the term while not necessarily endorsing Holling's theoretical framework. The ecologist's notion of resilience has been presented as interdisciplinary and thus as having the potential of building a bridge between the social sciences and engineering (Ostrom, 2007; Thorén, 2014). Holling corrected what he considered to be an unrealistic 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). Holling's socio-ecological systems (SES) approach appealed to social scientists since it highlighted the interaction between human societies (political, social, economic, and technological environments) and natural ecosystems. Consequently, resilience to climate change, for the social scientist, requires the reformation of established modes of thought (including conceptualizations of 'nature' and 'society'), lifestyles and consumer habits, production patterns, health issues, law, economy, science, technology, governance and politics (cf. Douglas & Wildavsky, 1983; Blühdorn, 2013; Fischer, 2017; Dryzek & Pickering, 2019).

Holling's ecological approach has been adopted by the Resilience Alliance, whose flagship journal, *Ecology and Society* (established in 1995), provides a platform for SES-based resilience research. In the social sciences, resilience to climate change has become a research topic since the Tsunami in 2004 and Katrina in 2005 (Pizzo, 2015). Katrina and, even more recently, Covid-19, social scientists point out, reveal a vulnerability that does not only consist in exposure to natural hazards. Instead, what has been made clear is that social, cultural, political, and economic conditions largely determine the resilience to these natural calamities (Tierney, 2015; Lockie, 2016). In the past decade, resilience to climate change has been addressed primarily as a policy discourse. Indeed, since 2010, in the wake of the global financial crisis (2007-2008), global governance actors and national and local governments – including the Rockefeller Foundation – have had profuse recourse to the language of resilience. The economic and political interest behind such discourses has gained the critical attention of social scientists (Hilhorst 2018). This has given rise to new resilience research, new outlets (such as the interdisciplinary journal *Resilience* (established in 2013)), and the establishment of resilience

research programs in universities around the world. This relatively recent development has meant the diversification of existing resilience research in the social sciences. As a result, many publications of the past decade address different definitions and understandings of resilience. Such diversity corresponds to the diversification of approaches in the social sciences. Resilience research in the social sciences had been predominantly naturalist. Today, social scientists are increasingly addressing climate change and resilience to climate change from constructivist angles.

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. Current research can broadly be classified into two main schools of thought, namely, naturalist and constructivist. The latter is a more recent development in resilience research where the natural sciences and mathematics have tended to be authoritative. The diversification of resilience research in the social sciences is thus addressed in the first section of this paper. Naturalism and constructivism are presented as two (social) scientific approaches underpinned by different epistemological and ontological commitments. 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

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). 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. 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 undergoing some external shock or disturbance (such as extreme weather conditions) (Estêvão, Calado & Capucha, 2017; Bergström, 2018; Davoudi, 2018). In the 1950s, psychologists re-adapted the common sense of the term to mental health and used it to study the coping mechanisms of concentration camp survivors. Later, the concept is used to study all sorts of trauma, misfortune, adversity, stress, and mental recovery (Bourbeau, 2015; Estêvão, Calado & Capucha, 2017; Bergström, 2018; Schwartz, 2018). In the 1970s, the ecologist C.S. Holling (1973: 14) redefines resilience as 'a measure of the persistence of systems and their ability to absorb change and disturbance.' Thus understood, resilience is widely conceived as the opposite of vulnerability, which is defined as the

111 inability to absorb change and disturbance (Gallopin, 2006; Miller et al, 2010) - for instance, a coastal
112 system that is vulnerable to accelerated sea-level rise is not resilient enough (Smit, Goosen &
113 Hulsbergen, 1998). In such discourses, greater resilience means becoming less vulnerable to change
114 and shocks. That said, a system can still be vulnerable to other changes while being resilient in other
115 respects (Gallopin, 2006). Holling incorporates resilience in a socio-ecological systems (SES) approach
116 to analyze the stability and strength of ecological systems, which are constituted by the interaction
117 between natural ecosystems and human societies (Alexander, 2013; Bergström, 2018; Béné et al,
118 2018; Hoekstra, Bredenhoff-Bijlsma & Krol, 2018). Ecosystems, as noted earlier, are rarely closed
119 systems, but are instead subjected to natural and human influences.

120 In the social sciences, resilience research that has emerged from Holling's SES approach has
121 developed along two different lines, which can be called naturalist and constructivist, respectively
122 (Miller et al, 2010). These two currents of research have different focuses, raise different questions,
123 and have recourse to different methods. The naturalist line of research is indebted to the accepted
124 methods and assumptions of the natural sciences. It has a predilection for mathematical and
125 simulation models. Social scientists dealing with resilience to climate change research questions
126 consider resilience as a property of a system, which can be (made) weak or strong. Society is modelled
127 as a social system that consists of parts (including agents and technologies) and physical properties
128 that can be objectively studied (Aiken, 2006; Floridi, 2017). Resilience as a system property is an
129 objective measure of the dynamic equilibrium, stability, strength, or survivability of a socio-ecological
130 system, including coastal systems, urban systems, forest systems, etc. (Hoekstra, Bredenhoff-Bijlsma
131 & Krol, 2018).

132 The naturalist approach to problems that arise through climate change can be very useful,
133 especially when both the problem and the solution are quite uncomplicated (and hence are primarily
134 of a technical nature, such as water purification, for instance). The story becomes more complicated
135 when, for instance, attempts to make communities more resilient to climate change overlook the
136 political and cultural reasons why particular groups are more vulnerable to the effects of climate

change. Since a model cannot include these reasons, the naturalist social scientist necessarily leaves out factors that are part of the problem and the solution. In so doing, naturalist social scientists may well become unwitting allies of political powers and help to perpetuate status quos. Constructivist social scientists have shown increased interest for resilience research precisely because resilience is a term profusely used by global and national powers during the last two decades.

Historically, constructivism in the social sciences has arisen in reaction to what was experienced as the narrowness of the naturalist approach. The constructivist does not believe that reality is so objective that it can be fully grasped and (s)he does not try to objectify it. Instead, natural and social phenomena can only understood by taking into account diverse human perceptions, experiences, meanings, interests, values, identities, patterns of domination, etc. Constructivist social scientists thus think that it is mistake to compress the social sciences into the mold of the natural sciences. In resilience research, they 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. Constructivists tend to be more critical and politically sensitive. They are generally more aware of the potential and actual abuse of power. When addressing resilience issues in the context of climate change, they typically express concern for vulnerable communities. Research topics 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 & Levine, 2014; Skillington, 2015; Sjöstedt, 2015; Weichselgartner & Kelman, 2015; Pizzo, 2015; Lockie, 2016; Derickson, 2016; Lyster, 2017; Schlosberg, Collins & Niemeyer, 2017; Mummery & Mummery, 2019). Davoudi (2018: 5), for instance, introduces the notion of 'unjust resilience'. Unjust resilience refers to absorption of changes or disturbance through a systematic neglect of vulnerable groups and marginalized people. Katrina and the Covid-19 crisis reveal such systematic injustice. And Glaser et al (2018: 3) refer to 'undesirable resilience', 'bad resilience' and 'wicked resilience'. These are notions that emphasize how resilience may go hand in hand with the enforcement of an undesirable or unjust condition. The resilience of

oppressive systems (like tyrannical regimes) that systematically marginalize, discriminate or persecute certain groups are an example of this.

2.1. The naturalist view on resilience

In the social sciences, naturalist research as such arose in the context of the development of cybernetics, computational power and automation (and automated decision making) (Simbirski, 2006; Floridi, 2017; 2018; Davoudi, 2018). Naturalist social studies are based on the cybernetic idea that machines, organisms, and societies show considerable similarity in structure and function; and can be described in terms of systems. Since the 1940s, such studies have typically adopted cybernetic complexity theory as their distinctive overarching theoretical outlook, within which other theories (for instance, on behavior change, on decision making under risk, or on social institutions) are incorporated. In complexity theory, machines, organisms, and societies are modelled as complex, non-linear, evolutionary systems. Complex systems are composed of many components, including properties, agents, resources, and governance systems. All components interact with each other, in response to ever-changing environments and disturbance (Walsh-Dilley & Wolford, 2015; Juncos, 2017; 2018). From this naturalist point of view, resilience to climate change is a matter of evolution: resilience is 'evolutionary resilience' (Pizzo, 2015: 137; Davoudi, 2018: 4).In the 1970s, naturalist social scientists incorporated Holling's notion of resilience within their own cybernetic complexity theory and cybernetic methodology (Wiese, 2016; Bergström, 2018). That is, socio-ecological systems are cybernetically conceptualized as adaptive complex systems. The ability to cope with uncertainty and complexity is one of the capacities of individual agents and interacting agents. The latter are able to interact and self-organize, learn and adapt (in an incremental or transformative way), making the system flexible in absorbing shocks and developing in face of changes (Jesse, Heinrichs & Kuchshinrichs, 2019).

