Reply to referee 3

Thank you for your careful reading of the text and we are truly sorry that it made for tedious reading. We have thoroughly re-written the text, bringing in the much needed nuances and getting rid of the irritating generalizations. The descriptive style could not be completely removed given the nature of the article. However, an argumentative style has also been included, unsubstantiated claims have been either removed or backed up by sources. The tendency towards dualism or polarization has also been corrected. We have also included a sample of the body of scholarship that mediates between 'naturalism' and 'constructivism' (in their strict or extreme senses). We have accepted most of the changes suggested by referee 3. The result is a trimmed text, without too much repetition.

As noted above, the whole text has been rewritten. More specifically, the whole introduction has been rewritten in such a manner that it is more argumentative and that the impression of polemic or dichotomy is avoided. We now speak of a dialectical field between naturalism and constructivism. Sections 2.1 (the 'naturalist' view) and 2.2 (the 'constructivist' view) have been merged and rewritten into a new whole. This means that there are many approaches and cross-fertilizations in that field, though there is still a 'naturalist' (in the strict sense) scholarship in the social sciences, that is to say, scholarship that draws on the methodology and conceptual framework common in (applied) natural sciences. We avoid speaking in terms of the 'naturalist' social scientist or the 'constructivist' social scientist.

In line 307 you may be interested in earlier origins, as Indirli 2019 reviews them: historical flight and some open questions towards a pluralistic but holistic view of resilience

Thank you for the additional reference. After line 307, we do mention other origins.

Lines 455: "Naturalist social studies are based on the cybernetic idea" Which are those "Naturalist social studies"? How did you methodologically assess it? And how do you know which variants exist? Why should they only follow a cybernetic approach??

These sentences have been removed.

Passages such as lines 758-762 are fine in general diction, but it is again not supported by sources, and the sources and claims in the sources following do not directly support this.

This passage has been rewritten.

Check wording in line 769, "into adaptive resilience tens to leave"

Thanks! Typo.

Lines 849ff: How did you decide and justify to select smart urbanism and AI among many technological trends?
Why is the whole section than not about "smart urbanism" at all?

That section has been removed.

Provide sources for your claims in lines 851-852.
And again; "all" have drafted their AI strategies so? A 190 countries you have checked?

The presentation of AI is one-sided and misses all the critique from natural sciences on the failures of AI, the software crisis in the 1980s related to it already, etc.
Again, this is rather an iteration of black and white stereotyping, missing structure, counterarguments and balance.

Has been removed.

Claims such as in lines 859-860 are again, worrisome; why should "Strengthening adaptive resilience to climate change through AI primarily" really only have resulted in "means that an integrated data system for circulating information (near) real time among agents needs to be developed" AI can do much more than just "circulating information"?!

That AI section still does not fit into the article. Maybe consider keeping it for a future article? Or embed it with more argumentation, as I tried to indicate.

We have removed that section.

Lines 994 following. The first sentence seems to be contradicted by the following sentence. And it would be good to see literature cited here that actually already tried to provide such mediation.

Thanks. It has been rewritten.

In section 4 it is a bit difficult to understand and find the six themes exactly. The beginning s of the sentences to each new theme could be made simpler to understand what are the main aspects of it. An example is in line 1016; it comes with.... but what do you mean? The whole section is rather long and once more, descriptive, narrative, with claims mixed with source-based review. The whole article is too much of the same in style. In 4, shorter would be better. Also, at least the first three themes, but actually, all of them simply repeat the previous sections.

The whole section has been rewritten and trimmed. However, there is bound to be some kind of continuity with rest of the article since we believe that particular ongoing or new lines of research should still be pursued. But we also make it clearer why they should be.

What is this dangling text from lines 1220 onwards? Content-wise it is really interesting and a bit novel and would warrant a paper. But as it is it is unclear what this part of text does.

That text has also been removed.

Line 1252 please avoid such jargon as "good old notion"

Done.

Only towards the end, the article comes back to climate change. Given the job background of most authors, it seems that this is the real intention, stated in line 1281 "are all connected to the issue of the political-administrative response"
Maybe, the paper could be rewritten from the perspective of such governance; how it deals with resilience and these six fields? Or at least, be more explicit on why administrations increasingly become interested in such questions? This would be of benefit to scientific discussion. But it is also ok I think, if you keep it and only make it more balanced and avoid one-sided claims.

We have tried to avoid one-sided claims. This suggestion is interesting, but for now not the right approach given the different backgrounds of the authors. But we shall bear it in mind for a future article.

Towards the end of the conclusion, the article meanders into speculations about giant tech companies. It is alright to use a conclusion to expand the horizon of the article, but here as at other parts, it sounds a bit much like a journalistic speculative style.

Has been removed/rewritten.

In the rebuttal letter, the authors indicate to uptake some of the suggestions. I am not sure they

have met the expectations of the first reviewers. One recommendation I would like to reiterate and this time request the authors to deliver it (maybe I just did not find them): the text could well be cut on many text parts and benefit greatly from tables and maybe, framework charts that summarise the findings, find criteria for them and therefore, provide something novel to readers.

One final request; I know I generate a lot more work for you, my apologies. I generally like the overview this paper provides, it is helpful as a guidance for readers unfamiliar with the discussions. But especially for them, it is of great importance not to be guided in an unbalanced way.

The general aim of the rewriting has been to bring in that needed balance. So thank you for your critical comments. We trust that we have achieved that goal.

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

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

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

Abstract

~~Since the 1970s, Holling'"s socio-ecological systems (SES) has been a popular approach has been the most predominant theoretical force in resilience research with regard to the climate crisis. An overview of the scholarship in the social sciences during the past five decades reveals two different re-~~

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

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

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

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

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

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

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

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

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

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

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

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~~appropriations of Holling'"s legacy, which can broadly be classified as naturalist and constructivist, respectively. Characteristic for naturalist resilience research is its indebtedness to the concepts, methods, and assumptions of the so-called '"life sciences'". This has resulted in the recasting of Holling'"s SES into complex systems that are marked by non-linearity and evolutionary changes. Constructivist resilience research, on the other hand, relies on the concepts, methods and assumptions that are common in the '"human sciences'". Accordingly, resilience is studied and critically appraised in its historical, social, and political context. In this paper, recent developments in resilience research in the social sciences are reviewed to the end of proposing new research questions. The focus is on the different approaches, models and commitments that underpin these two approaches to resilience in the context of the ecological crisis. Particular attention is thereby paid to the naturalist emphasis on adaptation and the constructivist emphasis on transformation.~~

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

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

1. Introduction

A brief and non-exhaustive overview of resilience scholarship published in the period 1970-2020 reveals a diversification of research foci and themes, approaches and methods, and theoretical frameworks. Resilience has been a prevalent research topic among ecologists for several decades and, very soon after, among cyberneticists. Given the association of resilience with the natural sciences and engineering (cf. Indirli, 2019), it is perhaps not so surprising that most social scientists did not see the need to have recourse to the terminology or concept until much later. And if they did adopt the idea earlier, they were likely to embrace the naturalist theoretical framework that accompanied it (Holling, 1973; 2001; cf. Chandler, 2014). Other social scientists are still reluctant to accept resilience as a universal and unifying concept, pointing out that the ~~:~~"core concepts and principles in resilience theory that create theoretical tensions and methodological barriers between the natural and social sciences~~:~~" (Olsson et al., 2015). This conceived opposition between the natural sciences and social sciences may not be experienced by all naturalists or social scientists. Even more importantly perhaps, such opposition – real or surmised – may hinder fruitful collaborations in the face of our ecological crisis. Yet, collaboration, integration or ~~:~~"transdisciplinarity~~:~~" in the real worlds of universities and research institutes may not always reflect a genuine transcendence of disciplinary boundaries, but instead largely consists of natural sciences and engineering research in sustainability (Groß ~~&~~and Stauffacher, 2014). That said, there have been genuine attempts to transcend the limitations of both naturalism – in the strict, technical sense of the term (Andler, 2014) – and forms of social constructivism that border on relativism (Proctor, 1998a; 1998b; Popa

et al., 2015). Such ‘“transdisciplinary”’ research is typically problem-oriented (Groß &and Stauffacher, 2014).

