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Dear referee,

Thank you very kindly for your comments on our paper and for your critical and constructive feedback that will enable us to improve it. You give us seven points of feedback. We have worked with your feedback in the following way.

1. You mention that the first sections (up to the proposed research agenda section) are difficult to follow for natural scientists and policy-focused scientists. In many ways this is the core of your feedback that also informs some of the other points of your feedback. We will take this point of feedback seriously, keeping your advice in mind (given in the points below) and revise the article – particularly up to the research agenda section. Specifically, we will ensure that the article's writing style, formulations, line of argumentation, conceptualization, choice of words etc. are easy to follow for a broader audience.

   We have actively rewritten the article (as can be seen in the track and trace version) in line with this comment. We have done our best to make our article readable and easy to follow.

2. The second point of your feedback stresses that the writing style is difficult to follow, which is linked to your first point. In line with your advice, we will improve the writing style, replacing complex terms and shortening sentences. We will also ensure that concepts are clearly defined, and better explained, illustrated and concretized, without introducing too many concepts. Further, we will have a careful look at the grammar and clarity of sentences. You give examples of unclear sentences, which we will address with care, and we will go through each sentence to ensure clarity throughout the paper.

   In our revision, we have actively worked with this comment. We have improved our writing style, actively shortened our sentences, and have more clearly defined and explained our concepts. In our revised manuscript, we have actively worked to improve our clarity.

3. Your third comment refers to the framing of the article. You give the useful suggestion that the article should be framed as resilience research in the social sciences and with the focus on climate change from the very beginning, in the introduction section (and in the abstract). We will implement this suggestion by the first author of our paper.

In our revision, we have actively worked with this comment. We have rewritten our introduction section and abstract. We have now stressed from the very beginning that the paper concerns resilience research in the social sciences and with a focus on climate change.

4. Your fourth comment refers to providing more historical background of the SES notion of resilience. This should include how it was debated in the 1990s and 2000s in the environmental sustainability field and the growing field of research on global environmental change. And as you suggest, we will emphasize the debates that occurred in the 2000s, to define resilience as opposed to vulnerability. Thank you for suggesting relevant references for describing and acknowledging this background. We take this fourth comment at heart and we will include the discussion on the historical background, along the lines that you suggest.

   We have actively worked with this comment, including some of the vulnerability literature that the reviewer suggested. We have included the resilience as opposed to vulnerability argument and included it in our line of argumentation.

5. You wonder why we do not emphasize adaptive capacity in our discussion, given that adaptive capacity has provided an analytical framework for much governance research on global environmental change. You suggest to link that strand of literature in our discussion of adaptive and transformative change. From our side, there were no principal reasons for omitting that body-of-literature in our discussion. We take your advice at heart and link up with that body of literature. In our revised article we will specifically work with the questions that you provided, namely, 'how is that strand of literature linked to the growing interest in adaptive and transformative change? In what ways do the later concepts offer fresh and new insights?' In our revised article we will specifically work with the questions that you provided, namely, 'how is that strand of literature linked to the growing interest in adaptive and transformative change? In what ways do the later concepts offer fresh and new insights?' Amongst other things, we will refer to Ziervogel, G., Cowen, A., & Ziniades, J. (2016). Moving from adaptive to transformative capacity: Building foundations for inclusive, thriving, and regenerative urban settlements. *Sustainability (Switzerland)*, *8*(9). https://doi.org/10.3390/su8090955

   In our revised manuscript we have worked actively with this comment and also included the Ziervogel, Cowen and Ziniades article, which was indeed very helpful and relevant for us.

6. You stress that the particular focus on ABM and AI need to be better justified, and explained why they are mentioned more than others. And you stress that 'the discussions on Section 3 could provide more concrete examples of the methodological implications of taking one approach or another.' For us this is a comment and advise that we take seriously. We will work with the comment, doing our best to improve our justification and concretization. The focus on ABM we will justify more strictly as a typical and frequently used approach that we encounter in contemporary naturalist resilience research. We will mention other naturalist approaches that are found in naturalist resilience research. And we will better justify AI in terms of the so-called 'AI revolution' that is currently shaped by governance actors. And this 'AI revolution' has implications for both socio-ecological systems and for resilience research.

In our revised manuscript we have worked actively with this comment, working to better embed ABM and AI in our article.

7. You suggest to improve the readability of the article with the use of figures and tables, for example to present definitions or how the core concepts of the paper relate to each other. In our revised article we will take this useful suggestion into consideration, as part of the general effort to improve readability of the article. Our plan is to develop a figure that visualizes how the core concepts of the paper relate to each other.

We have actively thought about this comment. After internal discussions amongst ourselves we have decided to leave out the visualization as we believe that it does not fit nicely with the style of our article. If the editor would insist on a visualization, we can of course include it, for instance in the form of a table.

Dear referee,

Thank you very kindly for your comments on our paper and for your critical and constructive feedback that will enable us to improve our paper. You give us six points of feedback. We wish to work with your feedback in the following way.

1. You mention that the introduction section is difficult to follow and unclear. You stress that in the introduction section it is difficult to follow whether it is a part of the background review or methodology. We take your comment at heart and revise the introduction section, in line with your comments.

   We have actively worked with this comment. We have rewritten the introduction section (as well as the abstract) in line with your comments.

2. You give us the advice to bring the panarchy theory in our discussion on adaptive and transformative resilience, particularly to find out whether "adaptive resilience obstructs transformative resilience" aligns or conflicts with the Panarchy theory of adaptive cycle and resilience building. We find this an interesting and relevant advice that we will follow in our revised manuscript. We will add the discussion on the panarchy theory to the discussion on adapative and transformative resilience.

   We have actively worked with this comment. We have included panarchy theory in our discussion.

3. You stress that we generalize too easily that the application of AI strengthens adaptive resilience and weakens transformative resilience; and that we need more examples and arguments for this. You stress that it cannot be generalized for all cases; and that AI can also help to build transformative resilience, given that the capacity for anticipating future events is an element of transformative resilience. We find your comment very relevant and will work with your comment in our revised manuscript, rethinking our argument. In revising our manuscript, we will include more concrete examples, which we will discuss amongst the co-authors of our article.

   We have actively worked with this comment. We have included more concrete examples. And we have emphasized that AI can also help to build transformative resilience.

4. You stress that section 2 needs more direction in the discussion. We take your comment at hear. We will revise this section, to ensure structure and readability and guidance for the reader, being explicit in the point that we seek to make. We will ensure that the article (its

writing style, its formulations, its line of argumentation, its conceptualizations, its choice of words etc.) is easy to follow for a broader audience. In line with your advice, we will revise the writing style, replacing complex terms and making shorter sentences. And in line with your feedback, we revise the article to ensure that concepts will be more clearly defined and better explained and illustrated and concretized, without introducing too many concepts. Also, in line with your feedback, we will have a careful look at the grammar and clarity of sentences. And our plan is to develop a figure that visualizes how the core concepts of the paper relate to each other.

We have actively revised section 2 (as can be seen in the trach and changes), in line with your advice. We have actively worked on our writing style, to make our article more readable.

5. You mention that in some places we fail to include appropriate references in our discussion; and you give examples of this. We will revise the paper with your comment in making, making sure that we make the appropriate references.

We have actively worked with this comment. We have included the examples you have given us and we have used the references, for which we are thankful.

6. You mention that we frequently introduce jargon that we leave undefined, and you give examples of this. With your comment in mind, we will revise the article, making sure that if we introduce jargon or concepts, we describe them accurately.