188 Naturalist social scientists tend to emphasize a type of laissez-faireism, pointing out that
189 adaptive complex systems have their own self-organizational structures that should not be interfered
190 with. Bureaucratic interventions to address vulnerability and increase resilience to climate change
191 typically generate unintended consequences that may well reduce a system's ability to absorb changes
192 and disturbances (Adger et al, 2011). In 2001, Holling introduced the notion of 'panarchy' as an
193 alternative to hierarchy, to safeguard the self-organization of complex systems against the threat of
194 bureaucratic intervention (Holling, 2001). Derived from the ancient Greek god of the woods, Pan,
195 panarchy refers to the structure in which complex (ecological and social) systems are interlinked in an
196 evolutionary process of adaptive cycles of growth, accumulation, restructuring, and renewal (Berkes
197 & Ross, 2016). Accordingly, when confronted with shocks (like extreme weather events), adaptive
198 systems stabilize with supporting self-organizing structures until those structures are overstretched
199 and can no longer absorb changes and disturbances; this is when there is a transformation of the
200 system(Allen et al, 2014). In other words, in naturalist research, the notion of panarchy (as an
201 evolutionary mode of system self-organization) complements Holling's earlier notions of socio-
202 ecological systems and resilience (as a system property). In Holling's naturalist theory of panarchy,
203 resilience is a primary system property that is measured by the magnitude of shocks that can be
204 absorbed before the structures of system change (Boyer, 2020).
205 Methodologically, naturalist social scientists have typically embraced agent-based modelling
206 (ABM) as their favorite mode of analysis in resilience research. They focus on the constant refinement
207 of simulation tools (that can cope with complexity, uncertainty and multiplicity of agents) and
208 techniques of regulation in favor of adaptation (cf. Cote & Nightingale, 2012; Patriarca et al, 2018).
209 Since the 1970s, when it emerged from mathematical sociology, ABM has been a much endorsed tool
210 used in complexity-theoretic research for analyzing complex systems. (Conte & Paolucci, 2014). ABM
211 is a computational mode of analysis that simulates complex (non-linear) systems that include diverse
212 interacting agents that make decisions, interact and learn or adapt in their ever-changing environment,
213 according to programmable rules . (Hawes & Reed, 2006; Farmer & Foley, 2009; Van Duinen et al,

214 2015; Martin & Schlüter, 2015; Sun, Stojadinovic & Sansavini, 2019). ABM computes, in probabilistic
215 terms, the recovery process of complex (non-linear) systems under stress and tracks the emergence of
216 new stages, phases or entries into new adaptive cycles (Filatova, Polhill & Van Ewijk, 2016). In the social
217 sciences, naturalist scholars calculate resilience to climate change at the system level as a system
218 property (Pumpuni-Lenss, Blackburn & Garstenauer, 2017). Since ABM traces feedbacks between
219 micro-macro scale explicitly, ABM also enables naturalist scholars to estimate the resilience of a
220 system's individual agents, communities or (sub)groups of agents.
221
222 **2.2 The constructivist view on resilience**
223
224 In the social sciences, constructivist resilience research is also inspired by Holling's SES
225 approach. Yet, for constructivists, resilience to climate change is not a system property. It is instead a
226 socio-political construct that is created by diverse stakeholders (Walsh-Dilley & Wolford, 2015;
227 Weichselgartner & Kelman, 2015; Kythreotis & Bristow, 2017). Constructivist research includes a
228 variety of (typically phenomenological and discursive) scientific perspectives. Constructivist resilience
229 research primarily focuses on the political context and socio-political implications of resilience
230 discourses. As a construct, resilience to climate change is not so much technical as political and
231 administrative in nature (Alexander, 2013; Bourbeau, 2015; Boas & Rothe, 2016; Juncos, 2018; Wessel,
232 2019). And given its political and administrative nature, resilience is invested with ideology and myth.
233 Constructivist scholars typically stress that resilience is a neoliberal construct. That neoliberal ideology
234 manifests itself in the belief in adaptive cycles governed by invisible laws and the non-interventionist
235 stance. It is thereby overlooked that the so-called self-organizing system is itself the result of political
236 decisions over a long period of time. Constructivists thus point out that resilience has become a
237 buzzword for governments that seek to shift the responsibility for vulnerable systems, floods,
238 pollution, safety, welfare, health, etc. to 'resilient' individuals. Governments, in these cases, have
239 recourse to resilience to make individuals more self-reliant (or less dependent on the government)

when it comes to coping with their own struggles in dealing with the challenges of climate change (Braun, 2014; Pizzo, 2015; Tierney, 2015; Howell, 2015; Anderson, 2015; Ksenia et al, 2016; Schwartz, 2018; Davoudi, 2018). For instance, governments that fail to provide basic access to water to millions of rural citizens advocate community-based water management schemes, the leading paradigm for rural water access in East Africa (Katomera & Georgiadou, 2018). Such schemes 'work' for the state (and donors) as a means of shifting (or offloading) responsibility for public service provision to the most vulnerable citizens for whom community management may not be a preferred option (Katomero & Georgiadou, 2018).

Constructivist scholars tend to critically analyze resilience as an ideological construct. Such critical studies are typically inspired by the works of Michel Foucault, in the sense that resilience is analyzed as a discursive construct or ideological discourse. For Foucault, a discourse 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. Language is not a neutral tool of communication. Through resilience discourses, a particular type of subject (like resilient or self-reliant rather than vulnerable or dependent citizens) and a particular type of society (like a market-based 'society') are discursively constructed and reinforced (Miller et al, 2010). Evans and Reid (2013) argue that as a discursive construct created by power holders, resilience has the character of a doctrine, according to which the resilient subject must constantly adapt to a dangerous and changing world, and is willing to accept this. Given this doctrine, vulnerability is rejected as weakness, a moral flaw (like a lack of character or a lack of will power) or simply illegitimate (the ability to absorb shocks being the new norm). Many critical constructivist scholars see the political reactions to events like Katrina (2005), Fukushima (2011), and Covid-19 (2020) as manifestations of such ideology. A problematic normativity is brought into existence when citizens are told that they must adapt to ecological and societal catastrophes, and when vulnerable citizens are left abandoned by their government as they are expected to be self-reliant (Fainstein, 2014; Tierney, 2015; Ribault, 2019). Constructivist scientists also stress that such catastrophes present themselves as

266 'anthropological shocks' (Beck (2015: 80). Such shocks may open up counter-discourses that contest
267 domination (Fazey et al, 2018). Katrina, for instance, proved to be such an anthropological shock
268 because it opened up a counter-discourse that brought up the issues of colonial patterns of racism,
269 slavery, vulnerability, and abandonment (Beck, 2015). As an anthropological shock , it is a potential
270 initiator of policy transformations beyond the resilience discourse.

271 Constructivist scholars not only emphasize the role of neoliberal ideology that legitimizes
272 established power relationships and patterns of domination in resilience discourses. They also point at
273 the role of myth and myth-making in the discursive construction of resilience. Constructed as a myth,
274 resilience is understood as a widely embraced narrative. Resilience is a story that connects diverging
275 ideologies, values, interests, worldviews and power relations. The 'myth of resilience' (Kuhlicke, 2013)
276 refers to the stories that stakeholders enact to make sense of the radically surprising discovery of
277 something entirely unknown (like Katrina or the Covid-19 crisis). As narrators, stakeholders interpret
278 their own capacities to deal with stresses and shocks, such as extreme weather events (like floods,
279 droughts, and heatwaves). In this context of making sense of an unknown phenomenon, stakeholders
280 develop the capacity to adapt and transform through mythmaking. For instance, the increasing
281 attention on 'urban climate resilience' (Tyler and Moensch, 2012) resonates with the myth that cities,
282 or 'local governments', are to lead and shape climate change adaptation as a form of bottom-up self-
283 organization for absorbing changes and disturbances (O'Hare et al., 2016; Klein et al., 2017).

284

285

286 **3. Bridging the naturalist and constructivist view on resilience**

287

288 In the social sciences, naturalist and constructivist resilience research are based on contrasted
289 premises, each having their own theoretical and methodological outlooks. Given such scientific
290 contrasts, it has been widely questioned whether resilience can possibly operate as a theoretical model
291 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). A unifying paradigm is neither possible nor desirable. Yet, naturalist and constructivist research can be brought together to enrich and renew understandings of resilience to climate change. Naturalist resilience research has the great merit that it may help to increase complex systems' robustness to system failure when faced with shocks and disturbances. ABM – a mode of analysis that complexity theorists tend to prefer – may be a valuable tool for developing procedural stability, environmental risk management under conditions of uncertainty, provision of planning security, and prevention of adverse consequences from disruptive shocks (Schilling, Wyss & Binder, 2018). Constructivist resilience research provides a critical and most penetrating understanding of resilience as a construct (first of all, a discursive construct, myth or narrative) that contains political intention and direction. Its interpretation of resilience to climate change is useful for generating understanding of how resilience is mobilized, taken up in climate governance, and resisted by social movements' counter-discourses, such as the Fridays for Future, Black Lives Matter and Extinction Rebellion, that push for less unsustainable trajectories and for more protection of vulnerable citizens and communities.

3.1 The debate on adaptive and transformative resilience

In recent years, the contrast between naturalism and constructivism in resilience research has come to revolve around the issue of adaptation and transformation (Chandler, 2014; Redman, 2014; Fainstein, 2014; Dahlberg et al, 2015; Sjöstedt, 2015; Boas & Rothe, 2016; Duit, 2016; Ziervogel, Cowen & Ziniades, 2016; Clément & Rivera, 2017; Lyster, 2017; Schlosberg, Collins & Niemeyer, 2017; Fazey et al, 2018; Glaser et al, 2018; Hoekstra, Bredenhoff-Bijlsma & Krol, 2018; Jesse, Heinrichs & Kuchshinrichs, 2019; Dryzek & Pickering, 2019). It is an urgent issue that emerges from an ambiguity in Holling's SES approach (Redman, 2014). In the 1970s, Holling (1973) reinterpreted resilience as bouncing back or forward in terms of SES adaptation. Adaptation refers, on the one hand, to the

capacity of agents to influence the system (and influence or strengthen resilience as a system property). And on the other hand, it alludes to panarchical adaptation to new (ecological and social) environments, as an evolutionary process towards a new stage, phase, or adaptation cycle (Boyd et al, 2015). Yet, as Holling emphasizes, the bouncing back and bouncing forward of a system not only refers to a return to some previous (dynamic) equilibrium or to the persistence and endurance of systems. It also refers to socio-ecological transformation in an ongoing process of non-equilibrium and instability and reinvention of systems in changing environments marked by different adaptive cycles (growth, accumulation, restructuring, and renewal) (Folke, 2006). Transformation refers to the capacity of agents to create a new system and a new discourse, particularly when conditions make the existing system untenable or illegitimate. Constructivist resilience research is primarily focused on transformation. Such research unsettles taken-for-granted assumptions and definitions of the situation expressed in established discourses; and it ignites new imaginations and counter-discourses needed 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 & Matyas, 2015; Mummery & Mummery, 2019: 920). Transformational adaptations, such as green growth or the greening of the established economy refer to changes that are aligned to the scale of projected, possible and desirable changes within systems that are informed by (ultimately constructivist) considerations of environmental and climate justice.