Crawford Stanley Holling’s ecological notion of resilience (Holling, 1973) is considered by some as a bridge between the social sciences and engineering (Ostrom, 2007; Thorén, 2014). The appeal of Holling’’s socio-ecological systems (SES) approach among some social scientists may be due to its being a corrective to the tendency of Holling’’s fellow ecologists to unconditionally embrace the methods and premises inherited from classical physics (cf. Holling, 1973; Thorén, 2014; Estêvão, Calado &and Capucha, 2017; Davoudi, 2018). Holling corrected what he considered to be a flawed view of the world and of ecosystems, namely, as closed or stable. Against the ‘“equilibrium-centered”’ view, he emphasized the influence of random events (natural or human-caused) on ecological systems (Holling, 1973, 15). Yet, even this complex systems approach does not score very highly at the level of reflexivity, which is required to discover and ‘“acknowledge overt or covert forms of dominance shaping public discourse and participation (Popa et al., 2015). Slightly more positively framed, societal resilience to climate change also involves political and institutional factors, lifestyles and consumer habits, production patterns, and structures of power in general ~~law, economy, science, technology, governance and politics~~ (cf. Douglas &and Wildavsky, 1983; Blühdorn, 2013; Kolers, 2016; Fischer, 2017; Dryzek &and Pickering, 2019). Resilience research that takes into account such social factors (which do not necessarily obey physical laws) can be broadly classified as belonging to ‘“social constructivism”’.

The Tsunami in 2004 and Katrina in 2005 seem to have acted as catalysts for generating more resilience research among social scientists (Pizzo, 2015). This increasing interest for resilience on the part of certain social scientists (and other scholars from different disciplines) cannot be detached from the popularity that the terminology has started to gain among national governments and global governance actors, including the Rockefeller Foundation, for instance, at the beginning of the new century. Such tendency became stronger with the global financial crisis of 2007-2008. The widespread recourse to the language of resilience by powerful private and public actors has incited a series of

scholarship critical of such discourse (Chandler, 2014; Pizzo, 2015; Lockie, 2016; Derickson, 2016; Hilhorst 2018). The latter, it is observed, easily hides vested political and economic interests, and distracts attention from structural and institutional defects by emphasizing resilience through technological innovations. Katrina and, even more recently, Covid-19, it is argued, reveal a vulnerability that is not simply an unavoidable fragility in the face of natural hazards, but is also the fruit of institutions and political decisions over a long period of time. Natural disasters tend to be perceived as indiscriminate and indifferent as to whom they affect. Yet, as Belkhir and Charlemaine (2007, p. 12) point out, "hurricanes may not single out victims by their race, or gender or class but neither do such disasters occur in historical, political, social, or economic vacuums". In other words, social, cultural, political, and economic conditions are conceived to be involved in the resilience or non-resilience of a nation or of particular groups to natural calamities (Henkel et al., 2006; Tierney, 2015; Lockie, 2016).

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

similarly wishes to avoid the danger of reductionism while profiting from the wealth of (applied) natural sciences.~~.~~

Hence, though we acknowledge the many varieties of both ~~'~~"naturalism~~'~~" and ~~'~~"constructivism~~'~~" and the various endeavors to transcend the limitations of both naturalism and constructivism, we observe that most resilience research in the social sciences still takes place in the dialectical field constituted by these two approaches, in their strict, traditional senses (cf. Andler, 2014). This is the theme of the next section. But first we briefly examine how ~~T~~resilience research in the social sciences has undergone a thorough diversification. ~~he diversification of resilience research in the social sciences is thus addressed in the first section of this paper.~~ Such diversity, however, sometimes means that research takes place in parallel worlds and that there is little cross-fertilization between scholars.

~~Naturalism and constructivism are presented as two (social) scientific approaches underpinned by different epistemological and ontological commitments.~~ It is suggested that social scientific inquiry into resilience in the context of climate change could be raised to a next level if these two different approaches meet and interact. To this end, we reconstruct contemporary debates in that particular field of studies and distil recurrent research topics that divide social scientists. The issues of adaption and transformation in the context of severe disturbances or shocks that come with climate change (such as hurricanes, floods, drought, and heatwaves) appear to be such divisive topics. Finally, naturalist and constructivist directions, as well as possible cross-fertilizations of these two currents, for future resilience research are identified. We point out that future resilience research in the social sciences – that is, the types of questions raised, theoretical frameworks and modes of analysis – will also be determined by changing conditions (ecological, political, and socioeconomic).

2. The diversification of resilience research in the social sciences

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

Despite the various meanings attributed to the term, the connotation attached to *resilire* was commonly that of rebounding (cf. Indirli, 2019). Up to the early nineteenth century, this was the predominant understanding of resilience in common language and imagination. A slight shift appeared when engineers started to use the term to refer to the properties and capacities of materials to absorb tensions and release energy, and recover their original forms, without breaking or disfiguration after undergoing some external shock or disturbance (such as extreme weather conditions) (Estêvão, Calado ~~&~~and Capucha, 2017; Bergström, 2018; Davoudi, 2018). In the 1950s, psychologists re-adapted the common sense of the term to mental health and used it to study the coping mechanisms of concentration camp survivors. Later, the concept is used to study ~~all sorts~~various kinds of trauma, misfortune, adversity, stress, and mental recovery (Bourbeau, 2015; Estêvão, Calado ~~&~~and Capucha, 2017; Bergström, 2018; Schwartz, 2018). In the 1970s, the ecologist C.S. Holling (1973, p. 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). ~~.~~ ~~f~~For instance, a coastal system that is vulnerable to accelerated sea-level rise is not resilient enough (Smit, Goosen ~~&~~and Hulsbergen, 1998). In such accounts, greater resilience means becoming less vulnerable to change and shocks. That said, a system can still be vulnerable to other changes while being resilient in other respects (Gallopin, 2006). Holling incorporates resilience in a socio-ecological systems (SES) approach to analyze the stability and strength of ecological systems, which are constituted by the interaction between natural ecosystems and human societies (Alexander, 2013; Bergström, 2018; Béné et al., 2018; Hoekstra, Bredenhoff-Bijlsma ~~&~~and Krol, 2018). Ecosystems, as noted earlier, are rarely closed systems, but are instead subjected to natural and human influences.