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

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155

156 **Abstract**

157 Since the 1970s, Holling's socio-ecological systems (SES) approach has been the most predominant
158 theoretical force in resilience research with regard to ~~in the context of~~ the climate crisis. An overview
159 of the scholarship in the social sciences during the past five decades reveals two different re-
160 appropriations of Holling's legacy, which can broadly be classified as naturalist and constructivist,
161 respectively. Characteristic for naturalist resilience research is its indebtedness to the concepts,
162 methods and assumptions of the so-called 'life sciences'. This has resulted in the recasting of Holling's
163 SES into complex systems that are marked by
164 ~~In the social sciences, From Holling's approach, however, two contrasting scientific approaches to~~
165 ~~resilience have developed from Holling's approaches, namely, naturalism and constructivism. While~~
166 ~~naturalist resilience research takes SES as complex systems marked by~~ non-linearity and evolutionary
167 changes.~~,~~ ~~c~~Constructivist resilience research, on the other hand, relies on the concepts, methods and
168 assumptions that are common in the 'human sciences'. Accordingly, resilience is studied and critically
169 appraised in its historical, social and political context. ~~focuses on the embeddedness of SES in~~
170 ~~heterogenous contexts. In naturalist resilience research resilience is defined as a system property,~~
171 ~~while in constructivist resilience research resilience is politically loaded and historically contingent.~~ In
172 this paper, recent developments in resilience research in the social sciences are reviewed to the end
173 of proposing new research questions. The focus is on the different approaches, models and
174 commitments that underpin these two approaches to resilience in the context of the ecological crisis.
175 Particular attention is thereby paid to the naturalist emphasis on adaptation and the constructivist
176 emphasis on transformation.
177 ~~The aim of this paper is to review and structure current developments in social scientific enquiry into~~
178 ~~resilience to climate change, research in the field of climate change studies, in terms of the approaches,~~
179 ~~definitions, models and commitments that are typical for naturalism and constructivism; identify the~~
180 ~~key tension between naturalist and constructivist resilience research in terms of the widely discussed~~

~~issue of adaptation and transformation, and discuss its implications for sustainable development; and propose a research agenda of topics distilled from the adaptation-transformation tension between naturalist and constructivist resilience research.~~

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

1. Introduction

~~In the social sciences, climate change is increasingly researched as a resilience topic. In the social sciences, Crawford Stanley Holling's ecological notion of resilience (Holling, 1973) is widely used as~~ ~~Since the publication of Crawford Stanley Holling's 'Resilience and Stability of Ecological Systems' (1973), the notion of resilience has become increasingly popular in a wide variety of scientific disciplines. Used as a concept, framework, style of thinking, metaphor~~metaphor, ~~or discourse~~. ~~For social scientists, rom a social sciences perspective, Holling's notion of resilience appears attractive as a theme for interdisciplinary research, including the bridging of the social sciences and engineering (Ostrom, 2007; Thorén, 2014).~~

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 ~~Crawford Stanley Holling's ecological notion of resilience (Holling, 1973) has become part and parcel of the social sciences.~~ 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). ~~For resilience research, Holling's socio-ecological systems (SES) approach has been widely adopted, and reinterpreted, as a lens that helps elucidate human-nature interactions (Ostrom, 2007). In~~ Holling's socio-ecological systems ~~the~~ (SES) approach appealed to social scientists since it highlighted the interaction between human societies (political, social, economic and technological environments) and natural ecosystems. ~~, which emerged in the 1970s, social phenomena eties are thought to exist in continuous interaction with their surrounding natural, political, social, cultural, economic and technological environments.~~ Consequently, ~~Hence, from a social sciences perspective,~~ resilience to climate change, for the social scientist, requires the ~~is not merely ecological change, but is first of all a social phenomenon that is marked by~~ reformation of ~~established~~ modes of thought (including conceptualizations of 'nature' and 'society'), ~~of~~ lifestyles and consumer habits, ~~of~~ production patterns, ~~of~~ health issues, ~~of~~ law, economy, science, technology, governance and politics ~~(the typical research topics for the social scientistsces)~~ (cf. Douglaous & Wildavsky, 1983; Blühdorn, 2013; Fischer, 2017; Dryzek & Pickering, 2019).

~~The SES approach is adopted by the Resilience Alliance, whose flagship journal, *Ecology and Society* (established in 1995), provides a platform for SES-based resilience research. The SES approach has not only been popularized but also recast and incorporated in other theoretical approaches. In fact, in resilience research, SES is typically redefined as complex systems, that is, it is incorporated in the context of the complexity theory approaches. Since its development in the 1940s, complexity theory has been a widely adopted theoretical approach in the naturalist social sciences.~~

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 ~~— Since the Tsunami in 2004, Katrina (2005), the global economic crisis (2007-2008), Fukushima Daiichi (2011) and recent El Niño events, and increased urgencies of the~~

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~~climate crisis (and calls for climate action), the political, social, cultural, economic, scientific and technological contexts in which resilience research takes place have changed~~ (Pizzo, 2015). ~~Since then,~~ ~~social scientists, inspired by Holling's SES approach, emphasize that~~ ~~Such climate disasters and crises have revealed that the~~ ~~vulnerability that, for instance, Katrina or today's Covid- 19 crisis reveal, is not a function solely of exposure to natural hazards.~~ 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 ~~For social scientists, , but it is a function of multiple dimensions of~~ social, cultural, ~~political~~political, and economic conditions largely determine the resilience to these natural calamities ~~disadvantage~~ (Tierney, 2015; Lockie, 2016). In the past decade, ~~social sciences have increasingly researched~~ resilience to climate change has been addressed primarily as a policy discourse. Indeed, ~~. S~~since 2010, in the wake of the global financial crisis (2007-2008), ~~Since 2010,~~ global governance actors and national and local governments – including the Rockefeller Foundation~~'s 100 resilient cities program~~ – 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.

~~developed resilience discourses in which relationships between governments, citizens and denizens are being ideologically reconfigured . Such policy discourses of bouncing back after crises and catastrophes have triggered new resilience practices, such 'resilience humanitarianism' based on the idea of crisis as a new normality~~ (Hilhorst 2018). ~~Such These policy discourses and practices have ignited new social scientific~~ 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. ~~With the increased social scientific interest in resilience topics, scientific approaches to resilience to climate change rapidly diversify. In the social sciences,~~ As a result, ~~m~~Many publications of the past decade address ~~the development of~~ different definitions and understandings of resilience ~~, marked by different scientific approaches.~~ Such

diversity corresponds to the diversification of approaches in the social sciences. ~~While r~~Resilience research in the social sciences had been predominantly ~~primarily~~ naturalist. ~~, t~~Today, social scientists are increasingly addressing climate change and resilience to climate change ~~widely research resilience to climate change~~ from constructivist angles.

~~Resilience research is no longer primarily naturalist. The naturalist approach to resilience is now balanced by constructivist scientific approaches that enrich resilience research. This is particularly so in the field of anthropogenic climate change, where fundamental changes in the governance of the earth system are urgently required, if extreme catastrophes and associated suffering and oppression are to be avoided (Redman, 2014; Yanarella & Levine, 2014; Lockie, 2016; Dryzek & Pickering, 2019).~~

The aim of this paper is to 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. ~~retrace the current directions of naturalist and constructivist resilience research~~ in the social sciences. Thereby, we seek to ~~– and thereby order contemporary debates in a diversified and rapidly changing field of social scientific resilience research.~~ U~~–, ultimately, we seek to do so~~ to identify upcoming research themes for the coming years. ~~First, current scientific approaches in resilience research are reconstructed in terms of the differences between naturalist and constructivist resilience research in the social sciences. While naturalist resilience research typically defines resilience to climate change as a physical property (like atoms, mass, molecules, cells, DNA, etc.) of complex systems, constructivist resilience research defines resilience as a political phenomenon that is historically embedded in a changing social, cultural, political, economic, scientific, technological environment.~~ Naturalism and constructivism are presented as two (social) scientific approaches underpinned by ~~with~~ different epistemological and ontological commitments~~assumptions~~. It is suggested that ~~, that,T to advance~~ social scientific inquiry

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into resilience in the context of climate change ~~resilience research~~ could be raised to a next level if these two different approaches meet and interact~~, we argue, these two approaches need to be bridged~~. 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. ~~Second, contemporary key issues of debate in naturalist and constructivist approaches to resilience to climate change research are identified. Ultimately, in the social sciences, naturalist and constructivist resilience research clashes on the issue of system adaptation and transformation in a context of severe disturbances or shocks that come with climate change (, such as hurricanes, floods, drought and heatwaves). The tension between adaptation and transformation has, amongst other things, implications for social scientific enquiry into the sustainable energy transformation, the relationship of resilience research to sustainability discourses, and the response of resilience research to new political and technological circumstances. Third~~Finally, naturalist and constructivist directions, as well as possible cross-fertilizations of these two currents, for future resilience research are identified~~., including the bridging of naturalist and constructivist resilience research.~~ 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). ~~We emphasize , with an emphasis on the likely impact of changing conditions – particularly in ecological, political and technological dimensions – on the questioning, theorizing, and modes of analysis in resilience research.~~