The naturalist emphasis on resilience as system adaptation to climate change means that resilience research 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 comes with short-term planning, uncertainty reductions, incremental and path-dependent changes (Borsje et al, 2011; Haasnoot et al, 2013). Adaptive resilience – the system's re-stabilizer – is taken as inherently positive, while disturbances and shocks (de-stabilizers) are taken as negative (Duit, 2016; Lockie, 2016). It is on the basis of the premise

that adaptive resilience is good that naturalist resilience research ties up with climate risk management, as a way of managing ecosystem services (critical for survival), under conditions of ecological and societal shocks and disturbances (Boyd et al, 2015; Berbés-Blázquez et al, 2017). For instance, when confronted with the near flood events of 1993 and 1995 along the river Rhine in the Netherlands, the Dutch government responded by increasing the flood conveyance capacity of the large rivers, thereby decreasing flood water levels (Hamers et al, 2015). Since its completion in 2015, the Room for the River project is considered effective thus far, particularly as its secondary objective to increase ecosystem values in the river appears successful. Warmink et al (2017) point out that in Dutch river management, such adaptation responses are typically conservative and within safety margins. This leads to over-dimensioning and high costs of water engineering works (like flood defenses).

The constructivist emphasis on resilience to climate change as system transformation refers to the emergent transformation of systems into something new beyond the status quo (Ziervogel, Cowen & Ziniades, 2016; Rothe, 2017; Béné et al, 2018). Transformative resilience is defined as the system's internal capacities, capabilities and relations that enables it to create a new condition marked by a new discourse (and accordingly, new or different power relationships). Flood protection, for instance, is typically a governmental responsibility, but, with a new myth, stakeholders can transform an established situation and realize alternative scenario's in which responsibilities may be distributed among different stakeholders (Warmink et al., 2017). Adaptive resilience comes with evolutionary change (the definition of change that naturalist research typically endorses). By contrast, transformative resilience comes with 'metamorphosis'. This type of change refers to a transformation of systems that is triggered by anthropological shocks that open up new horizons, reassessments (including of past ideas, beliefs and practices) and rediscoveries (Beck, 2015; Fazey et al, 2018). The middle ground of transformational adaptation bridges evolutionary change and metamorphosis, in the sense that such adaptation attends to broader socio-political processes of transformations (Kates, Travis & Wilbanks, 2012; Ziervogel, Cowen & Ziniades, 2016). The notion of transformational

adaptation picks up on and challenges the transformative logic of system transformation with simultaneous system adaptation, based on uncertainty regarding how fast and how far disruptions will go – or whether sustainable transformations will thrive as political projects at all.

Constructivist social scientists criticize the notion of adaptive resilience for not sufficiently addressing issues of environmental and climate justice. To address issues of power abuse and domination, the constructivist argument goes, system reconfiguration is needed: injustice inheres in the established systems. Naturalist resilience research, however, does not exclude considerations of justice from scientific analysis. Yet, it identifies justice, like resilience, as a system property. Thus, enhancing adaptive resilience to climate change may entail liberal principles of equity, fairness and access to resources and services, so as not to privilege or marginalize certain stakeholders (Redman, 2014; Thorén, 2014; Ksenia et al, 2016; Schlosberg, Collins & Niemeyer, 2017; Bergström, 2018). Yet, naturalist enquiry into adaptive resilience tens to leave the status quo of systems, including the problematic Global North-Global South relationship (marked by massive power inequality), unquestioned (Swyngedouw, 2011; Pizzo, 2015; Clément & Rivera, 2017; Davoudi, 2018; Glaser et al, 2018; Dryzek & Pickering, 2019). In constructivist resilience research, by contrast, the justice question is placed in a context of broader socio-political processes of system transformation: adaptive systems can be unjust and oppressive (Fainstein, 2014; Weichselgartner and Kelman, 2015; Huang, Boranbay-Akan and Huang, 2016; McGreavy, 2016; Ziervogel, Cowen & Ziniades, 2016; Ribault, 2019). Adaptive responses to shocks and disturbances may blur long term sustainability visions, while dominant (or dominating) stakeholders typically reify existing climate policy efforts in their (standardized) adaptive responses (Lockie, 2016; Derickson, 2016; Rothe, 2017; Estêvão, Calado and Capucha, 2017; Ribault, 2019). Kythreotis & Bristow (2017) call this phenomenon the 'resilience trap' – the reinforcement of established power relations (legitimized by dominant ideologies such as neoliberalism) and contemporary resilience discourses (Blühdorn, 2013; Redman, 2014; Yanarella & Levine, 2014; Lockie, 2016; VanderPlaat, 2016; Schilling, Wyss & Binder, 2018; Glaser et al, 2018; Ribault, 2019). Hence, constructivist scholars tend to 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. The middle ground of transformational adaptation, accordingly, must include a process of filtering out resilience traps that come with adaptive resilience. Transformational adaptation includes an understanding that adaptive resilience may well enforce a governance of unsustainability (cf. Van de Ven, 2017).

3.2 Transformative resilience and sustainability

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

of adaptive resilience to climate change, implies that the energy transition, including the use of renewables, can only go via incremental changes and greening of the established economy, to avoid system collapse (Berbés-Blázquez et al, 2017; Schilling, Wyss & Binder, 2018). The middle ground of transformational adaptation includes this adaptationist notion of energy resilience but aligns it to the scale of desirable ecological and societal changes that are informed by justice considerations and political direction towards less unsustainable futures. Given that established energy systems insufficiently respond to ecological and societal challenges of climate change, transformational adaptation may imply the metamorphosis of energy systems.

From the (typically constructivist) perspective of strengthening transformative resilience, energy resilience comes with the enactment of the energy system's status quo. This is a status quo that includes powerful agents that have a vested interest in promoting fossil energy. Such agents use all sorts of tactics (including sponsoring the climate change denial movement) to secure their established power position (Stegemann & Ossewaarde, 2018; Szablowski & Campbell, 2019). It enacts a condition of 'energy injustice', particularly in the Global South. The notion of energy injustice refers to current energy systems that distribute the ecological and economic benefits and burdens of established energy systems in unfair ways; dominate, degrade and devalue certain stakeholders; and exclude certain agents from processes that govern the benefits, burdens and recognitions (Jenkins et al, 2016; Heffron & McCauley, 2017). The transformative resilience of energy systems, which is tied up with the notion of 'energy justice', refers to the resistance to and negation of a fossil-based energy system and its oligarchical power structure (increasing the vulnerability of such a climate-unfriendly energy system); and the creation of a renewable-based system, energy commons and collaboratives beyond the energy establishment (VanderPlaat, 2016; Bourbeau & Ryan, 2018; Juncos, 2018; Schwartz, 2018; Acosta et al, 2018; Jesse, Heinrichs & Kuchshinrichs, 2019). The middle ground of transformational adaptation includes the long-term vision of energy governance (for instance, towards 2050), but it searches for realizing such transformation through adaptations by the status quo. Transformational adaptation means that the sustainable energy transformation comes with the

change of the energy establishment into agents of sustainability – a change that comes from within the power complex, for instance, via stakeholder participation (like shareholder activism).

3.3 AI for resilience and sustainability

Adaptive resilience to climate change comes with short-term systematic adjustments to a changing technological environment that is currently increasingly dominated by smart urbanism and artificial intelligence (AI) technologies. Governance actors like the UN, EU and national governments have all drafted their AI strategies for the making of an 'AI Revolution'. Such actors present AI as a leading technology that contributes to resolving resilience and sustainability challenges (cf. Taddeo & Floridi, 2018). Particularly in naturalist resilience research, AI is identified as a new systems property that permeates systems to generate productivity gains, improve efficiency, lower costs, predict climate change stress, track carbon emissions, monitor flood risks, etc. (Rajan & Saffiotti, 2017; Khakurel et al, 2018; Vahedifard, et al, 2019; Miller, 2019; Saravi et al, 2019). Strengthening adaptive resilience to climate change through AI primarily means that an integrated data system for circulating information (near) real time among agents needs to be developed. In an AI technological environment, resilience implies close collaboration between agents (tool/model developers, data stakeholders, community-level stakeholders, state-level institutions, etc.) (Vahedifard, et al, 2019). AI comes in both for combining datasets into usable information, as a monitoring method (like change detection algorithms) as well as a tool for forecasting (for instance likely occurrence of a natural hazard due to extreme events). Identifying, harnessing, synthesizing, and communicating pertinent yet structured and unstructured data (weather data, cell phone GPS data, social media feeds, traffic cameras, smart city sensors, images, videos, audio data, etc.) enables agents to better forecast, prepare for, respond to, and recover from disturbances and shocks (Rajan & Saffiotti, 2017; Vahedifard et al, 2019). In urban systems, so-called 'city dashboards' rely on big data and AI when it comes to ordering and visualizing

474 data through interactive maps and graphs (Kitchen, 2018). By being able to predict (estimate or
475 forecast) more accurately and learn from past disturbances and shocks, lessons can be learned and
476 applied in building adaptive resilience against disturbances (Saravi et al, 2019). AI, as for instance used
477 in city dashboards, quantifies the probabilities of occurrence of extreme events, essential in predicting
478 and preparing for future natural hazards, such as floods or landslides. For instance, with advances in
479 machine learning, water availability, ice surfaces and melting rates, saturated soils, pollution,
480 deforestation, etc. can be more precisely or smartly monitored in space and time so that changes over
481 time can be tracked. Yet, with monitoring also learning of agents and organizations is needed.