~~In the social sciences, resilience research that has emerged from Holling'"s SES approach has developed along two different lines, which can be called naturalist and constructivist, respectively (Miller et al, 2010). These two currents of research have different focuses, raise different questions, and have recourse to different methods. The naturalist line of research is indebted to the accepted methods and assumptions of the natural sciences. It has a predilection for~~

In the social sciences, resilience research has been influenced by these earlier studies. As a result, some social scientists have recourse to mathematical and simulation models and ~~. 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. In these studies, ~~S~~society is modelled as a social system that consists of parts (including agents and technologies) and physical properties that can be objectively studied (Aiken, 2006; Floridi, 2017). Resilience as a system property is an objective measure of the dynamic equilibrium, stability, strength, or survivability of a socio-ecological system, including coastal systems, urban systems, forest systems, etc. (Hoekstra, Bredenhoff-Bijlsma ~~&~~and Krol, 2018). Such approaches, indebted to applied natural sciences and the complex systems theory, can be very useful, especially when both the problem and the solution are primarily and solely of a technical nature. That said, even an apparently purely technical process such as water purification involves

reckoning with various social factors (for instance, changing habits, medicine uses and particular surroundings of water collection systems).

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

In resilience research, ~~they~~social constructivists typically model society as a historically embedded construct that is the result of particular understandings of nature, society and the person, of values, symbols and historical practices (which may not be very rational or just), and power relations. ~~Constructivists tend to be more critical and politically sensitive. They~~ These social scientists ~~are~~ tend to be more sensitive to ~~generally more aware of~~ the potential and actual abuse of power. When ~~addressing~~ engaging with resilience issues in the context of climate change, they typically express concern for vulnerable communities. Research topics can thus include the(un)equal distribution of

environmental burdens, struggles for recognition, claims to participation, and unequal impacts of anthropogenic climate change (Braun, 2014; Yanarella ~~&~~and Levine, 2014; Skillington, 2015; Sjöstedt, 2015; Weichselgartner ~~&~~and Kelman, 2015; Pizzo, 2015; Lockie, 2016; Derickson, 2016; Lyster, 2017; Schlosberg, Collins ~~&~~and Niemeyer, 2017; Mummery ~~&~~and Mummery, 2019). Davoudi (2018, p. 5), for instance, problematize the very notion of ~~'~~"resilience~~'~~", pointing out that there are ~~'~~"unjust resilience building programs~~'~~" that do not only neglect disadvantaged communities, but also create ~~'~~"~~'~~"resilient enclaves" for privileged elites~~'~~". ~~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.~~ Similarly, ~~And~~ Glaser et al (2018, p. 3) observe that resilience can be ~~'~~"wicked~~'~~" when an undesirable status quo is being maintained. Reflexivity is arguably an indispensable part of resilience research (cf. Popa et al., 2015).

~~refer to '"undesirable resilience'", '"bad resilience'" and '"wicked resilience'". These are notions that emphasize how resilience may go hand in hand with the enforcement of an undesirable or unjust condition. The resilience of oppressive systems (like tyrannical regimes) that systematically marginalize, discriminate or persecute certain groups are an example of this.~~

~~**2.1.The naturalist view on resilience**~~

2.1. The dialectic between naturalism and constructivism

Social scientists focusing on resilience to climate change have inherited an enormous body of scholarship on resilience stemming from the physical sciences and engineering, cybernetics, evolutionary biology and psychology, among others. In the 1970s, social scientists could thus have recourse to both closed-systems theories and complexity theory to think about resilience to climate change (Dahlberg, 2015; Davoudi, 2018). Some of them also merged the two models so that socio-ecological systems became conceptualized as adaptive complex systems (Wiese, 2016; Bergström,

2018). Holling~~"~~'s SES is an example of the integration of complexity theory in ecological science. According to the adaptive complex system line of thought, the resilience of a system depends on the capacity of individual agents to cope with uncertainty and complexity. They are able to interact and self-organize, learn and adapt (in an incremental or transformative way), thereby making the system flexible enough to absorb shocks and develop even in face of drastic changes (Jesse, Heinrichs ~~&~~and Kuchshinrichs, 2019).

Social scientists drawing on complexity theory and evolution-based models tend to emphasize a type of laissez-faireism, pointing out that adaptive complex systems have their own self-organizational structures that should not be interfered with (Adger et al., 2011). Bureaucratic interventions to address vulnerability and increase resilience to climate change are said to generate unintended consequences that may well reduce a system~~"~~'s ability to absorb changes and disturbances. In 2001, Holling introduced the notion of ~~"~~"panarchy~~"~~" as an alternative to hierarchy, to safeguard the self-organization of complex systems against the threat of bureaucratic intervention (Holling, 2001). Derived from the ancient Greek god of the woods, Pan, panarchy refers to the structure in which complex (ecological and social) systems are interlinked in an evolutionary process of adaptive cycles of growth, accumulation, restructuring, and renewal (Berkes ~~&~~and Ross, 2016). Accordingly, when confronted with shocks (like extreme weather events), adaptive systems stabilize with supporting self-organizing structures until those structures are overstretched and can no longer absorb changes and disturbances; this is when there is a transformation of the system (Allen et al., 2014). Resilience is therefore conceived as a primary system property that is measured by the magnitude of shocks that can be absorbed before the structures of system change (Boyer, 2020).

Some social scientists show a predilection for agent-based modelling (ABM) as their mode of analysis in resilience research (cf. Cote ~~&~~and Nightingale, 2012; ~~Patriarca et al, 2018;~~ Pumpuni-Lenss, Blackburn ~~&~~and Garstenauer, 2017; Patriarca et al., 2018; Mirchandani, 2020)~~)~~. They therefore aim at the constant refinement of simulation tools that can integrate complexity, uncertainty and multiplicity of agents and techniques of regulation in favor of adaptation. Since the 1970s, when it emerged from

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mathematical sociology, ABM has been used in complexity-theoretic research for analyzing complex systems (Conte &and Paolucci, 2014). ABM is a computational mode of analysis that simulates complex (non-linear) systems that include diverse interacting agents that make decisions, interact and learn or adapt in their ever-changing environment, according to programmable rules (Hawes &and Reed, 2006; Farmer &and Foley, 2009; Van Duinen et al., 2015; Martin &and Schlüter, 2015; Sun, Stojadinovic &and Sansavini, 2019). ABM computes, in probabilistic terms, the recovery process of complex (non-linear) systems under stress and tracks the emergence of new stages, phases or entries into new adaptive cycles (Filatova, Polhill &and Van Ewijk, 2016). Resilience to climate change, as a system property, can thus be calculated (Pumpuni-Lenss, Blackburn &and Garstenauer, 2017). Since ABM traces feedbacks between micro-macro scale explicitly, it also enables scholars to estimate the resilience of a system-'"s individual agents, communities or (sub)groups of agents.

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

protection of vulnerable individuals and groups (Fainstein, 2014; Derickson, 2016; Kolers, 2016; Lockie, 2016; Lyster, 2017; Mummery ~~&~~and Mummery, 2019).