2. The diversification of resilience research

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 meants rebounding. This Latin word can be found in the writings of Seneca the Elder, Pliny the Elder, Ovid, Cicero, and Livy; ~~Lucretius'~~ to rebound is also the sense in which *resilire* is used by Cicero in his *Orations* ~~*On the Nature of Things* and Cicero's *Orations*~~ (Alexander, 2013~~; Pizzo, 2015~~). The term also appears in Lu~~i~~cretius' *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 t~~h~~e early nineteenth century, this was~~is~~ the predominant understanding of resilience in common language and imagination. A slight shift appeared when engineers started to use the term to refer to ~~, until engineers come to employ the term. In engineering, resilience refers to , until engineers come to employ the term to describe~~ the properties and capacities of materials ~~and the capacity of materials~~ to absorb ~~stresses~~ tensions and release energy, and recover their original forms, without breaking or disfiguration~~ing,~~ after undergoing some external shock or disturbance (~~,~~ such as ~~an~~ extreme weather conditions~~event~~) (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 ~~turn to resilience to analyze~~study the coping mechanisms of concentration camp survivors. L~~;~~ later, the concept is used to study all sorts of trauma, misfortune, adversity, ~~stress~~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 inability to absorb change and disturbance (Gallopin, 2006; Miller et al, 2010) - ~~(~~for instance, a coastal system that is vulnerable to ~~'s incapability to cope with the consequences of climate change and~~ accelerated sea-level rise is not resilient enough~~-~~(Smit, Goosen & Hulsbergen, 1998). In such discourses, greater ~~Strengthening~~ resilience means ~~implies~~ becoming less vulnerable to change and shocks. ~~reducing vulnerability to not being able to absorb change and disturbance.~~ That said, ~~A~~a system can still be vulnerable to other changes while being resilient in other respects~~ be vulnerable to certain changes and disturbances and not to others~~ (Gallopin, 2006).

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

In the social sciences, resilience research that has emerged from Holling's SES approach has developed along two different lines~~in two contrasting directions~~, which can be called naturalist and constructivist, respectively~~: naturalism and constructivism~~ (Miller et al, 2010). ~~Each of these approaches incorporate their own definitions of resilience. In resilience research, resilience to climate change can mean many different things – including a concept, metaphor, ideology, governing rationality, policy, etc. (Anderson, 2015) –, yet, the particular meaning of resilience that is enacted in resilience research is typically either naturalist or constructivist.~~ These two currents of research have different focuses, raise different questions and have recourse to different methods. The naturalist line

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of research is indebted to the accepted methods and assumptions of the natural sciences. It has a predilection for mathematical and simulation models. Social scientists dealing with resilience to climate change research questions consider resilience as a property of a system, which can be (made) weak or strong. ~~Naturalism can be defined as a scientific approach that assumes that phenomena (including ecological and social phenomena) can be researched as objects and therefore be objectively defined and measured. In the social sciences, naturalists seek to explain social phenomena in the~~ ~~is a type of science that seeks to explain the world in the mmanner of the natural sciences. In resilience research, naturalist scientists they typically model s~~Society is modelled as a social system that consists of parts and~~, with the world being modelled as consisting of~~ physical properties that can be objectively studied ~~irrespective of the historical and cultural context – resembling atoms, mass, molecules, cells, DNA, etc.~~ (Aiken, 2006; Floridi, 2017). ~~Resilience~~ to climate change ~~is likewise defined as one of the system properties – Moreover, history and culture (in the sociological sense of the term) cannot be integrated in the various models.~~ Resilience as a system property is an objective measure of the dynamic equilibrium, stability, ~~strength~~strength, or survivability of a socio-ecological system, , including coastal systems, urban systems, forest systems, etc. (Hoekstra, Bredenhoff-Bijlsma & Krol, 2018). ~~In naturalist research, resilience is defined as a system property: resilience is an essential measure of the dynamic equilibrium or survivability of a socio-ecological system.~~

The naturalist approach to problems that arise through climate change can be very useful, especially when both the problem and the solution are quite uncomplicated (and hence are primarily of a technical nature, such as water purification, for instance). The story becomes more complicated when, for instance, attempts to make communities more resilient to climate change overlook the 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

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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.

~~While naturalist resilience research typically defines resilience to climate change as a physical property (like atoms, mass, molecules, cells, DNA, etc.) of complex systems, constructivist resilience research defines resilience as a political phenomenon that is historically embedded in a changing social, cultural, political, economic, scientific, technological environment.~~

~~is a type of science that seeks to explain the world in the manner of the natural sciences, with the world being modelled as consisting of physical properties (Aiken, 2006; Floridi, 2017). Resilience is likewise defined as one of the system properties (Hoekstra, Bredenhoff-Bijlsma & Krol, 2018). In naturalist research, resilience is defined as a system property: resilience is an essential measure of the dynamic equilibrium or survivability of a socio-ecological system.~~ ~~By contrast,~~ 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 ~~In the social sciences, co~~constructivism ~~is an anti-naturalist scientific approach that researches phenomena as subjects invested with~~ 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 the social sciences, constructivists emphasize that social sciences are fundamentally different from the natural sciences, because social phenomena are fundamentally different from physical properties.~~ In resilience research, they typically model society as a historically embedded construct that is the result of ~~invested with a~~ ~~is a type of science that denaturalizes and historicizes, in~~

~~the sense that it defines phenomena like resilience as a historically contingent social construct. It is focused on heterogenous contexts of natural and social science itself – contexts marked by diversity of (contested) knowledges,~~ 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. ~~values, power relations, practices and meanings. Precisely because constructivists theorize phenomena as constructs – and ultimately all constructs involve the exercise of power –, they~~ Constructivists tend to be more critical and politically sensitive. They are generally ~~Constructivists are~~more aware of the potential and actual abuse of power. When addressing resilience issues in the context of climate change, they ~~Therefore, in their researches of the phenomenon of resilience to climate change, constructivists~~ typically express concern for vulnerable communities~~, environmental and climate justice. In its resilience research, it therefore incorporates justice issues of , that is, to~~ Research topics thus include the

~~Constructivist scientists are~~~~It is more critical and politically sensitive. It typically expresses concern for issues of equity, domination, 'climate change gentrification' and 'climate apartheid' in resilience research. Its key concern and research focus is typically environmental and climate justice, which refer to~~ (un)equal distribution of environmental burdens, struggles for recognition, claims to participation, and unequal impacts of anthropogenic climate change (Braun, 2014; Yanarella & Levine, 2014; Skillington, 2015; Sjöstedt, 2015; Weichselgartner & Kelman, 2015; Pizzo, 2015; Lockie, 2016; Derickson, 2016; Lyster, 2017; Schlosberg, Collins & Niemeyer, 2017; Mummery & Mummery, 2019). ~~Duffield (2016), for instance, refers to digital humanitarianism as a 'resilience of ruins'.~~ Davoudi (2018: 5)~~,~~ 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. ~~defined as (marked by the systematic neglect of vulnerable groups and marginalized people (a systematic neglect that, for instance, Katrina and the Covid-19 crisis reveal).~~ 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. to show how, as a construct, the making of resilience to climate change comes with power abuse, domination and injustice. In other words, for the constructivist social scientist, resilience is far from being a neutral property of a neutral system (neutral in the sense of being 'value-free'). Therewith, the theme of anthropogenic climate change in general and the constructivist notion of resilience in particular is placed within wider problematic contexts marked by unequal power relationships.