482 In the social sciences, constructivist scientists tend to have a critical view of AI. They do
483 recognize that AI may help building transformative resilience, given AI's capacity for anticipating future
484 events. AI may also play a positive role in phasing out of unsustainable yet adaptive systems.
485 Governance actors, such as the UN in its AI for good program (2017-), the EU in its AI strategy (2018),
486 and various national governments in their AI programs emphasize the transformative potentials of AI.
487 Yet, strengthened adaptive resilience can also weaken the transformative resilience that is needed for
488 materializing sustainable transformations (Khakurel et al, 2018). From a critical constructivist angle, to
489 make AI serve transformative resilience requires that the domination of giant AI firms (like Google,
490 Amazon, Microsoft, Facebook, Alibaba, Tencent, etc.) is kept in check. It requires high levels of
491 transparency and stakeholder involvement in how algorithms are designed, built and applied. In
492 constructivist researches, it is frequently argued that although big data can be openly accessible (like
493 satellite imagery for geospatial and data scientists), big data and AI are often in the hands of giant tech
494 oligarchs (Miller, 2019; Ossewaarde, 2019) that have a vested interest in the further acceleration and
495 consumption of technological devices (Khakurel et al, 2018). Because of such an oligarchical power
496 structure, AI tends to obstruct transformative resilience, exerting power beyond rule of law and
497 democratic will and understanding. Such power abuse is found in the many recent privacy rights
498 violations and scandals (like the Facebook-Cambridge Analytica data scandal (2018) and the many
499 Google scandals) (cf. Taddeo & Floridi, 2018).

4. Six upcoming themes in diversified resilience research

In the social sciences, the bridging of naturalist and constructivist scientific approaches in theorizing change as system adaptation, transformation, or transformational adaptation triggers new research themes for the study of resilience to climate change. Theorizing change within and of systems has become the key issue in resilience research, in the wake of changing societal, ecological, and technological environments. In naturalist research, resilience to climate change is presented as 'evolutionary resilience' and as 'adaptive resilience'. From this angle, the key issue of changing environments is the survivability of established complex systems under stress. Change is, accordingly, evolutionary change. In constructivist research, resilience to climate change is presented as discursive, ideological, mythical (the 'myth of resilience') and as transformative resilience. The key issue of change is the overcoming of 'resilience to change', 'resilience traps' and 'unjust resilience' or 'bad resilience' that the status quo that organize established systems produce. Such overcoming of the establishment is presented as an indispensable condition for enhancing change. Such change refers to metamorphosis of systems and comes with transformative politics and climate governance. The reconciliation of naturalism and constructivism in terms of change can be found in the middle ground of transformational adaptation, which ties incrementalism to long term sustainability visions. It is a notion that comes with the search for the conditions and tempo of transformations in different ecological and societal contexts and adaptative cycles. Ultimately, 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).

A first promising direction for future resilience research concerns the reconciliation of naturalist and constructivist scientific approaches to resilience. Given the diversification of scientific approaches, resilience cannot operate as a theoretical model or unifying paradigm (Mummery &

Mummery, 2019). Yet, as a metaphor resilience provides a sound basis for reconciling contrasting scientific approaches, mainly because of its heterogeneity and high level of abstraction (Thorén, 2014). Intellectually, the reconciling of naturalism and constructivism implies an appreciation of diverse scientific vocabularies, many visions of what counts as scientific knowledge, other approaches' scientific worlds, a certain embracing (which includes making manifest) of the tensions between the contrasting types of science, and creating spaces for constructive contestation (Pfeffer & Georgiadou, 2019). Thereby, new resilience perspectives may develop. New questions may be posed (or new answers to long-standing questions may be provided). The resilience trap – typically marked by the promotion of adaptive strategies that reify responses and corresponding power structures in the short-term – may be avoided (via challenging current assumptions underpinning resilience research). Current adaptation and transformation and transformational adaptation approaches may be further refined. And much-needed new ways of scientific thinking and possibilities may be opened in resilience research, beyond old conceptualizations and modes of analyses (cf. Fazey et al, 2018). These developments ask for new collaboration frameworks and platforms that empower stakeholders to bring both their resilience research questions and their assets to the table to collectively explore and define potential futures from the perspective of all present worldviews.

A second theme for future resilience research comes with a change in political environment, in which the legitimacy of adaptive, transformative, and transformational adaptive responses to climate change is constantly contested. Anthropogenic climate change comes with a political-administrative crisis, which manifests itself in the form of a legitimacy crisis, authority crisis (including the crisis of scientific authority), crisis of democracy, a crisis of human rights, a crisis of modernity (Swyngedouw, 2011; Blühdorn, 2013; Fischer, 2017; Ossewaarde, 2018; Stegemann & Ossewaarde, 2018; Dryzek & Pickering, 2019). Crisis and the ability to absorb changes and shocks has been widely constructed as the new normal (Hilhorst, 2018). In an increasingly toxic political environment (marked by climate change denial, anti-immigration policies, and nationalist protectionism) adaptive and transformative resilience and transformational adaptation may be expressed and contested in

552 manifold ways. For instance, on the one hand, environmental protest movements are stakeholders
553 that develop a leverage required to transform established systems (such as energy systems) and their
554 governance arrangements. On the other hand, agents who hold power thanks to such arrangements
555 typically use tactics of repression and criminalization, particularly in the extractive sectors of the Global
556 South (Szablowski & Campbell, 2019). New research questions emerge on the one hand from
557 polarization and the exercise of (il)legitimate power in the governing of and for resilience to climate
558 change. This is the question of how the adaptation and metamorphosis of systems under pressures of
559 climate change comes with power inequalities, polarization, injustice, battle for resources, democratic
560 deficits and post-democratic tendencies, climate change denial tactics, attacks on legal rights, and the
561 resilient governance of unsustainability. To put it in more positive terms, urgent questions concern the
562 meanings of transformation, the theorization of transformation in terms of just resilience, the linkage
563 of resilience to sustainable futures, the development of a transformation agenda in participative,
564 proactive and deliberative ways, and the comparison of different administrative capacities and new
565 governance arrangements that explain differences in system adaptation and reconfiguration (cf.
566 Blühdorn, 2013; Fischer, 2017; Davoudi, 2018; Köhler et al, 2019; Mummery & Mummery, 2019).

567 A third promising topic for future resilience research concerns the relationship between
568 adaptive resilience and transformative resilience and transformational adaptation in the reactive and
569 proactive governance responses to anthropogenic climate change (Clément & Rivera, 2017). In the
570 coming decade, questions like how adaptive and transformative resilience to climate change is
571 strengthened or weakened; how the current performance of systems when it comes to responding to
572 possible disturbance (for instance, through the use of monitoring systems) can be better understood;
573 how unjust resilience can be disabled (and therewith 'positive vulnerability' can be increased to
574 generate beneficial transformation (cf. Gallopin, 2006); and how transformational adaptation
575 manifests itself (how multiple adaptations may lead to transformational adaptation and what are the
576 tipping points for igniting transformation), become urgent ones for resilience research (Grove &
577 Chandler, 2017; Glaser et al, 2018). The notion of 'tentative governance' appears particularly relevant

in the context of transformational politics, when it comes to phasing out systems and weakening adaptive resilience. Tentative governance is marked by interventions that are designed as preliminary rather than as persistent, for purposes of probing and learning rather than for stipulating definite targets or fixating existing systems and their underlying assumptions (Kuhlmann, Stegmaier & Konrad, 2019). It is likely that stakeholder engagement (including resistance) in transformational politics and tentative governance varies, and manifests itself differently, across different policy fields. For instance, the sustainable energy transformation may include multi-layer governance challenges, many pro-active stakeholders, new investment opportunities and job opportunities. Given that multiple public and private actors are responsible for the performance of different parts of a system, tentative governance comes with transformational adaptations that must be arranged. Hence arises the question which adaptations allow for transformation? In contrast with the sustainable energy transformation, sea level rise and the disruption and relocation of coastal cities may trigger a more limited transformative politics, despite inevitable transformation of systems due to shocks and disturbances (metamorphosis). Yet, in the coming decade, transformational politics and tentative governance – including anthropogenic topics like population displacement, privatization of climate adaptation, conflict organized around scarce resources (like water resources), intergenerational environmental conflict, and the closing of old infrastructures that are too costly to maintain – becomes a more urgent research topic.