One of the major points of contention between naturalism, in the strict sense, and social constructivism is that most social constructivists are unwilling to conceive resilience to climate change as a system property (an intellectual attitude that does not imply that all naturalistic approaches actually ~~-~~conceive resilience as a system property) (cf. Andler, 2014). Instead, resilience ~~it~~ is perceived as a socio-political construct created by diverse stakeholders (Walsh-Dilley ~~&~~and Wolford, 2015; Weichselgartner ~~&~~and Kelman, 2015; Kythreotis ~~&~~and Bristow, 2017). This means that it is not a neutral or technical element and, accordingly, requires constant critical scrutiny to uncover its possible ideological and mythical nature (Alexander, 2013; Bourbeau, 2015; Boas ~~&~~and Rothe, 2016; Juncos, 2018; Wessel, 2019). Some scholars have pointed out the neoliberal ideology underpinning both theories/models and policies that rely on the idea of adaptive cycles governed by invisible laws, which make intervention undesirable (Chandler, 2014; Tierney, 2015). It is thereby overlooked that the so-called self-organizing system is itself the result of political decisions over a long period of time. Governments are thus accused of shifting the responsibility for vulnerable systems (which are themselves the products of formal and informal institutions and political decisions, among other things), floods, pollution, safety, welfare, health, etc. onto ~~-~~"resilient~~-~~" individuals or individuals who ought to be become more resilient, which is another word for self-reliant (Braun, 2014; Pizzo, 2015; Tierney, 2015; Howell, 2015; Anderson, 2015; Ksenia et al., 2016; Schwartz, 2018; Davoudi, 2018). In some cases, such resilience discourse enables governments to avoid their public responsibility. An instance of such ~~-~~"wicked~~-~~" dynamics is governments~~-~~" shifting the responsibility for the provision of access to water onto local ~~-~~"communities~~-~~" while the latter might be absent due to strife or inadequate management capacities (Katomero ~~&~~and Georgiadou, 2018). In such situations, vulnerable individuals and groups are denied this basic human right, while other powerful groups claim sole access to water.

Social constructivists are generally critical of the very language of resilience. Those who point out the discursive or narrative nature of resilience-based political speeches and policies are usually

indebted to Michel Foucault''s idea of a discourse. The latter refers to systems of thoughts and beliefs expressed through language and practices that systematically construct subjects and societies of which they speak. In other words, both language and practices are creative acts. Through resilience discourses, a particular type of subject (like resilient or self-reliant) and a particular type of society (like a market-based "society") are discursively constructed and reinforced (Miller et al., 2010). Evans and Reid (2013) thus argue that resilience has the character of a doctrine, according to which the resilient subject must accept and constantly adapt to a dangerous and changing world. Given this doctrine, vulnerability is rejected as weakness, a moral flaw (very much like a lack of character or will power) (Cole, 2016). A problematic normativity is brought into existence when citizens are expected to adapt to ecological and societal catastrophes by becoming self-reliant (Fainstein, 2014; Tierney, 2015; Kolers, 2016; Ribault, 2019). In other words, some (or most) social constructivists do not merely try to answer the question of how to make societies and individuals resilient to climate change, but instead question the normativity of the concept "resilience". Such a critical approach is arguably problematic and counterproductive in some cases. The urgency of real problems (like rising water levels that threaten millions of people) makes a dialogue between different approaches highly desirable.

In the social sciences, naturalist research as such arose in the context of the development of cybernetics, computational power and automation (and automated decision making) (Simbirski, 2006; Floridi, 2017; 2018; Davoudi, 2018). Naturalist social studies are based on the cybernetic idea that machines, organisms, and societies show considerable similarity in structure and function; and can be described in terms of systems. Since the 1940s, such studies have typically adopted cybernetic complexity theory as their distinctive overarching theoretical outlook, within which other theories (for instance, on behavior change, on decision making under risk, or on social institutions) are incorporated. In complexity theory, machines, organisms, and societies are modelled as complex, non-linear, evolutionary systems. Complex systems are composed of many components, including

properties, agents, resources, and governance systems. All components interact with each other, in response to ever-changing environments and disturbance (Walsh-Dilley &and Wolford, 2015; Juncos, 2017; 2018). From this naturalist point of view, resilience to climate change is a matter of evolution: resilience is '"evolutionary resilience'" (Pizzo, 2015: 137; Davoudi, 2018: 4).In the 1970s, naturalist social scientists incorporated Holling'"s notion of resilience within their own cybernetic complexity theory and cybernetic methodology (Wiese, 2016; Bergström, 2018). That is, socio-ecological systems are cybernetically conceptualized as adaptive complex systems. The ability to cope with uncertainty and complexity is one of the capacities of individual agents and interacting agents. The latter are able to interact and self-organize, learn and adapt (in an incremental or transformative way), making the system flexible in absorbing shocks and developing in face of changes (Jesse, Heinrichs &and Kuchshinrichs, 2019).

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. Bureaucratic interventions to address vulnerability and increase resilience to climate change typically generate unintended consequences that may well reduce a system'"s ability to absorb changes and disturbances (Adger et al, 2011). In 2001, Holling introduced the notion of '"panarchy'" as an alternative to hierarchy, to safeguard the self-organization of complex systems against the threat of bureaucratic intervention (Holling, 2001). Derived from the ancient Greek god of the woods, Pan, panarchy refers to the structure in which complex (ecological and social) systems are interlinked in an evolutionary process of adaptive cycles of growth, accumulation, restructuring, and renewal (Berkes &and Ross, 2016). Accordingly, when confronted with shocks (like extreme weather events), adaptive systems stabilize with supporting self-organizing structures until those structures are overstretched and can no longer absorb changes and disturbances; this is when there is a transformation of the system(Allen et al, 2014). 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,

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resilience is a primary system property that is measured by the magnitude of shocks that can be absorbed before the structures of system change (Boyer, 2020).

Methodologically, naturalist social scientists have typically embraced agent-based modelling (ABM) as their favorite mode of analysis in resilience research. They focus on the constant refinement of simulation tools (that can cope with complexity, uncertainty and multiplicity of agents) and techniques of regulation in favor of adaptation (cf. Cote &and Nightingale, 2012; Patriarca et al, 2018). Since the 1970s, when it emerged from mathematical sociology, ABM has been a much endorsed tool used in complexity theoretic research for analyzing complex systems. (Conte &and Paolucci, 2014). ABM is a computational mode of analysis that simulates complex (non-linear) systems that include diverse interacting agents that make decisions, interact and learn or adapt in their ever-changing environment, according to programmable rules . (Hawes &and Reed, 2006; Farmer &and Foley, 2009; Van Duinen et al, 2015; Martin &and Schlüter, 2015; Sun, Stojadinovic &and Sansavini, 2019). ABM computes, in probabilistic terms, the recovery process of complex (non-linear) systems under stress and tracks the emergence of new stages, phases or entries into new adaptive cycles (Filatova, Polhill &and Van Ewijk, 2016). In the social sciences, naturalist scholars calculate resilience to climate change at the system level as a system property (Pumpuni-Lenss, Blackburn &and Garstenauer, 2017). Since ABM traces feedbacks between micro-macro scale explicitly, ABM also enables naturalist scholars to estimate the resilience of a system'"s individual agents, communities or (sub)groups of agents.