2.1. The naturalist view on resilience

In the social sciences, nNaturalist social scientific research as such , which has its origins in the logical positivism of the Vienna Circle of the 1920s and 1930s, mainly developed arose in the context of the Cold War, with the development of cybernetics, computational power and automation (and automated decision making) (Simbirski, 2006; Floridi, 2017; 2018; Davoudi, 2018). Naturalist social studies are based on the cybernetic idea that machines, organismsorganisms, and societies show considerable similarity in structure and function; and can be described in terms of (the metaphor of) systems. Since the 1940s, such studies have typically adopted cybernetic complexity theory as their distinctive overarching theoretical outlook, within which other theories (for instance, on behavioral change, on decision making under risk, or on social institutions) are incorporated. In complexity theory, machines, organismsorganisms, and societies ecology and society are modelled as complex, non-linear, evolutionary systems. ComplexSuch systems are composed of many components, including (properties, agents, resources, and governance systems). All And these 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, Hence, resilience to climate change is a matter

of evolution: resilience is ~~in naturalist social science resilience is presented as~~ 'evolutionary resilience' (Pizzo, 2015: 137; Davoudi, 2018: 4).~~ In the 1970s, naturalist social scientists come to When this type of science comes to embrace Holling's SES approach. They in the 1970s, it~~ incorporate~~d~~s~~ Holling's ~~SES~~ the notion of resilience within their own ~~context of of~~ cybernetic complexity theory and cybernetic methodologys ~~its complexity theoretic orientation~~ (Wiese, 2016; Bergström, 2018). That is, socio-ecological systems are cybernetically conceptualized as ~~treated as~~ adaptive complex systems. The ability to cope with uncertainty and complexity ~~– and to limit vulnerability in not being able to absorb changes and disturbances –~~ is one of the capacities of individual agents and interacting agents. The latter ~~found in the capacities and relations between multiple agents. Such agents~~ that 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).

~~The notion of panarchy. Given the complexity of systems, nN~~Naturalist social scientists tend to emphasize a type of laissez-faireism, pointing out that adaptive complex systems have their own self-organizational structures that should not be interfered with. ~~governance structure beyond simple notions of hierarchy.~~ Bureaucratic interventions ~~that are designed for~~to address ~~limiting~~ vulnerability and increase ~~for strengthening~~ resilience to climate change typically generate unintended consequences that ~~actually~~may well reduce a system's ability to absorb changes and disturbances ~~resilience~~ (Adger et al, 2011). ~~Hence the danger of politicizing and top down organizing socio-ecological systems, which may increase a system's vulnerability.~~

In 2001, Holling introduced the notion of 'panarchy' ~~(~~as an alternative to hierarchy, to safeguard the self-organization of complex systems against the threat of bureaucratic intervention ~~) to characterize socio-ecological systems as complex systems that are dynamically organized and structured within and across scales~~ (Holling, 2001). Derived from the ancient Greek god of the woods, Pan, panarchy refers to the structure in which complex (ecological and social) systems are interlinked in an evolutionary process of adaptive cycles of growth, accumulation, restructuring, and renewal (Berkes & Ross, 2016).

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Accordingly, ~~Adaptive cycles describe how,~~ when confronted with shocks (like extreme weather events), adaptive ~~socio-ecological~~ systems stabilize with supporting self-organizing structures until those structures are overstretched and ~~reduce resilience and lose their capacity to~~ can no longer absorb changes and disturbances; this is when ~~when systems become vulnerable, then~~ there is a transformation of the system~~the adaptive mechanisms and properties lead the system to a new phase~~ (Allen et al, 2014). In other words, in naturalist research, the notion of panarchy (as an evolutionary mode of system self-organization) complements Holling's earlier notions of socio-ecological systems and resilience (as a system property). In Holling's naturalist theory of panarchy, resilience is a primary system property that ~~controls the adaptive cycleing,~~is measured by the magnitude of shocks that can be absorbed before the structures of system change~~s its structure~~ (Boyer, 2020).

Methodologically, naturalist social scientists have typically embraced agent-based modelling (ABM) as their favorite mode of analysis in resilience research. They focus

~~Point is that this becomes a predominant methodological approach. Why?~~

~~Cybernetics. In the social sciences, naturalism typically focusses~~ on the constant refinement of simulation tools (that can cope with ~~radical~~ complexity, uncertainty and multiplicity of agents) and techniques of regulation in favour of adaptation (cf. Cote & Nightingale, 2012; Patriarca et al, 2018).

Since the 1970s, when it emerged from mathematical sociology, ~~agent-based modelling (~~ABM~~)~~ ~~is~~has been a much endorsed tool used in complexity-theoretic research for analyzing complex systems. ~~for analyzing complex, non-linear interactions of autonomous yet interconnected (social and ecological) properties~~ (Conte & Paolucci, 2014). ABM is a computational mode of analysis that simulates complex (non-linear) systems that include ~~an artificial society of~~ diverse interacting agents ~~– households, farmers, organizations, governments~~that make~~– making~~ decisions, interact and learn or adapt in their ever-changing environment, according to programmable rules ~~(Farmer & Foley, 2009)~~. ~~In naturalist resilience research, ABM is widely used for analyzing the interdependencies between agents, the nonlinear interactions between agents, and the emergent adaptive behavior that arises from these interactions~~ (Hawes & Reed, 2006; Farmer & Foley, 2009; Van Duinen et al, 2015; Martin & Schlüter,

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2015; Sun, Stojadinovic & Sansavini, 2019). ABM computes, in probabilistic terms, the recovery process of complex (non-linear) systems under stress and tracks the emergence of new stages, phases or entries into new adaptive cycles ~~states~~ (Filatova, Polhill & Van Ewijk, 2016). In the social sciences, naturalist scholars calculate resilience to climate change ~~Resilience could be calculated~~ at the system level as a system property ~~using standard the resilience metrics~~ (Pumpuni-Lenss, Blackburn & Garstenauer, 2017). Since ABM traces feedbacks between micro-macro scale explicitly, ABM also enables naturalist scholars to ~~one could also~~ estimate the resilience of a system's individual agents, communities or (sub)groups of agents.

2.2 The constructivist view on resilience

In the social sciences, constructivist resilience research is also inspired by Holling's SES approach. ~~But~~Yet, for constructivists, resilience to climate change is not a system property. It is instead ~~but, instead,~~ a socio-political construct that is created by diverse ~~a variety of~~ stakeholders ~~In constructivist social science, also inspired by Holling's approach, resilience to climate change presents itself as an object of scientific inquiry or guiding concept rather than as a system property~~ (Walsh-Dilley & Wolford, 2015; Weichselgartner & Kelman, 2015; Kythreotis & Bristow, 2017). ~~In contrast with naturalists, constructivists do not research resilience within. In constructivist resilience research, resilience is not researched within the framework of complexity theory. Instead, they study resilience , defined as a social construct, is studied from a variety of theoretical angles.~~ Constructivist research includes ~~, involving~~ a variety of (typically phenomenological and discursive) scientific ~~ideational orientations~~perspectives. Constructivist resilience research primarily focuses on the political context and socio-political implications of resilience discourses. As a construct, resilience ~~, emphasizing that resilience~~ to climate change is not so much technical as political and administrative in nature (Alexander, 2013; Bourbeau, 2015; Boas & Rothe, 2016; Juncos, 2018; Wessel, 2019). And given its

political and administrative nature, resilience is invested with ideology and myth. Constructivist scholars typically stress that resilience is a neoliberal construct. That neoliberal ideology~~ism~~ manifests itself in the belief in adaptive cycles governed by invisible laws and the non-interventionist stance. It is thereby overlooked that the so-called self-organizing system is itself the result of political decisions over a long period of time. Constructivists thus point out that ~~. In policy discourses~~ resilience has become~~s~~ a buzzword for governments that seek to shift the responsibility ~~Resilience is typically presented as a neoliberal construct of governments that fail to address the challenges that come with anthropogenic climate change and seek to shift responsibility (~~for vulnerable systems, floods, pollution, safety, welfare, health, etc.~~)~~ to 'resilient' individuals. ~~Such g~~Governments, in these cases, have recourse to ~~use the concept of~~ resilience to make ~~, limit legal entitlements (including human rights), and make~~ individuals ~~less vulnerable and~~ more self-reliant (or less dependent on the government)~~,~~ when it comes to ~~in~~ coping with their own struggles in dealing with the challenges of climate change ~~a market dominated world~~ (Braun, 2014; Pizzo, 2015; Tierney, 2015; Howell, 2015; Anderson, 2015; Ksenia et al, 2016; Schwartz, 2018; Davoudi, 2018). For instance, governments that fail to provide basic access to water to millions of rural citizens advocate ~~for~~ community-based water management schemes, the leading paradigm for rural water access in East Africa (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. ~~in a critical way~~. Such critical studies are typically inspired by the works of Michel Foucault, in the sense that resilience is analyzed as a discursive construct or ~~n~~ 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