A fourth topic for future resilience research concerns the relationship between phasing out of unsustainable systems and societal transformations. The sustainable energy transformation is a most obvious phasing out of old systems (like coal energy systems) and change of worldviews, middle class consumerism, lifestyles, etc. towards new energy systems, given that burning fossil fuels has such a major impact on climate change. Adaptative and transformational responses to climate change are intermingled with responses to many societal and ecological developments. A response like investment in transportation systems that aims to address increasing transportation demand must accordingly include possible climate change impacts. In the Anthropocene epoch, systems typically

face pressures to change, to establish new (less unsustainable) interactions between society and ecology. Pressures on existing systems not only emerge from ecological adversity, over-exploitation, resource depletion, etc., but particularly from counter-discourses and new ways of thinking, new lifestyles, and new contestations (like the Fridays for Future, the Anti-Mining, the Transition Towns, Black Lives Matter, and Degrowth movements) that increase the positive vulnerability of undesirable systems (Bergmann & Ossewaarde, 2020). At the same time, anthropogenic climate change comes with the development of a multi-trillion market of the emerging green economy, which proves new climate investment opportunities. Given such societal pressures and opportunities, new research topics include the governing and accelerating of the decline of existing systems and their adaptive cycles (Stegmaier, Visser & Kuhlmann, 2014; Hoffmann, Weyer & Longen, 2017; Stegmaier, Visser & Kuhlmann, 2020); the particular circumstances in which accelerations can manifest themselves; the identification of, and coping with, uncertainties in processes of adaptation and transformation and transformational adaptation; and the construction of new incentive structures, for accelerating sustainable transformation (cf. Clément & Rivera, 2017; Warmink et al, 2017; Köhler et al, 2019). This branch of discontinuation research assumes that technologies influence socio-ecological systems. Some technologies threaten resilience to climate change, while others enhance it (Smith & Stirling 2010). Such research informs that political objectives like drastic reduction of CO2 emissions (as can be found in the European Green Deal (2019) will hardly be achieved by using single cleaner (green) technologies alone, but structural system metamorphosis is needed to qualitatively alter established systems (Vögele, Kunz, Rübbelke & Stahlke 2018; Rogge & Johnston, 2017; Stegmaier 2019). One of the challenges for the coming decade is to reverse the negative, alarmist, catastrophic, apocalyptic or paralyzing image of climate change: transformational adaptation comes with stakeholders taking a pro-active and positive view on climate change and on positive vulnerability, with new opportunities emerging from responses to climate change. How can climate change and vulnerability of established (and typically unsustainable) systems be regarded as an opportunity rather than as a risk in the governance of transformational adaptation to climate change?

A fifth theme for future resilience research concerns the role of environmental, energy and climate justice in theorizing, modeling, interpreting, and explaining resilience to climate change (cf. Skillington, 2015; Fazey et al, 2018; Mummery & Mummery, 2019). For future research, theories of environmental justice, energy justice and climate justice can be conducive to helping furthering comprehension of adaptive and transformative resilience and transformational adaptation. How can justice claims be made more responsive to newly unfolding ecological and societal circumstances and uncertainties? How can principles of equity, fairness and access to resources and services be secured in a toxic political environment? And how can – in the problematic context of climate-induced migration and a political environment marked by anti-immigration policies – the wellbeing of migrants be ensured? Theories of environmental, energy and climate justice are also highly relevant for developing understanding of how adaptive and transformative resilience and transformational adaptation are perceived and experienced in everyday life by different stakeholders that face anthropogenic challenges. Constructivist enquiry into perceptions, experiences and prioritizations of resilience constructs is a promising topic for future resilience research. In this regard, insurance decisions of citizens against the risks associated with climate extremes can gain further research attention. As addressed by O'Hare et al. (2016), citizens are faced with an increasing responsibility to make decisions to 'insure' themselves and their assets against the possible damages of climate change. Such decisions can have diverse justice implications in different political and economic contexts that influence how citizens perceive, experience, and prioritize climate risks. Similarly, the cross-sectional dimensions of justice, particularly gender and racial relations, is becoming increasingly relevant and yet challenging to understand and integrate into climate justice (Terry, 2009), and energy justice (Feenstra and Özerol, 2018) frameworks. And in the Global South, addressing issues of corruption, violence, poverty and lack of access to resources (and violent battles for resources) and services (like education and sanitation) may have a higher priority than global environmental considerations (Köhler et al, 2019).

A sixth theme for future resilience research comes with a changing (geo)technological environment, that is, the so-called 'AI revolution' in the making. Given worldwide investments and top-down AI strategies that global governance actors and national governments have recently published, AI will most plausibly become a major force that shapes resilience to climate change by means of monitoring, forecasting and learning. A relevant example of big data is the G-Earth Engine and the vast amount of satellite imagery made available by space agencies, which opens up an unprecedented dataset of satellite images for scientific research. Such extensive datasets, marked by high spatial and temporal resolution, are essential for monitoring a changing earth system. In the past decade, resilience discourses have increasingly incorporated phenomena like big data, AI, cybersecurity and smart city. In the coming decade, resilience discourses may increasingly become algorithmic technology discourses. New interplays between automation, (un)sustainability, and adapting and transforming systems trigger new questions for future resilience research (cf. Köhler et al, 2019). For instance, in the near future, not only the number of climate disasters is expected to rise. Also the data – satellite data, drone data, sensor data, social media data, volunteer geographic information (VGI) data, Internet of Things data, etc. – available on such disasters is expected to increase in size and resolution, amounting to vast volumes of climate disaster data. However, AI, due to the unstructured nature or coverage of input data, may omit those phenomena, places and social groups that are not present in the data (Hoefsloot et al. 2019). Alternative ways of knowing can refine or contribute complementary insights to the precise measurements and data gaps (Pfeffer and Georgiadou 2019). New research questions for naturalist and constructivist research emerge from challenges of organizing big data and how to make it available and usable, given the variety of public and private stakeholders, workflows and incentive structures involved in the (social) construction of big data (Wright, 2016). How can AI be augmented with alternative ways of knowing to strengthen adaptive/transformative resilience? How to incorporate the socio-spatial dimension in resilience research, to pronounce the different capabilities of different groups and places? And what role can AI play in creating a dialogue between the naturalist and constructivist resilience research? In the coming

years, AI tools – mainly tracking (for instance, tracking of deforestation tracking or energy/water consumption) and machine learning techniques – are expected to be widely used. Among other things, for detecting and predicting how climate disasters probably develop, for locating areas or communities at risk, for analyzing the consequences of climate disasters, and for assisting in climate disaster responses. Working with AI for purposes of learning from data – for instance, via the use of data mining or deep learning techniques for dissecting patterns in satellite images – comes with the design of procedures for data analytics, forecasting and intervention (Rodríguez-González, Zanin & Menasalvas-Ruiz, 2019) and requires domain and local knowledge as well as a dialogue between naturalist and constructivist researchers. In contrast to the official national statistics of the past, which diffused societal controversies, big data analytics create myriad parallel realities, stand in the way of achieving a minimal consensus about basic facts and amplify controversies. A recent example where AI and alternative ways of knowledge came together is the resilient settlement program led by UN HABITAT which brought together a multitude of actors (policy, private, academic, community organizations) and data and algorithms and local knowledges to identify settlements at risks. In sum, next to technologization of resilience discourses, social processes of big data construction, the inclusion and exclusion of diverse stakeholders, the embeddedness of AI in everyday practices, the various uses of AI in the exploitation of data, fair, transparent and accountable (FAT) AI, as well as the integration and inclusion of alternative knowledges are promising fields of resilience research.

In the coming decade, several AI challenges are most likely to increasingly come to the fore in resilience research. First, monitoring systems (for instance, monitoring the status and behavior of infrastructure or human settlement dynamics) that incorporate machine learning make that systems are automatically checked rather than regularly inspected by experts. When AI is integrated with knowledge of how systems work, expertise is outsourced to AI, which implies that expert knowledge may get lost or become obsolete. Moreover, AI classifications may have unintended consequences for certain places or communities. For example, by labelling areas at risks, property prices may go down or insurance agencies are not willing to provide an insurance certificate. Second, the digitalization of

SES makes systems vulnerable to, for instance, breakdowns, power outages and cyberattacks – hence resilience strategies and digital strategies are intertwined (Wessel, 2019). 'Digital resilience' has recently become a key concept in resilience research that refers to strengthening resilience of digital systems to potential cyberattacks, including the adaptive capacity to respond to such attacks (Wright, 2016). The making of digital resilience typically implies bringing in tech firms for the protection of SES, whose algorithms are typically opaque. Third, because of the reliance on AI and associated data, other realities are neglected, excluding certain places or communities from digital resilience strategies. Fourth, AI systems facilitate governing at a distance, with governing becoming more invisible and possibly unaccountable. For instance, when disaster management (for instance, in the context of an extreme weather event) becomes 'digital humanitarianism', the distance between the saviors and survivors becomes big, with survivors becoming reified abstract entities that inspire limited empathy. In fact, survivors are confronted with the risks of AI systems, in terms of privacy breaches and identity frauds. In other words, while AI is expected to become a key theme in resilience research, a promising topic for future resilience research concerns the challenge of uncovering resilience traps and neutralizing the ecological and societal damage and injustice done through the reinforcement of AI technologies in governance processes like digitally-based service provision or humanitarian interventions in the Global South.

5. Conclusion

In the social sciences, resilience to climate change is a concept that is incorporated in different theoretical approaches that are linked to contrasting scientific approaches. Holling originally reinterpreted and incorporated the good old notion of resilience in his SES approach, which was then picked up by naturalist scientists who incorporated Holling's reinterpretation of resilience in their own cybernetic complexity theory. The naturalist complexity theoretic approach to resilience as system

adaption to climate change was dominant in the social sciences, until the ecological and political (and increasingly also the technological) context of resilience research changed. When a decade ago actors at global, national and local governance levels drafted their resilience policies in the wake of socio-ecological catastrophes, financial crises, climate crises, pandemics, governance failures, and the breakdown of infrastructures, constructivist approaches developed to take resilience research far beyond complexity theory and associated methods. And it introduced a variety of new concepts for resilience research, such as the resilience discourse, myth of resilience, just resilience, resilience trap, transformative resilience, and transformational adaptation. Resilience cannot operate as a unifying paradigm, but it can facilitate the reconciliation of naturalism and constructivism. Thereby, the two contrasting scientific approaches can provide a liberating perspective on each other (without the one repressing the other) and brought into a theory-energizing tension with each other. Such reconciling – igniting theory-energizing tension – is needed for reimagining resilience to climate change and for specifying how new political-administrative institutions (including panarchical self-organization) and practices can respond in legitimate ways (taken justice and vulnerability considerations into account) to the challenges of climate change, in different ecological, political and technological contexts (cf. Johnsson et al., 2018).