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2.2 The constructivist view on resilience

In the social sciences, constructivist resilience research is also inspired by Holling'"s SES approach. Yet, for constructivists, resilience to climate change is not a system property. It is instead a socio-political construct that is created by diverse stakeholders (Walsh-Dilley &and Wolford, 2015; Weichselgartner &and Kelman, 2015; Kythreotis &and Bristow, 2017). Constructivist research includes a variety of (typically phenomenological and discursive) scientific perspectives. Constructivist

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resilience research primarily focuses on the political context and socio-political implications of resilience discourses. As a construct, resilience to climate change is not so much technical as political and administrative in nature (Alexander, 2013; Bourbeau, 2015; Boas &and 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 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 resilience has become a buzzword for governments that seek to shift the responsibility for vulnerable systems, floods, pollution, safety, welfare, health, etc. to '"resilient" individuals. Governments, in these cases, have recourse to resilience to make individuals more self-reliant (or less dependent on the government) when it comes to coping with their own struggles in dealing with the challenges of climate change (Braun, 2014; Pizzo, 2015; Tierney, 2015; Howell, 2015; Anderson, 2015; Ksenia et al, 2016; Schwartz, 2018; Davoudi, 2018). For instance, governments that fail to provide basic access to water to millions of rural citizens advocate community-based water management schemes, the leading paradigm for rural water access in East Africa (Katomera &and 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 &and Georgiadou, 2018).

Constructivist scholars tend to critically analyze resilience as an ideological construct. Such critical studies are typically inspired by the works of Michel Foucault, in the sense that resilience is analyzed as a discursive construct or ideological discourse. For Foucault, a discourse refers to systems of thoughts and beliefs, expressed through language and practices that systematically construct subjects and societies of which they speak. In other words, both language and practices are creative acts. Language is not a neutral tool of communication. Through resilience discourses, a particular type of subject (like resilient or self-reliant rather than vulnerable or dependent citizens) and a particular

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type of society (like a market-based '"society'") are discursively constructed and reinforced (Miller et al, 2010). Evans and Reid (2013) argue that as a discursive construct created by power holders, resilience has the character of a doctrine, according to which the resilient subject must constantly adapt to a dangerous and changing world, and is willing to accept this. Given this doctrine, vulnerability is rejected as weakness, a moral flaw (like a lack of character or a lack of will power) or simply illegitimate (the ability to absorb shocks being the new norm). Many critical constructivist scholars see the political reactions to events like Katrina (2005), Fukushima (2011), and Covid-19 (2020) as manifestations of such ideology. A problematic normativity is brought into existence when citizens are told that they must adapt to ecological and societal catastrophes, and when vulnerable citizens are left abandoned by their government as they are expected to be self-reliant (Fainstein, 2014; Tierney, 2015; Ribault, 2019). Constructivist scientists also stress that such catastrophes present themselves as '"anthropological shocks'" (Beck (2015: 80). Such shocks may open up counter-discourses that contest domination (Fazey et al, 2018). Katrina, for instance, proved to be such an anthropological shock because it opened up a counter-discourse that brought up the issues of colonial patterns of racism, slavery, vulnerability, and abandonment (Beck, 2015). As an anthropological shock , it is a potential initiator of policy transformations beyond the resilience discourse.

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 mythmaking. For instance, the increasing

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~~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).~~

3. Bridging the naturalist and constructivist view on resilience

~~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,~~

Given the different appraisals of the very concept resilience with respect to climate change among social scientists, it has been widely questioned whether resilience can possibly operate as a theoretical model or unifying paradigm – and whether such a unifying paradigm would be desirable in the first place (Alexander, 2013; Thorén, 2014; Bourbeau, 2015; Fainstein, 2015; Pizzo, 2015). ~~A unifying paradigm is neither possible nor desirable.~~ The question of whether such unifying paradigm is possible or desirable need not be answered here. It can still be argued that it is desirable to bring together the insights gained from naturalistic and constructivist approaches~~ Yet, naturalist and constructivist research can be brought together~~ to enrich and renew understandings of resilience to climate change. ~~Naturalist r~~Resilience to climate change research that relies on naturalist and naturalistic premises may be able to provide quick solutions to crises precisely because various unpredictable and apparently irrelevant elements are discounted. The focus on the obvious problem without taking into account the broader context – which may be problematic – has many advantages, certainly if the bigger picture is taken into account after recovery from an acute crisis. In the event of a flood, for instance, the first concerns should arguably be evacuation and preventing another flood. Once everyone is safe, the question as to why the flood has affected a particular group can be raised. The particular choices made with regard to urban and rural planning can be critically scrutinized. Answers to the various questions

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that a flood and its aftermath raise will require knowledge from many disciplines. ~~'~~"Resilience~~'~~" to floods will mean much more than building dams. It will also involve criticism of particular social structures, institutions and decisions that have rendered some people or areas more vulnerable to natural hazards or the effects of climate change.

~~has the great merit that it may help to increase complex systems'' robustness to system failure when faced with shocks and disturbances. ABM – a mode of analysis that complexity theorists tend to prefer – may be a valuable tool for developing procedural stability, environmental risk management under conditions of uncertainty, provision of planning security, and prevention of adverse consequences from disruptive shocks (Schilling, Wyss &and Binder, 2018). Constructivist resilience research provides a critical and most penetrating understanding of resilience as a construct (first of all, a discursive construct, myth or narrative) that contains political intention and direction. Its interpretation of resilience to climate change is useful for generating understanding of how resilience is mobilized, taken up in climate governance, and resisted by social movements'' counter-discourses, such as the Fridays for Future, Black Lives Matter and Extinction Rebellion, that push for less unsustainable trajectories and for more protection of vulnerable citizens and communities.~~

3.1 The debate on adaptive and transformative resilience

~~In recent years, the contrast between naturalism and constructivism in resilience research has come to revolve around the issue of adaptation and transformation~~ Resilience research in recent years reveals divergence between social scientists when it comes to the issue of adaptation and transformation (Chandler, 2014; Redman, 2014; Fainstein, 2014; Dahlberg et al., 2015; Sjöstedt, 2015; Boas ~~&~~and Rothe, 2016; Duit, 2016; Ziervogel, Cowen ~~&~~and Ziniades, 2016; Clément ~~&~~and Rivera, 2017; Lyster, 2017; Schlosberg, Collins ~~&~~and Niemeyer, 2017; Fazey et al., 2018; Glaser et al., 2018;

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Hoekstra, Bredenhoff-Bijlsma ~~&~~and Krol, 2018; Jesse, Heinrichs ~~&~~and Kuchshinrichs, 2019; Dryzek ~~&~~and Pickering, 2019). Such disagreement can partly be explained by ~~.It is an urgent issue that emerges from a~~n particular ambiguity in Holling~~'~~'s SES approach (Redman, 2014). In the 1970s, Holling (1973) reinterpreted resilience as bouncing back or forward in terms of SES adaptation. Adaptation refers, on the one hand, to the capacity of agents to influence the system (and influence or strengthen resilience as a system property). And on the other hand, it alludes to panarchical adaptation to new (ecological and social) environments, as an evolutionary process towards a new stage, phase, or adaptation cycle (Boyd et al., 2015).