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citizens) and a particular type of society (like a market-based 'society'~~world~~) are discursively constructed and reinforced~~, as an act of domination that reproduces power imbalances~~ (Miller et al, 2010). Evans and Reid (2013) argue that as a discursive construct created by power holders, ~~ccuse the perspective of~~ resilience has ~~of~~ the character of a doctrine, according to which the resilient subject must constantly adapt to a dangerous and changing world, and is willing to accept this. Given this doctrine, vulnerability is rejected as weakness, ~~ or even as~~ a moral flaw (like a lack of character or a lack of will power) or simply illegitimate (the ability to absorb shocks ~~is~~being the new norm). Many critical constructivist scholars see the political ~~point at~~ reactions to ~~-~~events like~~Ecological and societal catastrophes like~~ Katrina (2005), ~~and~~ Fukushima (2011), and Covid-19 (2020) as manifestations of such ideology. ~~manifest~~ A problematic~~new~~ normativity is brought into existence when citizens are told that they ~~ such neo-liberalized resilience through which it is normalized that resilient subjects~~ must adapt to ecological and societal catastrophes, and when ~~while~~ vulnerable citizens are left abandoned by their government as they are expected to be self-reliant ~~that is divorced from concerns of justice~~ (Fainstein, 2014; Tierney, 2015; Ribault, 2019). Constructivist scientists also stress that such catastrophes present themselves ~~Such costly catastrophes present themselves~~ as 'anthropological shocks' (Beck (2015: 80). Such shocks ~~ that~~ may open up counter-discourses ~~, in the sense that they open up a new consciousness~~that contest domination~~-~~ (Fazey et al, 2018). Katrina, for instance, proved to be such ~~is~~ an anthropological shock because it ~~ that~~ opened~~s~~ up a counter-discourse that ~~not only an ecological, economic and deadly disaster, but it is also a 'racial flood' that~~ brought up the issues ~~ings back~~ of colonial patterns of racism, slavery, vulnerability, and abandonment (Beck, 2015). As an anthropological shock ~~; and~~, ~~-~~it is a potential ~~n~~ initiator of policy transformations beyond the resilience discourse.

~~From a critical constructivist viewpoint (typically inspired by the works of Michel Foucault), resilience as neoliberal discourse is analyzed as a phenomenon that reproduces power imbalances, domination, lawlessness, inadequate public services, and injustice.~~ ~~Evans and Reid (2013) accuse the perspective of resilience of the character of a doctrine, according to which the resilient subject must constantly adapt to a dangerous and changing world and is willing to accept this. Ecological and societal catastrophes like Katrina (2005) and Fukushima (2011) manifest such neo-liberalized resilience that is divorced from concerns of justice (Fainstein, 2014; Tierney, 2015; Ribault, 2019). Such costly catastrophes present themselves as 'anthropological shocks' (Beck (2015: 80), in the sense that they open up a new consciousness (Fazey et al, 2018). Katrina, for instance, is not only an ecological, economic and deadly disaster, but it is also a 'racial flood' that brings back colonial patterns of racism, slavery, vulnerability and abandonment; and it is an initiator of policy transformations.~~

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

their neoliberal repercussions. In the past few years, various constructivist scholars have moved beyond the idea that resilience to climate change is a neoliberal construct marked. Chandler (2014), for instance, argues that resilience can be understood as a post-neoliberal construct. In resilience discourses, Chandler argues, the art of governing is fundamentally reframed in recognition of the self-organization of systems – capacities of everyday democracy that are embedded in the relational, creative, reflexive and transformative capacities of stakeholders (Chandler, 2014; Boas & Rothe, 2016). In such self-organization, myth-makingmythmaking is key in constructing resilience. Constructed as a myth, resilience is understood as , in the sense that a widely embraced narrative that connects diverging ideologies, values, interests, worldviews and power relations – and provides research opportunities for scientists. Resilience is one of those myths. The 'myth of resilience' (Kuhlicke, 2013) refers to the stories that stakeholders enact to make sense of the radically surprising discovery of something entirely unknown (like Katrina or the Covid-19 crisis). As narrators, stakeholders interpret their own capacities to deal with stresses and shocks, such as extreme weather events (like in the form of floods, droughtsdroughts, and heatwaves). In many regions, these events occur with increasing frequency and intensity, exposing the stakeholders to unprecedented risks and uncertainties. In this context t is in this contextof making sense of an unknown phenomenon, of sense-making process that stakeholders develop the capacity to adapt and transform. In other words, constructing resilience to climate change, as a form of self-organization, comes with myth-making, storytelling and narratives that unify diverse stakeholders. For instance, the increasing attention on '"urban climate resilience'" (Tyler and Moensch, 2012) resonates with the narrative that cities, or 'local governments', are to lead and shape climate change adaptation as a form of bottom-up self-organization for absorbing changes and disturbances . This narrative and the associated process is conceptualized as 'responsibilization', the increasing legal and financial responsibility of local government, private companies and individual citizens in climate change adaptation (O'Hare et al., 2016; Klein et al., 2017).

3. Bridging the naturalist and constructivist view on resilience

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In the social sciences, naturalist and constructivist resilience research are based on contrasted premises, each having their own theoretical and methodological outlooks. Given such scientific contrasts, it ~~Given the two scientific approaches in resilience research, each based on contrasting premises, it~~ has been widely questioned whether resilience can possibly operate as a theoretical model or unifying paradigm – and whether such a unifying paradigm would be desirable in the first place (Alexander, 2013; Thorén, 2014; Bourbeau, 2015; Fainstein, 2015; Pizzo, 2015). A ~~Although a~~ unifying paradigm is neither possible nor desirable. Yet, ~~, yet,~~ naturalist and constructivist research can be brought together to ~~approaches must be bridged to~~ enrich and renew ~~our~~ understandings of resilience to climate change. ~~– an enrichment and renewal of resilience research that is much-needed for responding to the ecological and societal challenges of anthropogenic climate change.~~ Naturalist resilience research has the great merit that it may help to increase complex systems'~~s~~ 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 ~~has the great merit of providing~~ a critical and most penetrating understanding of resilience as a construct (first of all, a discursive construct, myth or narrative) ~~political phenomenon~~ that contains political intention and direction. Its interpretation of resilience to climate change ~~as a social (political, ideological, mythical, discursive) construct~~ is useful for generating understanding of how resilience is mobilized, taken up in climate governance, and resisted by social movements' 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~~subjects~~ and communities.

3.1 The debate on adaptive and transformative resilience

In recent years, the contrast ~~dialectic~~ between naturalism and constructivism in resilience research has come to revolve around the issue of adaptation and transformation (Chandler, 2014; Redman, 2014; Fainstein, 2014; Dahlberg et al, 2015; Sjöstedt, 2015; Boas & Rothe, 2016; Duit, 2016; 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~~s~~ resilience as bouncing back or forward in terms of SES adaptation. ~~SES a~~Adaptation refers, on the one hand, to the capacity of agents to influence the system~~SES. socio-ecological 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). ~~Naturalist social science typically focusses on the constant refinement of simulation tools like ABM (that can cope with radical complexity, uncertainty and multiplicity of agents) and techniques of administrative regulation in favour of adaptation as evolutionary resilience (cf. Cote & Nightingale, 2012; Patriarca et al, 2018).~~ Yet, as Holling emphasizes, the bouncing back and bouncing forward of a system~~SES~~ not only refers to a return to some previous (dynamic) equilibrium or to the persistence and endurance of systems. It also refers to socio-ecological transformation in an ongoing process of non-equilibrium and instability and reinvention 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 ~~and~~ 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 ~~In the recent notion of~~ 'transformational adaptation~~s~~' (Pelling, O'Brien & Matyas, 2015; Mummery & Mummery, 2019: 920~~; Pelling, O'Brien & Matyas, 2015~~). ~~, adaptation and transformation are bridged~~reconciled. Transformational adaptations, such as green growth or the greening of the ~~capitalist~~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 ~~to climate change~~ 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). ~~Warmink et al (2017) point out that in Dutch river management, uncertainty analysis typically complicates decision making, with typical adaptation responses being conservative and within safety margins. This leads to over-dimensioning and high costs of water engineering works (like flood defences).~~ Given unpredictability and uncontrollability, adaptive resilience comes with short-term planning, uncertainty reductions, incremental and path-dependent changes (Borsje et al, 2011; Haasnoot et al, 2013). Adaptive resilience – the system's re-stabilizer – is taken as inherently positive, while disturbances and shocks (de-stabilizers) are taken as negative (Duit, 2016; Lockie, 2016).