Given recent developments in the social sciences, the key resilience issue concerns the political response in the form of adaptation, transformation, and transformational adaptation in newly unfolding political, ecological, and technological environments. The six resilience themes for the coming decade that this paper has identified are all connected to the issue of the political-administrative response to the challenges that come with anthropogenic climate change. A first theme concerns the reconciliation of naturalism and constructivism, to be able to move beyond established assumptions, theories, concepts, and modes of analysis; and to trigger new imaginations to be able to create new, theory-rich, resilience perspectives. A second theme is the legitimacy of the political response in a toxic political environment, in which top-down and bottom up responses, including new governance arrangements and system reconfigurations, may suffer from legitimacy deficits. A third

759 theme is how, in a toxic political environment, adaptation, transformation and transformational
760 adaptation can be materialized; and under which conditions such governance responses are sufficient
761 for addressing climate change challenges. A fourth theme is how systems are under pressure due to
762 climate change, ultimately igniting a phasing out of systems and a departure from environment-
763 unfriendly consumerist lifestyles, values, and assumptions. A fifth theme is how governance responses
764 can be made legitimate, by incorporating considerations of environmental and climate and energy
765 justice, thereby strictly connecting resilience to justice considerations. A sixth theme is how new
766 technologies (mainly AI) come to intermingle with resilience: what is the role of such technologies and
767 giant tech oligarchies like Google and Amazon in political-administrative responses to challenges that
768 come with climate change? And, correspondingly, what are the undesired consequences that come
769 with AI and giant tech firms, when it comes to responding to climate change. How does AI enact
770 existing power structures, thereby reinforcing resilience traps?
771
772
773 **References**
774
775 Acosta, C., M. Ortega, T. Bunsen, B.P. Koirala & A. Ghorbani (2018) 'Facilitating energy transition
776 through energy commons: an application of socio-ecological systems framework for integrated
777 community energy systems', *Sustainability* 10: 366.
778 Adger, W.N., K. Brown, D.R. Nelson, F. Berkes, H. Eakin, C. Folke, K. Galvin, L. Gunderson, M. Goulden,
779 K. O'Brien, J. Ruitenbeek & E.L. Tompkins (2011) 'Resilience implications of policy responses to climate
780 change', *WIRE's Climate Change* 2 (5): 757-766.
781 Aiken, S.F. (2006) 'Pragmatism, Naturalism, and Phenomenology', *Human Studies* 29: 317-340.
782 Alexander, D.E. (2013) 'Resilience and disaster risk reduction: an etymological journey', *Natural
783 Hazards and Earth System Sciences* 13, 2707-2716.

784 Allen, C.R, D.G. Angeler, A.S. Germestani, L.H. Gunderson & C.S. Holling (2014) 'Panarchy: Theory and
785 Application', *Ecosystems* 17: 578-589.
786 Anderson, B. (2015) 'What Kind of Thing is Resilience?', *Politics* 35(1): 60-66.
787 Beck, U. (2015) 'Emancipatory catastrophism: What does it mean to climate change and risk society?',
788 *Current Sociology* 63(1): 75-88.
789 Béné, C, L. Mehta, G. McGranahan, T. Cannon, J. Gupte & T. Tanner (2018) 'Resilience as a policy
790 narrative: potentials and limits in the context of urban planning', *Climate and Development* 10(2): 116-
791 133.
792 Berbés-Blázquez, M., C.L. Mitchell, S.L Burch & J. Wandel (2017) 'Understanding climate change and
793 resilience: assessing strengths and opportunities for adaptation in the Global South', *Climatic Change*
794 141: 227-241.
795 Berendt, B. (2019) 'AI for the Common Good?! Pitfalls, challenges, and ethics pen-testing', *Paladyn:*
796 *Journal of Behavioral Robotics* 10 (1): 44–65.
797 Bergmann, Z. & R. Ossewaarde (2020) 'Youth Climate Activists Meet Environmental Governance: Ageist
798 Depictions of the FFF movement and Greta Thunberg in German Newspaper Coverage', *Journal of*
799 *Multicultural Discourses*.
800 Bergström, J. (2018) 'An archaeology of societal resilience', *Safety Science* 110: 32-38.
801 Berkes, F. & H. Ross (2016) 'Panarchy and community resilience: Sustainability science and policy
802 implications', *Environmental Science & Policy* 61: 185-193.
803 Blühdorn, I. (2013) 'The governance of unsustainability: ecology and democracy after the post-
804 democratic turn', *Environmental Politics* 22(1): 16-36.
805 Boas, I. & D. Rothe (2016) 'From conflict to resilience? Explaining recent changes in climate security
806 discourse and practice', *Environmental Politics* 25(4): 613-632.
807 Boyer, J. (2020) 'Toward an Evolutionary and Sustainability Perspective of the Innovation Ecosystem:
808 Revisiting the Panarchy Model', *Sustainability* 12(8): 3232.

809 Borsje, B.W., van Wesenbeeck, B., Dekker, F., Paalvast, P., Bouma, T.J., & M.B. de Vries (2011) 'How
810 ecological engineering can serve in coastal protection – a review', Ecological Engineering 37: 113-122.
811 Bourbeau, P. (2015) 'Resilience and International Politics: Premises, Debates, Agenda', *International*
812 *Studies Review* 17: 374-395.
813 Bourbeau, P. & C. Ryan (2018) 'Resilience, resistance, infrapolitics and enmeshment'**,** *European Journal*
814 *of International Relations* 24(1): 221-239.
815 Boyd, E., B. Nykvist, S. Borgström & I.A. Stacewicz (2015) 'Anticipatory governance for social-ecological
816 resilience', *Ambio* 44 (supplement 1): 149-161.
817 Bracking, S. (2019) 'Financialisation, Climate Finance, and the Calculative Challenges of Managing
818 Environmental Change', Antipode 51(3): 709-729.
819 Braun, B.P. (2014) 'A new urban dispositif? Governing life in an age of climate change', *Environment*
820 *and Planning D: Society and Space* 32: 49-64.
821 Chandler, D. (2014) 'Beyond neoliberalism: resilience, the new art of governing complexity', *Resilience*
822 2(1): 47-63.
823 Ching, L. (2016) 'Resilience to climate change events: The paradox of water (In)-security', *Sustainable*
824 *Cities and Society* 27: 439-447.
825 Clément, V. & J. Rivera (2017) 'From Adaptation to Transformation: An Extended Research Agenda for
826 Organizational Resilience to Adversity in the Natural Environment', *Organization & Environment* 30(4):
827 346-365.
828 Conte, R. & M. Paolucci (2014) 'On agent-based modeling and computational social science', *Frontiers*
829 *in Psychology* 5: 668.
830 Cote, M. & A.J. Nightingale (2012) 'Resilience thinking meets social theory: Situating social change in
831 socio-ecological systems (SES) research', *Progress in Human Geography* 36(4): 475-489.
832 Dahlberg, R., C.T. Johannessen-Henry, E. Raju & S. Tulsiani (2015) 'Resilience in disaster research: three
833 versions', *Civil Engineering and Environmental Systems* 32(1-2): 44-54.
834 Davoudi, S. (2018) 'Just resilience', *City & Community* 17(1): 3-7.

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

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

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

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

841 Duit, A. (2016) 'Resilience thinking: Lessons for public administration', *Public Administration* 94(2):
842 364-380.

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

845 Evans, B. & J. Reid (2013) 'Dangerously exposed: the life and death of the resilient subject', *Resilience,*
846 1(2): 83-98.

847 Fainstein, S. (2014) 'Resilience and justice', *International Journal of Urban and Regional Research*, 157-
848 167.

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

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

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

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

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

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

861 Folke, C. (2006) 'Resilience: The emergence of a perspective for social–ecological systems analyses',
862 *Global Environmental Change* 16(3): 253-267.
863 Frost, T. (2019) 'The *Dispositif* between Foucault and Agamben', *Law, Culture and the Humanities*
864 15(1): 151-171.
865 Gallopin, G.C. (2006) 'Linkages between vulnerability, resilience, and adaptive capacity', *Global*
866 *Environmental Change* 16: 293–303.
867 Geels, F. W., & J. Schot (2007) 'Typology of sociotechnical transition pathways', *Research Policy*, 36(3),
868 399-417.
869 Gim, C., C.A. Miller & P.W. Hirt (2019) 'The resilience work of institutions', *Environmental Science and*
870 *Policy* 97: 36-43.
871 Glaser, M., J.G. Plass-Johnson, S.C.A. Ferse, M. Neil, D.Y. Satari, M. Teichberg & H. Reuter (2018)
872 'Breaking Resilience for a Sustainable Future: Thoughts for the Anthropocene', *Frontiers in Marine*
873 *Science* 5: 34.
874 Grove, K. & D. Chandler (2017) 'Introduction: resilience and the Anthropocene: the stakes of
875 'renaturalising' politics', *Resilience* 5(2): 79-91.
876 Haan, F.J. de & J. Rotmans (2018) 'A proposed theoretical framework for actors in transformative
877 change', *Technological Forecasting and Social Change* 128: 275-286.
878 Haasnoot, M., J.H., Kwakkel, W.E. Walker & J. ter Maat (2013) 'Dynamic adaptive policy pathways: A
879 method for crafting robust decisions for a deeply uncertain world', *Global Environmental Change* 23(2):
880 485-498.
881 Hamers, T., J.J. Kamstra, J. van Gils, M.C. Kotte-Albertus & G.M. van Hattum (2015) 'The influence of
882 extreme river discharge conditions on the quality of suspended particulate matter in Rivers Meuse and
883 Rhine (The Netherlands)', *Environmental Research* 143 A: 241-255.
884 Hawes C. & C. Reed (2006) 'Theoretical Steps Towards Modelling Resilience in Complex Systems'.
885 In: Gavrilova M. et al. (eds) *Computational Science and Its Applications*. ICCSA 2006. Lecture Notes
886 in Computer Science, vol 3980. Berlin: Springer.