Yet, as Holling emphasizes, the bouncing back and bouncing forward of a system not only refers to a return to some previous (dynamic) equilibrium or to the persistence and endurance of systems. It also refers to socio-ecological transformation in an ongoing process of non-equilibrium and instability and reinvention of systems in changing environments marked by different adaptive cycles (growth, accumulation, restructuring, and renewal) (Folke, 2006). Transformation means that ~~refers to the capacity of~~ agents are capable of ~~to~~ creating~~e~~ a new system and a new discourse, particularly when ~~conditions make~~ the existing system is untenable or illegitimate. This focus on undesirable status quos and hence on transformation – after a crisis, for example – is characteristic of many social constructivists, but may also be important to those who have somehow combined the goods of several worlds (Carolan, 2005; Code, 2005). Scholars critical of resilience discourses propounded by national and international governance actors, therefore, do not try to find ways to increase resilience, but above all things, try to ~~Constructivist resilience research is primarily focused on transformation. Such research unsettles taken-for-granted assumptions and definitions of the situation expressed in established discourses; and it ignites~~ ignite new imaginations and counter-discourses ~~needed~~ necessary for realizing less unsustainable futures (Fazey et al., 2018). Recently, a middle ground between adaptation and transformation has been developed, in the form of ~~'~~'transformational adaptation~~'~~' (Pelling, O~~'~~'Brien ~~&~~and Matyas, 2015; Mummery ~~&~~and Mummery, 2019). Examples of t~~T~~ransformational adaptations include ~~, such as~~ green growth or the greening of ~~the established~~

present economies. ~~economy.~~ These are ~~refer to~~ changes that are aligned ~~to~~with the scale of projected, possible and desirable changes within systems that are informed by ~~(ultimately constructivist)~~ considerations of justice.

~~The naturalist emphasis on resilience as system adaptation to climate change means that resilience research focusses~~ Resilience research that emphasizes system adaption to climate change focusses on the degree to which complex systems can build capacity for learning, as a way to respond to shocks or disturbances, embrace evolutionary change, and live with complexity and uncertainty (Thorén, 2014; Juncos, 2017; Warmink et al., 2017; Béné et al., 2018). Given unpredictability and uncontrollability, adaptive resilience is especially a matter of ~~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 conceived ~~taken~~ as inherently positive, while disturbances and shocks (de-stabilizers) are ~~taken as~~ negative (Duit, 2016; Lockie, 2016). ~~It is on the basis of the premise that adaptive resilience is good that naturalist resilience research ties up with climate risk management, as a way of managing ecosystem services (critical for survival), under conditions of ecological and societal shocks and disturbances.~~ Research building on the premise that adaptive resilience is desirable thus partners well with climate risk management (Boyd et al., 2015; Berbés-Blázquez et al., 2017). The response of the government to the overflowing of the Meuse River in 1993 and 1995 illustrates research-based risk reduction through adaption that involves a break with the past. The government did not simply have recourse to building more dykes and strengthening existing barriers, which has been the traditional approach, but instead opted for river deepening and widening measures (Dijkman et al., 1997; Hamers et al., 2015). ~~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 to be successful. However, a research completed in 2013 (Ward et al., 2013) points

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

~~Warmink et al (2017) point out that in Dutch river management, such adaptation responses are typically conservative and within safety margins. This leads to over-dimensioning and high costs of water engineering works (like flood defenses).~~

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

cannot possibly integrate thoroughly unequal power relationships – such as the Global North-Global South relationship – into their models (Swyngedouw, 2011; Pizzo, 2015; Clément &and Rivera, 2017; Davoudi, 2018; Glaser et al., 2018; Dryzek &and Pickering, 2019).

The limitations of models need not be a problem unless they become the political tools to implement adaptive measures (Fainstein, 2014; Weichselgartner and Kelman, 2015; Huang, Boranbay-Akan and Huang, 2016; McGreavy, 2016; Ziervogel, Cowen &and Ziniades, 2016; Ribault, 2019).

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

~~Constructivist social scientists criticize the notion of adaptive resilience for not sufficiently addressing issues of environmental and climate justice. To address issues of power abuse and domination, the constructivist argument goes, system reconfiguration is needed: injustice inheres in the established systems. Naturalist resilience research, however, does not exclude considerations of justice from scientific analysis. Yet, it identifies justice, like resilience, as a system property. Thus, enhancing adaptive resilience to climate change may entail liberal principles of equity, fairness and access to resources and services, so as not to privilege or marginalize certain stakeholders (Redman, 2014; Thorén, 2014; Ksenia et al, 2016; Schlosberg, Collins &and Niemeyer, 2017; Bergström, 2018). Yet, naturalist enquiry into adaptive resilience tends to leave the status quo of systems, including the problematic Global North-Global South relationship (marked by massive power inequality), unquestioned (Swyngedouw, 2011; Pizzo, 2015; Clément &and Rivera, 2017; Davoudi, 2018; Glaser et al, 2018; Dryzek &and Pickering, 2019). In constructivist resilience research, by contrast, the justice question is placed in a context of broader socio-political processes of system transformation: adaptive systems can be unjust and oppressive (Fainstein, 2014; Weichselgartner and Kelman, 2015; Huang, Boranbay-Akan and Huang, 2016; McGreavy, 2016; Ziervogel, Cowen &and Ziniades, 2016; Ribault, 2019).~~

Adaptive responses to shocks and disturbances may blur long term sustainability visions and enable powerful stakeholders to maintain their positions~~, 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 ~~&~~and 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 ~~&~~and Levine, 2014; Lockie, 2016; VanderPlaat, 2016; Schilling, Wyss ~~&~~and Binder, 2018; Glaser et al., 2018; Ribault, 2019). Hence, some constructivist scholars ~~tend to~~ reject Holling~~'~~"s panarchy concept, emphasizing that transformation towards more

sustainable worlds is not an evolutionary process of adaptive cycles but a political-administrative phenomenon (cf. Boyer, 2020). ~~The middle ground of transformational adaptation, accordingly, must include a process of filtering out resilience traps that come with adaptive resilience. Transformational adaptation includes an understanding that adaptive resilience may well enforce a governance of unsustainability (cf. Van de Ven, 2017).~~

3.2 Transformative resilience and sustainability

~~For constructivist scholars, transformative resilience is a post-neoliberal construct that is intertwined with the notion of sustainability. For constructivist scholars, sustainability is based on the idea that existing systems can be transformed – with respect to social, cultural, political, administrative, economic, technological and environmental factors –, with the right governance interventions and reconfigurations of the ecological and social underpinnings of SES~~