~~Warmink et al (2017) point out that in Dutch river management, uncertainty analysis typically complicates decision making, with typical adaptation responses being conservative and within safety margins. This leads to over-dimensioning and high costs of water engineering works (like flood defences).~~~~As a consequence of the near-flood events of 1993 and 1995 along the river Rhine in the Netherlands, the Dutch government responded by increasing the flood conveyance capacity of the large rivers, thereby decreasing flood water levels (Hamers et al, 2015). Since its completion in 2015, the Room for the River project is considered effective thus far, particularly as its secondary objective to increase ecosystem values in the river appears successful.~~

It is on the basis of the premise that adaptive resilience is good that naturalist resilience research ties up with climate risk management, as a way of managing ecosystem services (critical for survival), under conditions of ecological and societal shocks and disturbances (Boyd et al, 2015; Berbés-Blázquez et al, 2017). 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 defensees).

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 ~~is typically~~ 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) ~~in which responsibilities may be shifted~~. Flood protection, for instance, is typically a governmental responsibility, but with a new myth ~~new storytelling~~ stakeholders can transform an established situation and realize alternative scenario's in which responsibilities may be distributed among different stakeholders (Warmink et al., 2017). Adaptive resilience comes with evolutionary change (the definition of change that naturalist research typically endorses). By contrast, ~~, whereas~~ transformative resilience comes with 'metamorphosis'. This type of change refers to~~, that is,~~ a transformation~~iguration~~ of systems ~~culture~~ that is triggered by anthropological ~~the~~ shocks that open up new horizons, ~~and disturbances that come with radical newness and reinventions,~~ reassessments (including of past ideas, beliefs and practices) and rediscoveries (Beck, 2015; Fazey et al, 2018). The middle ground of t~~T~~ransformational adaptation bridges evolutionary change and metamorphosis, in the sense that such adaptation attends to broader

socio-political processes of transformation~~. The argument for transformational adaptation is that the ecological and societal challenges of climate change are unprecedented in scale and intensity and come with new risks and locations of activitie~~s (Kates, Travis & Wilbanks, 2012; Ziervogel, Cowen & Ziniades, 2016). The notion of transformational adaptation picks up on and challenges the transformative logic of system transformation~~iguration~~ 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, ~~Although constructivist social science manifests a higher degree of sensitivity to issues of environmental and climate justice in a current oppressive situation that is marked by high degrees of injustice, naturalist resilience research does not exclude considerations of justice. On the contrary,~~ enhancing adaptive resilience to climate change may entail liberal principles of equity, fairness and access to resources and services, so as not to privilege or marginalize certain stakeholders (Redman, 2014; Thorén, 2014; Ksenia et al, 2016; Schlosberg, Collins & Niemeyer, 2017; Bergström, 2018). Yet, naturalist enquiry into adaptive resilience tens to leave~~s~~ the status quo of systems, including the problematic Global North-Global South relationship (marked by massive power inequality), ~~typically~~ unquestioned~~. It tends to treat adaptive resilience as a technical property that is devoid of political and moral substance~~ (Swyngedouw, 2011; Pizzo, 2015; Clément & Rivera, 2017; Davoudi, 2018; Glaser et al, 2018; Dryzek & Pickering, 2019). In constructivist resilience research, 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; Ribault, 2019). ~~Short-term, incremental, a~~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; Ziervogel, Cowen & Ziniades, 2016; Schilling, Wyss & Binder, 2018; Glaser et al, 2018; Ribault, 2019). Hence, constructivist scholars tend to reject Holling's ~~the~~ 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 t~~T~~ransformational adaptation, accordingly, must include a process of filtering out resilience traps that come with adaptive resilience. Transformational adaptation includes an ~~the constructivist~~ understanding that adaptive resilience ~~to climate change~~ may well enforce a governance of unsustainability (cf. Van de Ven, 2017). ~~, yet, it offers no radical vision of metamorphosis. Its vision of change is one of change within rather than of established systems.~~

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, ~~. In constructivist resilience research, the notion of sustainability is transformative.~~ ~~s~~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 t~~T~~ransformational adaptation includes this adaptationist notion of energy ~~resilience, but~~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 ~~– and it uses~~ all sorts of tactics (including sponsoring the climate change denial movement) ~~–~~to secure their ~~its~~ established power position (Stegemann & Ossewaarde, 2018; Szablowski & Campbell, 2019). It ~~is an energy-political constellation that~~ enacts a condition of 'energy injustice', particularly in the Global South. The notion of energy injustice refers to current energy systems that distribute the

ecological and economic benefits and burdens of 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 ~~agents'~~ 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). ~~In other words, the sustainable energy transformation comes with transformative resilience and energy justice that typically assumes the form of resistance to the most hegemonic powers (VanderPlaat, 2016; Bourbeau & Ryan, 2018; Juncos, 2018; Schwartz, 2018).~~ The middle ground of t~~T~~ransformational 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).

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3.3 AI for resilience and sustainability

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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). ~~Such technologies are shaped by and reshape systems and their ecological and societal~~

~~environments~~ (cf. Taddeo & Floridi, 2018). Particularly in naturalist resilience research, AI is identified as a new systems property that permeates systems to generate productivity gains, improve efficiency, lower costs, predict climate change stress, track carbon emissions, monitor flood risks, etc. (Rajan & Saffiotti, 2017; Khakurel et al, 2018; Vahedifard, et al, 2019; Miller, 2019; Saravi et al, 2019). Strengthening adaptive resilience to climate change through AI primarily means that an integrated data system for circulating information (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 data through interactive maps and graphs (Kitchen, 2018). ~~Such dashboards are typically a collaboration between those who have big data and algorithmic tools with those who have local knowledge.~~ By being able to predict (estimate or forecast) more accurately and learn from past disturbances and shocks, lessons can be learned and applied in building adaptive resilience against disturbances (Saravi et al, 2019). AI, as for instance used in city dashboards, quantifies the probabilities of occurrence of extreme events, essential in predicting and preparing for future natural hazards, such as floods or landslides. For instance, with advances in machine learning, water availability, ice surfaces and melting rates, saturated soils, pollution, deforestation, etc. can be more precisely or smartly monitored in space and time so that changes over time can be tracked. Yet, with monitoring also learning of agents and organizations is needed.

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

~~More specifically, strengthened adaptive resilience typically (but not necessarily) may weaken the transformative resilience that is needed for materializing sustainable transformations (Khakurel et al, 2018). In the social sciences, constructivist scientists tend to have a critical view of AI. They do recognize that AI may help building transformative resilience, for instance, when it comes to the~~

phasing out of systems. Yet, from their critical angle, they stress that to make AI serve transformative resilience requires that the domination of giant AI firms is kept in check. And it requires high levels of transparency and stakeholder involvement in how algorithms are designed, built and applied.