887 Heffron, R.J. & D. McCauley (2017) 'The concept of energy justice across the disciplines', *Energy Policy*
888 105: 658-667.
889 Hilhorst, D. (2018) 'Classical humanitarianism and resilience humanitarianism: making sense of two
890 brands of humanitarian action', *International Journal of Humanitarian Action* 3: 15.
891 Hoefsloot, F. I., Pfeffer, K., & C. Richter (2019). *People and Places Uncounted: Legibility in the Water*
892 *Infrastructure of Lima, Peru*. 1-17. Paper presented at City Futures 2019, Dublin, Ireland.
893 Hoekstra, A.Y., R. Bredenhoff-Bijlsma & M.S. Krol (2018) 'The control versus resilience rationale for
894 managing systems under uncertainty', *Environmental Research Letters* 13: 103002.
895 Hoffmann, S., Weyer, J., & J. Longen (2017) 'Discontinuation of the automobility regime. An
896 integrated approach to multi-level governance', *Transportation Research*, Part A 103, 391-408.
897 Holling, C.S. (1973) 'Resilience and Stability of Ecological Systems', *Annual Review of Ecology and*
898 *Systematics* 4: 1-23.
899 Holling, C.S. (2001) 'Understanding the Complexity of Economic, Ecological, and Social Systems,'
900 *Ecosystems* 4: 390-405.
901 Howell, A. (2015) 'Resilience as Enhancement: Governmentality and Political Economy beyond
902 "Responsibilisation"', *Politics* 35(1): 67-71.
903 Huang, H., S. Boranbay-Akan & L. Huang (2016) 'Media, Protest Diffusion, and Authoritarian
904 Resilience', *Political Science Research and Methods* 7(1): 23-42.
905 Hughes, S. (2017) 'The Politics of Urban Climate Change Policy: Towards a Research Agenda', *Urban*
906 *Affairs Review* 53(2): 362-380.
907 Jenkins, K. D. McCauley, R. Heffron, H. Stephan & R. Rehner (2016) 'Energy justice: A conceptual
908 review', *Energy Research & Social Science* 11: 174-182.
909 Jesse, B-J., H.U. Heinrichs & W. Kuchshinrichs (2019) 'Adapting the theory of resilience to energy
910 systems: a review and outlook', *Energy, Sustainability and Society* 9: 27.

911 Johnson J.L. et al. (2018) 'Interplays of Sustainability, Resilience, Adaptation and Transformation'. In:
912 W. Leal Filho, R. Marans & J. Callewaert (eds) *Handbook of Sustainability and Social Science Research*.
913 World Sustainability Series. Springer, Cham.
914 Johnston, P. & A. Stirling (2018) 'Comparing nuclear trajectories in Germany and the United Kingdom:
915 From regimes to democracies in sociotechnical transitions and discontinuities', *Energy Research and*
916 *Social Science*, 59, 101245.
917 Juncos, A.E. (2017) 'Resilience as the new EU foreign policy paradigm: a pragmatist turn?', *European*
918 *Security* 26(1): 1-18.
919 Juncos, A.E. (2018) 'Resilience in peacebuilding: Contesting uncertainty, ambiguity, and complexity',
920 *Contemporary Security Policy* 39 (4): 559-574.
921 Kates, R.W., W.R. Travis & T.J. Wilbanks (2012) 'Transformational adaptation when incremental
922 adaptations to climate change are insufficient', *Proceedings of the National Academy of Sciences of the*
923 *United States of America* 109 (19): 7156-7161.
924 Katomero, J. & Y. Georgiadou (2018) 'The Elephant in the Room: Informality in Tanzania's Rural
925 Waterscape', *ISPRS International Journal of Geo-Information 7:* 437.
926 Khakurel, J., B. Penzenstadler, J. Porras, A. Knutas & W. Zhang (2018) 'The Rise of Artificial Intelligence
927 under the Lens of Sustainability', *Technologies* 6, 100.
928 Kitchen, R. (2018) 'Steering the real-time city through urban big data and city dashboards?'.
929 https://urbact.eu/steering-real-time-city-through-urban-big-data-and-city-dashboards-0
930 Klein, J., S. Juhola & M. Landauer (2017) 'Local authorities and the engagement of private actors in
931 climate change adaptation', *Environment and Planning C: Politics and Space 35*(6): 1055-1074.
932 Köhler, J., F.W. Geels, F. Kernc, J. Markard, E. Onsongo, A. Wieczorek, F. Alkemade, F. Avelino, A.
933 Bergek, F. Boons, L. Fünfschilling, D. Hess, G. Holtz, S. Hyysalok, K. Jenkins, P. Kivimaa, M. Martiskainen,
934 A. McMeekin, M.S. Muhlemeier, B. Nykvist, B. Pel, R. Raven, H. Rohracher, B. Sandén, J. Schot, B.
935 Sovacool, B. Turnheim, D. Welch & P. Wells (2019) 'An agenda for sustainability transitions research:
936 State of the art and future directions', *Environmental Innovation and Societal Transitions* 31: 1-32.

937 Kolers, A. (2016) 'Resilience as a Political Ideal', *Ethics, Policy & Environment* 19(1): 91-107.
938 Ksenia, C., G. Lizarralde, A. Dainty & L. Bosher (2016) 'Unpacking resilience policy discourse', *Cities* 58:
939 70-79.
940 Kuhlicke, C. (2013) 'Resilience: a capacity and a myth: findings from an in-depth case study in disaster
941 management research', *Natural Hazards* 67: 61-76.
942 Kuhlmann, S., P. Stegmaier & K. Konrad (2019) 'The tentative governance of emerging science and
943 technology—A conceptual introduction', *Research Policy* 48(5): 1091-1097.
944 Kythreotis, A.P. & G.I. Bristow (2017) 'The 'resilience trap': exploring the practical utility of resilience
945 for climate change adaptation in UK city-regions, *Regional Studies* 51 (10): 1530-1541.
946 Lockie, S. (2016) 'Beyond resilience and systems theory: reclaiming justice in sustainability discourse,
947 *Environmental Sociology* 2(2): 115-117.
948 Lund, J.R. (2015) 'Integrating social and physical sciences in water management', *Water Resources*
949 *Research* 51: 5905–5918.
950 Lyster, R. (2017) 'Climate justice, adaptation and the Paris Agreement: a recipe for disasters?',
951 *Environmental Politics* 26(3): 438-458.
952 Martin, R. & M. Schlüter (2015) 'Combining system dynamics and agent-based modeling to analyze
953 social-ecological interactions—an example from modeling restoration of a shallow lake', *Frontiers in*
954 *Environmental Science* 3: 66.
955 Marvin, S., Luque-Ayala, A., & McFarlane, C. (2016). *Smart urbanism: Utopian vision or false dawn*.
956 New York, NY: Routledge.
957 McGreavy, B. (2016) 'Resilience as Discourse', *Environmental Communication* 10(1): 104-121.
958 Miller, F., H. Osbahr, E. Boyd, F. Thomalla, S. Bharwani, G. Ziervogel, B. Walker, J. Birkmann, S. Van der
959 Leeuw, J. Rockström, J. Hinkel, T. Downing, C. Folke & D. Nelson (2010) 'Resilience and vulnerability:
960 complementary or conflicting concepts?' *Ecology and Society* 15(3): 11.
961 Miller, T. (2019) 'Explanation in artificial intelligence: Insights from the social sciences', *Artificial*
962 *Intelligence* 267: 1-38.

963 Mummery, J. & J. Mummery (2019) 'Transformative climate change adaptation: bridging existing
964 approaches with post-foundational insights on justice', *Local Environment* 24(10): 919-930.
965 Ogunbode, C.A., G. Böhm, S.B Capstick, C. Demski, A. Spence & N. Tausch (2019) 'The resilience
966 paradox: flooding experience, coping and climate change mitigation intentions', *Climate Policy* 19(6):
967 703-715.
968 O'Hare, P., I. White & A. Connelly (2016) 'Insurance as maladaptation: Resilience and the 'business as
969 usual' paradox', *Environment and Planning C: Government and Policy* 34(6): 1175-1193.
970 Ostrom, E. (2007) 'A diagnostic approach for going beyond panaceas', *Proceedings of the National*
971 *Academy of Sciences 104*(39): 15181–15187.
972 Paradiso, M. (2006) 'Information Geography: A Bridge between Engineering and the Social Sciences',
973 *Journal of Urban Technology* 13(3): 77-92.
974 Park, S.E., N.A. Marshall, E. Jakku, A.M. Dowd, S.M. Howden, E. Mendham & A. Fleming (2012)
975 'Informing adaptation responses to climate change through theories of transformation', *Global*
976 *Environmental Change* 22: 115-126.
977 Patriarca, R., J. Bergström, G. Di Gravio & F. Costantino (2018) 'Resilience engineering: Current status
978 of the research and future challenges', *Safety Science* 102: 79-100.
979 Pelling, M., K. O'Brien & D. Matyas (2015) 'Adaptation and transformation', *Climatic Change* 133(1):
980 113-127.
981 Pfeffer, K. & Y. Georgiadou (2019) 'Global Ambitions, Local Contexts: Alternative Ways of Knowing the
982 World', *ISPRS International Journal of Geo-Information 8*, 516.
983 Pietrapertosa, F., M. Salvia, S. De Gregorio Hurtado, V. D'Alonzo, J.M. Church, D. Geneletti, F. Musco &
984 D. Reckien (2019) 'Urban climate change mitigation and adaptation planning: Are Italian cities ready?',
985 *Cities* 91: 93-105.
986 Pizzo, B. (2015) 'Problematizing resilience: implications for planning theory and practice', *Cities* 43:
987 133-140.