For some constructivist scholars, genuine sustainability presupposes transformative resilience because inherently unsustainable systems cannot be made more wholesome by tweaking a few of their constituents. In cases of inherent or structural defects, resilience refers to the capacity to ~~'~~"use~~'~~" a crisis to reappraise critically the social, cultural, and political choices underpinning SES, and if necessary, to make new choices (Pizzo, 2015; Weichselgartner ~~&~~and Kelman, 2015; VanderPlaat, 2016; Ziervogel, Cowen ~~&~~and Ziniades, 2016; Hughes, 2017; Jesse, Heinrichs ~~&~~and Kuchshinrichs, 2019). The reconfigurations of SES do require interventions by all governance actors. Transformative resilience used in this sense is thus a post-neoliberal concept. ~~Currently, the sustainable energy transformation is no doubt the best example of such a reconfiguration.~~ When applied to the energy transition, transformative resilience entails a more radical change than adaptive resilience does. In the former case, this means concrete plans to phase out fossil fuels and hence to reorganize economies, where the old fossil fuel industry no longer holds the reins (Alexander ~~&~~and Yacoumis, 2018; Stegemann ~~&~~and

Ossewaarde, 2018; Bergmann &and Ossewaarde, 2020). Adaptive resilience is involved when the phasing out of fossil fuels is being delayed and when certain discourses ensure that the fossil industry is given carte blanche to carry on business as usual (Buschmann &and Oels, 2019). Geels (2014, p. 24) explains how ‘“the coal regime has so far resisted climate change pressures through a ‘“clean coal’” discourse and the innovation promise of carbon capture and storage (CCS).’”.

It is widely agreed that non-renewable Ffossil energy sources like coal, oil and gas are largely responsible for landscape degradation, water pollution, as well as greenhouse gas carbon dioxide emissions and other pollutants that , which generate have been causing global warming (Cook et al., 2016). The sustainable energy transformation, accordingly, is, amongst other things, a response to climate change. In a more robust sense, it is more than simply a response to climate change. Instead, the latter is a symptom of the inherent unsustainability of the present socioeconomic system and is therefore an additional, urgent reason to radically transform the latter (Alexander &and Yacoumis, 2018). Hence, those who conceive an energy transition as an adaptive necessity are primarily concerned with what several scholars call ‘“energy resilience’” (Béné et al., 2018, p. 120; Jesse, Heinrichs &and Kuchshinrichs, 2019, p. 21), that is, with the continuing supply of energy to support the prevailing socioeconomic system and prevention of power outage during the transition. 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 &and 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 In other words, reliable energy supplies at stable costs must be kept going to support the present socioeconomic system , even in a turbulent ecological and political environment (Wiese, 2016). Since system collapse is to be avoided at any cost, The notion of energy resilience, as a form of adaptive resilience to climate change means incremental changes and the increasing use of renewables without stopping the use of fossil fuels , 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 ~~&~~and Binder, 2018; Stegemann ~~&~~and Ossewaarde). Adaptive resilience here means the gradual greening of energy and hence the gradual greening of the system through green technological without essentially changing the old system (Geels, 2014). In fact, important stakeholders of the ~~'~~"old regime~~'~~" resist the transition to a new order (ibid). Such resistance takes, among other things, the form of continuing investments in fossil-fuel-based energy and greening measures – which create the impression of a transition (especially in the media) – thereby further anchoring the existing system (Alova, 2020; Gençsü et al., 2020). The incentives to ~~'~~"destabilize~~'~~" such a flourishing economic system are thus weakened.

~~The middle ground of transformational adaptation includes this adaptationist notion of energy resilience but aligns it to the scale of desirable ecological and societal changes that are informed by justice considerations and political direction towards less unsustainable futures. Given that established energy systems insufficiently respond to ecological and societal challenges of climate change, transformational adaptation may imply the metamorphosis of energy systems.~~

~~From the (typically constructivist) perspective of strengthening transformative resilience, energy resilience comes with the enactment of~~ Scholars who challenge existing social structures therefore critically point out that the primary and sole focus on ~~'~~"energy resilience~~'~~" (that is to say, energy security) is more likely to maintain the energy system~~'~~"s status quo, which further allows powerful stakeholders to promote fossil energy and keep their established positions. ~~. This is a status quo that includes powerful agents that have a vested interest in promoting fossil energy.~~ As Simpson (2013, p. 249) notes, the ~~'~~"critical approach to energy security challenges the existing economic, political and technical assumptions that underpin traditional debates on energy production and consumption, but it also challenges traditional notions of security that have the nation-state as their referent object~~'~~".

~~Such agents use all sorts of tactics (including sponsoring the climate change denial movement) to secure their established power position (Stegemann &and Ossewaarde, 2018; Szablowski &and Campbell, 2019).~~ An uncritical adaptive energy resilience approach can thus reinforce ~~'~~"energy injustice~~'~~", that is, the ~~'~~"the unequal distribution of ills~~'~~" throughout the energy system, whereby that system is defined as ~~'~~"the entire energy chain, from mining, conversion, production, transmission, and distribution, right through to energy consumption and waste~~'~~" (Jenkins et al., 2016, p. 179).

~~It enacts a condition of '"energy injustice'", particularly in the Global South. The notion of energy injustice refers to~~

~~current energy systems that distribute the ecological and economic benefits and burdens of established energy systems in unfair ways; dominate, degrade and devalue certain stakeholders; and exclude certain agents from processes that govern the benefits, burdens and recognitions (Jenkins et al, 2016; Heffron &and McCauley, 2017).~~

Scholars who focus on ~~T~~the transformative resilience of energy systems are therefore generally committed to energy justice and have a more critical approach to energy resilience (or security) because the latter presumes the socioeconomic order and unequal structures of power (Jenkins et al., 2016; Heffron &and McCauley, 2017). ~~, which is tied up with the notion of '"energy justice'", refers to the resistance to and negation of a fossil-based energy system and its oligarchical power structure (increasing the vulnerability of such a climate-unfriendly energy system);~~ They propose ~~and~~ the creation of a renewable energy-based system, energy commons and collaboratives beyond the energy establishment (VanderPlaat, 2016; Bourbeau ~~&~~and Ryan, 2018; Juncos, 2018; Schwartz, 2018; Acosta et al., 2018; Jesse, Heinrichs ~~&~~and Kuchshinrichs, 2019). ~~The middle ground of transformational adaptation includes the long-term vision of energy governance (for instance, towards 2050), but it searches for realizing such transformation through adaptations by the status quo. Transformational adaptation means that the sustainable energy transformation comes with the change of the energy establishment into agents of sustainability – a change that comes from within the power complex, for instance, via stakeholder participation (like shareholder activism).~~

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746 **3.3 AI for resilience and sustainability**