In constructivist researches, it is frequently argued that although big data can be openly accessible (like satellite imagery for geospatial and data scientists), big data and AI are often in the hands of giant tech oligarchs like Google, Amazon, Apple, Microsoft, Facebook and Chinese forces (Miller, 2019), that, like the oil barons, are established powers that have a vested interest in the further acceleration and consumption of technological devices (Khakurel et al, 2018). Because of such an oligarchical power structure, AI tends to obstruct transformative resilience, exerting power beyond rule of law and democratic will and understanding (as found in the many recent privacy rights violations, scandals (like the Facebook-Cambridge Analytica data scandal (2018), the many Google scandals, etc.), and mistrust of new technologies) (cf. Taddeo & Floridi, 2018; Ossewaarde, 2019). Moreover, constructivist scholars mention that AI can weaken transformative resilience because we trust too much on the possibility to adapt, and then do not want to change things structurally in a democratic and sustainable way.

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. Such technologies reshape systems and their ecological and societal environments (cf. Taddeo & Floridi, 2018). Particularly in naturalist resilience research, AI is identified as a new systems property that permeates systems to generate productivity gains, improve efficiency, lower costs, predict climate change stress, track carbon emissions, monitor flood risks, etc. (Rajan & Saffiotti, 2017; Khakurel et al, 2018; Vahedifard, et al, 2019; Miller, 2019; Saravi et al, 2019). Strengthening adaptive resilience to climate change through AI primarily means that an integrated

data system for circulating information among agents needs to be developed. In an AI technological environment, resilience implies close collaboration between agents (data stakeholders, community-level stakeholders, state-level institutions, etc.) (Vahedifard, et al, 2019). AI comes in both for converting datasets into usable information and as a monitoring method (like change detection algorithms). Identifying, harnessing, synthesizing, and communicating pertinent yet unstructured data (weather data, cell phone GPS data, social media feeds, traffic cameras, smart city sensors, images, videos, audio data, etc.) enables agents to better forecast, prepare for, respond to, and recover from disturbances and shocks (Rajan & Saffiotti, 2017; Vahedifard et al, 2019). By being able to predict (estimate or forecast) more accurately and learn from past disturbances and shocks, lessons can be learned and applied in building adaptive resilience against disturbances (Saravi et al, 2019). AI quantifies the probabilities of occurrence of extreme events, essential in predicting and preparing for future natural hazards, such as floods. For instance, with advances in machine learning, water availability, ice surfaces and melting rates, pollution, deforestation, etc. can be more precisely or smartly monitored so that changes over time can be tracked. Yet, with monitoring also learning of agents and organizations is needed.

More specifically, strengthened adaptive resilience typically weakens the transformative resilience that is needed for materializing sustainable transformations (Khakurel et al, 2018). In constructivist resilience research, it is typically emphasized that AI, like resilience, not only has a positive impact on sustainable trajectories, but also enacts resilience traps (typically via adapting and rebadging existing short-term strategies) and enforces injustice and unsustainability (for instance, via massive energy usage and the production of electronic waste). Big data and AI are typically in the hands of giant tech oligarchs like Google, Amazon, Apple, Microsoft, Facebook and Chinese forces (Miller, 2019), that, like the oil barons, are established powers that have a vested interest in the further acceleration and consumption of technological devices (Khakurel et al, 2018). Given such an oligarchical power structure, AI typically tends to obstruct transformative resilience, exerting power beyond rule of law and democratic will and understanding (as found in the many recent privacy rights

violations, scandals (like the Facebook-Cambridge Analytica data scandal (2018), the many Google scandals, etc.), and mistrust of new technologies). Given such problematic power structures, AI thereby weakens transformative resilience (cf. Taddeo & Floridi, 2018). In other words, from the critical angle of constructivist resilience research, AI typically comes with unjust resilience and tends to close down alternative futures. Transformative resilience to climate change, accordingly, comes with resistance to big tech firms and their handling of data and digital surveillance and domination of vulnerable people. Reconciling adaptive and transformative resilience – in the form transformational adaptation – comes with the change of big tech firms from within the oligarchical complex, with AI redesigned and politically (democratically or technocratically) controlled for the making of less unsustainable futures.

4. Six upcoming themes in diversified resilience research

In the social sciences, the bridging of naturalist and constructivist scientific approaches in The diversification of resilience research and the tension between, and the reconciliation of, naturalism and construction in theorizing (and, in their practical implications, pushing for) change as system adaptation, transformation or transformational adaptation triggers new research themes for the study of resilience to anthropogenic climate change. Theorizing change within and of systems has become the key issue in resilience research, in the wake of changing societalpolitical, ecological and technological environments. In naturalist research, resilience to climate change is presented as 'evolutionary resilience' and as 'adaptive resilience'. From this angle, , with the key issue of changing environments is being 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. , with Tthe key issue of change is being the overcoming of 'resilience to change', 'resilience traps' and 'unjust

resilience' or 'bad resilience' that the status quo that ~~rule~~ 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 ~~notion~~ of transformational adaptation, which ties incrementalism to long term sustainability visions. It is a notion that comes with the search for the conditions and tempo of transformations in different ecological and societal contexts and adaptative~~on~~ 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 ~~that emerges from the diversification of resilience research~~ concerns the reconciliation of naturalis~~t~~m and constructivis~~t~~m scientific approaches to resilience. Given the diversification of scientific approaches, r~~R~~esilience cannot operate as a theoretical model or unifying paradigm~~, given that naturalism and constructivism are grounded in contrasting epistemological and ontological assumptions; and reflect contrasting scientific universes and manifest different scientific and political commitments~~ (Mummery & Mummery, 2019). Yet, as a metaphor resilience provides a sound basis for reconciling contrasting scientific approaches~~types of science~~, mainly because of its heterogeneity and high level of abstraction (Thorén, 2014). Intellectually, the reconciling of naturalism and constructivism implies an appreciation of diverse scientific vocabularies, many visions of what counts as scientific knowledge, other approaches~~sciences~~' scientific worlds, a certain embracing (which includes making manifest) of the tensions between the contrasting types of science, and creating spaces for constructive contestation (Pfeffer & Georgiadou, 2019). Thereby, new resilience perspectives may develop. New questions may be posed (or new answers to long-standing questions may be provided). The resilience trap – typically marked by the promotion of adaptive strategies that reify responses and corresponding power structures in the short-term – may be avoided (via challenging current assumptions underpinning resilience research). Current adaptation

and transformation and transformational adaptation approaches may be further refined. And much-needed new ways of scientific thinking and possibilities may be ~~opened up~~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 ~~all types of~~ stakeholders to bring both their resilience research questions and their assets to the table to collectively explore and define potential futures from the perspective of all present world~~-~~views.

A second theme for future resilience research comes with a change in political environment, in which the legitimacy of adaptive, ~~transformative~~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 manifold ways. For instance, on the one hand, environmental protest movements are stakeholders that develop a leverage required to transform~~change~~ established systems (such as energy systems) and their governance arrangements. On ~~, while on~~ the other hand agents who hold~~gain~~ power thanks to ~~by~~ such arrangements typically use tactics of repression and criminalization, particularly in the extractive sectors of the Global South (Szablowski & Campbell, 2019). New research questions emerge on the one hand from polarization and the exercise of (il)legitimate power in the governing of and for resilience to climate change. This is the question of how the adaptation and metamorphosis ~~reconfiguration~~ of systems under pressures of climate change comes with power inequalities, polarization, injustice, battle for resources, democratic deficits and post-democratic tendencies, climate change denial tactics, attacks on legal rights, ~~climate injustice,~~