988 Pumpuni-Lenss, G., T. Blackburn & A. Garstenauer (2017) 'Resilience in complex systems: An agent-
989 based approach', *Systems Engineering* 20(2): 158-172.
990 Rajan, A. & A. Saffiotti (2017) 'Towards a science of integrated AI and robotics', *Artificial Intelligence*
991 247: 1-9.
992 Redman, C. L. (2014) 'Should sustainability and resilience be combined or remain distinct
993 pursuits?', *Ecology and Society* 19(2): 37.
994 Ribault, T. (2019) 'Resilience in Fukushima: Contribution to a Political Economy of Consent',
995 *Alternatives: Global, Local, Political* 44 (2-4) 94-118.
996 Rodríguez-González, A., M. Zanin & E. Menasalvas-Ruiz (2019) 'Public Health and Epidemiology
997 Informatics: Can Artificial Intelligence Help Future Global Challenges? An Overview of Antimicrobial
998 Resistance and Impact of Climate Change in Disease Epidemiology', *IMIA Yearbook of Medical*
999 *Informatics*: 224-231.
1000 Rogge, K. S., & P. Johnston (2017) 'Exploring the role of phase-out policies for low-carbon energy
1001 transitions: The case of the German Energiewende', *Energy Research & Social Science*, 33, 128-137.
1002 Rogge, K. S., Kern, F., & M. Howlett (2017) 'Conceptual and empirical advances in analysing policy mixes
1003 for energy transitions', *Energy Research & Social Science*, 33, 1-10.
1004 Rothe, D. (2017) 'Gendering Resilience: Myths and Stereotypes in the Discourse on Climate-induced
1005 Migration', *Global Policy* 8: 40-46.
1006 Ruinen, R. van, T. Filatova, W. Jager & A. van der Veen (2015) 'Going beyond perfect rationality:
1007 drought risk, economic choices and the influence of social networks', *The Annals of Regional Science*
1008 57(2-3): 335-369.
1009 Samarakoon, S. (2019) 'A justice and wellbeing centered framework for analysing energy poverty in
1010 the Global South', *Ecological Economics* 65(C), 106385.
1011 Saravi, S., R. Kalawsky, D. Joannou, M. Rivas Casado, G. Fu & F. Meng (2019) 'Use of Artificial
1012 Intelligence to Improve Resilience and Preparedness Against Adverse Flood Events', *Water* 11, 973.

1013 Schilling, T., R. Wyss and C.R. Binder (2018) 'The Resilience of Sustainability Transitions', *Sustainability*
1014 10, 4593.
1015 Schlosberg, D., L.B. Collins & S. Niemeyer (2017) 'Adaptation policy and community discourse: risk,
1016 vulnerability, and just transformation', *Environmental Politics* 26(3): 413-437.
1017 Schwartz, S. (2018) 'Resilience in psychology: A critical analysis of the concept', *Theory and Psychology*
1018 28(4): 528-541.
1019 Sjöstedt, M. (2015) 'Resilience revisited: taking institutional theory seriously', *Ecology and Society*
1020 20(4): 23.
1021 Simbirski, B. (2006) 'Cybernetic Muse: Hannah Arendt on Automation, 1951-1958', *Journal of the*
1022 *History of Ideas* 77(4): 589-613.
1023 Skillington, T. (2015) 'Climate justice without freedom: Assessing legal and political responses to
1024 climate change and forced migration', *European Journal of Social Theory* 18(3): 288-307.
1025 Smit, M.J., H. Goosen & C.H. Hulsbergen (1998) 'Resilience and Vulnerability: Coastal Dynamics or
1026 Dutch Dikes? *The Geographical Journal* 164(3) 259-268.
1027 Stegemann, L. & M. Ossewaarde (2018) 'A Sustainable Myth: A Neo-Gramscian Perspective on the
1028 Populist and Post-Truth Tendencies of the European Green Growth Discourse', *Energy Research &*
1029 *Social Science* 43: 25-32.
1030 Stegmaier, P., Visser, V. R., & S. Kuhlmann (2020) 'The incandescent light bulb phase-out. Exploring
1031 patterns of framing the governance of discontinuing a socio-technical regime' (under review).
1032 Stegmaier, P. (2019) 'Killing the Coal. On governing the discontinuation of coal energy production',
1033 Paper presented at the Nordic STS Conference; Session: How do technologies die?, Tampere.
1034 Stegmaier, P., Kuhlmann, S., & V.R. Visser (2014) 'The Discontinuation of Socio-Technical Systems as
1035 Governance Problem'. In: Borrás, S. & J. Edler (eds.) *Governance of Systems Change* (pp. 111-131).
1036 Cheltenham: Edward Elgar.
1037 Strunz, S. (2014) 'The German energy transition as a regime shift', *Ecological Economics*, 100, 150-
1038 158.

1039 Sun, L., B. Stojadinovic & G. Sansavini (2019) 'Agent-Based Recovery Model for Seismic Resilience
1040 Evaluation of Electrified Communities', *Risk Analysis* 39(7): 1597-1614.
1041 Swyngedouw, E. (2010) 'Apocalypse forever? Post-political populism and the spectre of climate
1042 change', *Theory Culture & Society* 27 (2-3): 213-232.
1043 Swyngedouw, E. (2011) 'Depoliticized environments: the end of nature, climate change and the post-
1044 political condition', *Royal Institute of Philosophy Supplement* 69: 253-274.
1045 Szablowski, D. & B. Campbell (2019) 'Struggles over extractive governance: Power, discourse, violence,
1046 and legality', *The Extractive Industries and Society* 6 (2019) 635–641.
1047 Taddeo, M. & L. Floridi (2018) 'How AI can be a force for good', *Science* 361 (6404): 751-752.
1048 Terry, G. (2009) 'No climate justice without gender justice: an overview of the issues', *Gender &*
1049 *Development 17*(1): 5-18.
1050 Thorén, H. (2014) 'Resilience as a Unifying Concept', *International Studies in the Philosophy of Science*
1051 28 (3): 303-324.
1052 Tierney, K. (2015) 'Resilience and the Neoliberal Project: Discourses, Critiques, Practices—And Katrina',
1053 *American Behavioral Scientist* 59(10): 1327-1342.
1054 Tyler, S. & M. Moench (2012) 'A framework for urban climate resilience', *Climate and Development*,
1055 4(4): 311-326.
1056 Ungar, M. (2018) 'Systemic resilience: principles and processes for a science of change in contexts of
1057 adversity', *Ecology and Society* 23(4): 34.
1058 Vahedifard, F., A. Ermagun, K. Mortezaei & A. AghaKouchak (2019) 'Integrated data could augment
1059 resilience', *Science* 363 (6423), 134.
1060 VanderPlaat, M. (2016) 'Activating the sociological imagination to explore the boundaries of resilience
1061 research and practice', *School Psychology International* 37(2): 189-203.
1062 Ven, A. van de (2017) 'The innovation journey: you can't control it, but you can learn to maneuver it',
1063 *Innovation* 19(1), 39-42.

1064 Verrest, H. & K. Pfeffer (2019) 'Elaborating the urbanism in smart urbanism: distilling relevant
1065 dimensions for a comprehensive analysis of Smart City approaches', *Information, Communication &*
1066 *Society* 22 (9): 1328-1342.
1067 Vögele, S., Kunz, P., Rübbelke, D. & T. Stahlke (2018) 'Transformation pathways of phasing out
1068 coal-fired power plants in Germany', *Energy, Sustainability and Society*, 8(25): 1-18.
1069 Walker, J. & M. Cooper (2011) 'Genealogies of resilience: from systems ecology to the political
1070 economy of crisis adaptation', *Security Dialogue*, 42(2): 143-160.
1071 Walsh-Dilley, M. & W. Wolford (2015) '(Un)Defining resilience: subjective understandings of
1072 'resilience' from the field', *Resilience* 3(3): 173-182.
1073 Warmink, J.J., M. Brugnach, J. Vinke-de Kruijf, R. M. J. Schielen & D. C. M. Augustijn (2017) 'Coping with
1074 Uncertainty in River Management: Challenges and Ways Forward', *Water Resources Management* 31:
1075 4587-4600.
1076 Weichselgartner, J. & I. Kelman (2015) 'Geographies of resilience: Challenges and opportunities of a
1077 descriptive concept', *Progress in Human Geography* 39(3): 249-267.
1078 Wessel, R.A. (2019) 'Cybersecurity in the European Union: Resilience through Regulation', in E. Conde
1079 Pérez, Z. Yaneva & M. Scopelliti (eds.), *Routledge Handbook of EU Security Law and Policy*. London:
1080 Routledge, pp. 283-300.
1081 Wiese, F. (2016) 'Resilience Thinking as an Interdisciplinary Guiding Principle for Energy System
1082 Transitions', *Resources* 5, 30.
1083 Wright, D.J. (2016) 'Towards a *digital* resilience', *Elementa: Science of the Anthropocene* 4: 000082.
1084 Yanarella, E.J. & R.S. Levine (2014) 'From Sustainability to Resilience: Advance or Retreat?',
1085 *Sustainability* 7(4): 197-208.
1086 Ziervogel, G., A. Cowen & J. Ziniades (2016) 'Moving from Adaptive to Transformative Capacity:
1087 Building Foundations for Inclusive, Thriving, and Regenerative Urban Settlements',
1088 *Sustainability* 2016, *8*(9), 955.
1089

1090

1091

1092