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

A third promising topic for future resilience research concerns the relationship between adaptive resilience and transformative resilience and transformational adaptation in the reactive and proactive governance responses to anthropogenic climate change (Clément & Rivera, 2017). In the coming decade, questions like how adaptive and transformative resilience to climate change is strengthened or weakened; how the current performance of systems when it comes to responding to possible disturbance (for instance, through the use of monitoring systems) can be better understood; how unjust resilience can be disabled (and therewith 'positive vulnerability' can be increased to generate beneficial transformation (cf. Gallopin, 2006); ~~;~~ and how transformational adaptation manifests itself (how multiple adaptations may lead to transformational adaptation and what are the tipping points for igniting transformation), become urgent ones for resilience research (Grove & Chandler, 2017; Glaser et al, 2018). The notion of 'tentative governance' appears particularly relevant in the context of transformational politics, when it comes to phasing out systems and weakening adaptive resilience. Tentative governance is marked by interventions that are designed as preliminary rather than as persistent, for purposes of probing and learning rather than for stipulating definite targets or fixating existing systems and their underlying assumptions (Kuhlmann, Stegmaier & Konrad, 2019). It is likely that stakeholder engagement (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, sSea level rise and the disruption and relocation of coastal cities , by contrast, may trigger a more limited transformative politics, despite inevitable transformationiguration 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 consumerismvalues, 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 manyother societal and ecological developments. A Hence, a response like investment in transportation systems that aims to address increasing transportation demand must accordingly include possible climate change impacts. In the Anthropocene epoch, systems typically face pressures to change, to establish new (less unsustainable) interactions between society and ecology. Pressures on existing systems – typically those that are marked by unjust resilience and resilience traps (like established energy systems) – not only emerge from ecological adversity, over-exploitation, resource depletion, etc., but particularly from 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, etc (Bergmann & Ossewaarde, 2020). At the same time, anthropogenic climate change comes with the development of a multi-trillion market of the emerging

~~climate~~ 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~~iguration~~ and transformational adaptation; and the construction of new incentive structures, for accelerating sustainable transformation (cf. Clément & Rivera, 2017; Warmink et al, 2017; Köhler et al, 2019). This branch of discontinuation research assumes ~~that socio-technical systems~~that technologies ~~-~~influence socio-ecological systems. S~~, so that s~~ome 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 ~~SES transformations are~~ needed to qualitatively alter established systems (Vögele, Kunz, Rübbelke & Stahlke 2018; Rogge & Johnston, 2017; Stegmaier 2019). One of the challenges for the coming decade is to reverse the negative, alarmist, ~~-or~~ catastrophic, ~~-or-~~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~~interpreting, and explaining resilience to climate change (cf. Skillington, 2015; Fazey et al, 2018; Mummery & Mummery, 2019). For future research, theories of environmental justice, energy justice and climate justice~~, that is, theoretical insights on (un)equal distribution of environmental and social burdens, struggles for recognition, claims to participation, and unequal impacts of climate change,~~ can be conducive to helping furthering

comprehension of adaptive and transformative resilience and transformational adaptation. How can justice claims be made more responsive to newly unfolding ecological and societal circumstances and uncertainties? How can principles of equity, fairness and access to resources and services be secured in a toxic political environment? And how can – in the problematic context of climate-induced migration and a political environment marked by anti-immigration policies – the wellbeing of migrants be ensured? Theories of environmental, energy and climate justice are also highly relevant for developing understanding of how adaptive and transformative resilience and transformational adaptation are perceived and experienced in everyday life by different stakeholders that face anthropogenic challenges. Constructivist enquiry into perceptions, experiences and prioritizations of resilience 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~~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)~~, and treatment of nature as a sacred entity (rather than as an economic resource),~~ may have a higher priority than global environmental considerations (Köhler et al, 2019).

~~A sixth theme for future resilience research comes with a changing (geo)technological environment, that is, the so-called 'AI revolution' in the making. Given worldwide investments and top-down AI strategies that global governance actors and national governments have recently published, AI will most plausibly become a major force that shapes adaptive and transformative resilience to~~

climate change by means of monitoring and learning. A relevant example of big data is the G-Earth Engine, which opens up an unprecedented dataset of satellite images for scientific research. Such extensive datasets, marked by high temporal resolution, are essential for monitoring a changing earth system. In the past decade, resilience discourses have increasingly incorporated phenomena like big data, AI, cybersecurity and smart city; in the coming decade, resilience discourses may increasingly become technology or AI discourses. New interplays between automation, (un)sustainability, and adapting and transforming systems trigger new questions for future resilience research (cf. Köhler et al, 2019). For instance, in the near future, not only the number of climate disasters is expected to rise but also the data – satellite data, drone data, sensor data, social media data, volunteer geographic information (VGI) data, Internet of Things data, etc. – available on such disasters is expected to increase in size, amounting to vast volumes of climate disaster data. However, AI, due to the unstructured nature of input data, may omit those phenomena, places and social groups that are not present in the data (Hoefsloot et al. 2019). Alternative ways of knowing can refine or contribute complementary insights to the precise measurements and data gaps (Pfeffer and Georgiadou 2019). New research questions for naturalist and constructivist research emerge from challenges of organizing big data and how to make it available and usable, given the variety of public and private stakeholders, workflows and incentive structures involved in the (social) construction of big data (Wright, 2016). How can AI be augmented with alternative ways of knowing to strengthen adaptive/transformative resilience? How to incorporate the socio-spatial dimension in resilience research, in order toto pronounce the different capabilities of different groups and places? And what role can AI play in creating a dialogue between the naturalist and constructivist resilience research? In the coming years, AI tools – mainly tracking (for instance, tracking of deforestation tracking or energy/water consumption) and machine learning techniques – are expected to be widely used, among other things, for detecting and predicting how climate disasters probably develop, for locating areas or communities at risk, for analyzing the consequences of climate disasters, and for assisting in climate disaster responses. Working with AI for purposes of learning from data – for instance, via the use of data mining or deep learning techniques

~~for dissecting patterns in satellite images – comes with the design of procedures for data analytics, forecasting and intervention (Rodríguez-González, Zanin & Menasalvas-Ruiz, 2019) and requires domain and local knowledge as well as a dialogue between naturalist and constructivist researchers. In contrast to the official national statistics of the past, which diffused societal controversies, big data analytics create a myriad parallel realities~~myriad parallel reality~~, stand in the way of achieving a minimal consensus about basic facts and amplify controversies. In sum, next to technologization of resilience discourses, social processes of big data construction, the inclusion and exclusion of diverse stakeholders, the embeddedness of AI in everyday practices, the various uses of AI in the exploitation of data as well as the integration and inclusion of alternative knowledges are promising fields of resilience research.~~ 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 approachestypes of science. Holling originally reinterpreted and incorporated the good old notion of resilience in hisa 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 resilienceresilience, and transformational adaptation. Resilience cannot operate as a unifying paradigm, given that naturalism and constructivism are grounded in different epistemological and ontological assumptions, definitions of what counts as scientific knowledge, and definitions of change (evolutionary change and metamorphosis). But resiliencebut it can facilitate the reconciliation of naturalism and constructivism. Thereby, the two contrasting scientific approaches , so that the two types of science can provide a liberating perspective on each other (without the one repressing the other) and brought into a theory-energizing tension with each other. The urgent challenges that come

~~with anthropogenic climate change – which may potentially cause extreme degrees of human misery in the coming decades –, necessitate the reconciliation of naturalist and constructivist resilience research.~~ Such reconciling – igniting theory-energizing tension – is needed for reimagining resilience to climate change and ~~which is needed~~ 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 ~~the development~~ in~~of~~ ~~resilience research in~~ the social sciences ~~past decade, with the rise of constructivist resilience research and its reconciliation with naturalism~~, the key resilience issue ~~in resilience research~~ 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 ~~in problematic contexts~~ 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~~concepts, and modes of analysis; and to trigger new imaginations to be able to create new, theory-rich, resilience perspectives. A second theme is the legitimacy of the political response in a toxic political environment, in which top-down and bottom up responses, including new governance arrangements and system reconfigurations, may suffer from legitimacy deficits. ~~-~~A third theme is how, in a toxic political environment, adaptation, transformation and transformational adaptation can be materialized; and under which conditions ~~are~~ such governance responses are sufficient ~~enough~~ for addressing climate change challenges. A fourth theme is how systems are under pressure due to climate change, ultimately igniting a phasing out of systems and a departure from environment-unfriendly consumerist lifestyles, ~~values~~values, and assumptions. A fifth theme is how governance responses can be made legitimate, by incorporating considerations of environmental and climate and energy justice, ~~—~~thereby strictly connecting resilience to justice considerations. A sixth

theme is how new technologies (mainly AI) comes to intermingle with resilience: what is the role of such technologies and giant tech oligarchies like Google and Amazon its role in political-administrative responses to challenges that come with climate change? And, correspondingly, what are the undesired consequences that come with AI and giant tech firms, when it comes to responding to climate change. How does AI enact existing power structures, thereby reinforcing resilience traps?

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