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748 Adaptive resilience to climate change comes with short-term systematic adjustments to a
749 changing technological environment that is currently increasingly dominated by smart urbanism and
750 artificial intelligence (AI) technologies. Governance actors like the UN, EU and national governments
751 have all drafted their AI strategies for the making of an '"AI Revolution'". Such actors present AI as a
752 leading technology that contributes to resolving resilience and sustainability challenges (cf. Taddeo
753 &and Floridi, 2018). Particularly in naturalist resilience research, AI is identified as a new systems
754 property that permeates systems to generate productivity gains, improve efficiency, lower costs,
755 predict climate change stress, track carbon emissions, monitor flood risks, etc. (Rajan &and Saffiotti,
756 2017; Khakurel et al, 2018; Vahedifard, et al, 2019; Miller, 2019; Saravi et al, 2019). Strengthening
757 adaptive resilience to climate change through AI primarily means that an integrated data system for
758 circulating information (near) real time among agents needs to be developed. In an AI technological
759 environment, resilience implies close collaboration between agents (tool/model developers, data
760 stakeholders, community level stakeholders, state level institutions, etc.) (Vahedifard, et al, 2019). AI
761 comes in both for combining datasets into usable information, as a monitoring method (like change
762 detection algorithms) as well as a tool for forecasting (for instance likely occurrence of a natural hazard
763 due to extreme events). Identifying, harnessing, synthesizing, and communicating pertinent yet
764 structured and unstructured data (weather data, cell phone GPS data, social media feeds, traffic
765 cameras, smart city sensors, images, videos, audio data, etc.) enables agents to better forecast,
766 prepare for, respond to, and recover from disturbances and shocks (Rajan &and Saffiotti, 2017;
767 Vahedifard et al, 2019). In urban systems, so-called '"city dashboards'" rely on big data and AI when it
768 comes to ordering and visualizing data through interactive maps and graphs (Kitchen, 2018). By being
769 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. 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 &and Floridi, 2018).

4. Six upcoming themes in diversified resilience research

Current research on resilience to climate change in the social sciences reflects a diversity of focusses and commitments, ranging from climate-resilient infrastructure to issues of justice and power. Some critical scholars question the very notion of resilience and point to the -"wicked-" dynamics involved as -"resilience-" becomes a policy instrument to consolidate one particular, often established social reality at the expense of other, fairer possible alternatives. Research that unwittingly supports such political purpose has thus attracted the criticism of scholars who emphasize transformation towards new social constellations, where power (to influence the course of things), responsibility, burdens, and benefits are fairly distributed ~~(~~(Derickson, 2016; Jenkins et al., 2016; Heffron ~~&~~and McCauley, 2017; Alexander ~~&~~and Yacoumis, 2018; Davoudi, 2018; Glaser et al., 2018; Stegemann ~~&~~and Ossewaarde, 2018)~~)~~. -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). -Based on our overview of recent scholarship, which cannot possibly be exhaustive, we have identified six research avenues that deserve continuing attention.

One of them is the further development of transdisciplinarity, which includes the collaboration between constructivist and naturalistic approaches to resilience, not only at the institutional level, but especially at the level of research itself. Such transdisciplinarity thus means that a scholar draws on different scientific traditions to approach one particular problem. In other words, transdisciplinarity does not restrict itself to -"forced-" collaboration between scholars from different disciplines, which is a prevalent organization of inter, multi and trans -disciplinarity (cf. Pohl, 2001). It also does not mean homogenization of science and the repression of the diversity of human thinking. It does entail an appreciation of diverse scientific vocabularies, of the variety of scientific knowledge, and the acknowledgement of clashes, which can be conducive to the advancement of human knowledge (cf.

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Pfeffer &and Georgiadou, 2019). Bringing together various perspectives of a complex reality arguably fosters our understanding of that same reality.

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

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

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

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

and more generally, the idea that we cannot simply wait for evolutionary change, or for systems to explode, but instead have to realize alternatives imagined by human imagination.

This brings us to the second theme, which could be dubbed '"critical resilience'" research. Critical thinking is arguably a precondition for, and characteristic of, science in general. This means that reservations with regard to the very concept '"resilience'", in policies and models, need to be taken seriously. Research that constantly analyses the dominant and new – and often, implicit – conceptions of resilience must thus be stimulated even if it does not seem to serve practical purposes. Critical resilience research thus also includes the integration of reflexivity in transdisciplinary research, which involves '"a reflexive questioning of values, background assumptions and normative orientations'" (Popa et al., 2015, p. ÷46) of various approaches to resilience. Critical resilience research is expected to pay attention to diverse conceptions of resilience and also to address the '"question of outcomes and who gets to define them as resilient or otherwise'", '"the potential exclusions in determining system "boundaries"'", and '"the question of the political—resilience from what, to what, and who gets to decide?'" (Porter &and Davoudi, 2012, p. ÷331). Such critical resilience research can accompany other resilience research, thereby preventing science from serving ideological goals.

~~In the social sciences, the bridging of naturalist and constructivist scientific approaches in theorizing change as system adaptation, transformation, or transformational adaptation triggers new research themes for the study of resilience to climate change. Theorizing change within and of systems has become the key issue in resilience research, in the wake of changing societal, ecological, and technological environments. In naturalist research, resilience to climate change is presented as '"evolutionary resilience'" and as '"adaptive resilience'". From this angle, the key issue of changing environments is the survivability of established complex systems under stress. Change is, accordingly, evolutionary change. In constructivist research, resilience to climate change is presented as discursive, ideological, mythical (the '"myth of resilience'") and as transformative resilience. The key issue of~~

~~change is the overcoming of '"resilience to change'", '"resilience traps'" and '"unjust resilience'" or '"bad resilience'" that the status quo that organize established systems produce. Such overcoming of the establishment is presented as an indispensable condition for enhancing change. Such change refers to metamorphosis of systems and comes with transformative politics and climate governance. The reconciliation of naturalism and constructivism in terms of change can be found in the middle ground of transformational adaptation, which ties incrementalism to long term sustainability visions. It is a notion that comes with the search for the conditions and tempo of transformations in different ecological and societal contexts and adaptative cycles. Ultimately, the overarching challenge for future research is to ensure that resilience to climate change does not compromise sustainability and considerations of justice (including, environmental, climate and energy justice).~~

~~A first promising direction for future resilience research concerns the reconciliation of naturalist and constructivist scientific approaches to resilience. Given the diversification of scientific approaches, resilience cannot operate as a theoretical model or unifying paradigm (Mummery &and Mummery, 2019).~~

~~Yet, as a metaphor resilience provides a sound basis for reconciling contrasting scientific approaches, mainly because of its heterogeneity and high level of abstraction (Thorén, 2014).~~

~~Intellectually, the reconciling of naturalism and constructivism implies an appreciation of diverse scientific vocabularies, many visions of what counts as scientific knowledge, other approaches'" scientific worlds, a certain embracing (which includes making manifest) of the tensions between the contrasting types of science, and creating spaces for constructive contestation (Pfeffer &and Georgiadou, 2019). Thereby, new resilience perspectives may develop. New questions may be posed (or new answers to long-standing questions may be provided). The resilience trap – typically marked by the promotion of adaptive strategies that reify responses and corresponding power structures in the short-term – may be avoided (via challenging current assumptions underpinning resilience research). Current adaptation and transformation and transformational adaptation approaches may~~

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

~~A second theme for future resilience research comes with a change in political environment, in which the legitimacy of adaptive, transformative, and transformational adaptive responses to climate change is constantly contested.~~

A third research avenue, somewhat related to the second theme, consists in the contextualization of resilience research and discourse, that is, in embedding it in its political and cultural context. By understanding the bigger picture in which both the ecological crisis and the responses to it arise, it may be possible to govern resilience research towards sustainability and justice, and to identify the factors – which may be institutional, cultural or political – that stimulate or deter such change (cf. Bahadur ~~&~~and Tanner, 2014). In a system thinking language, such research can identity the various agents that maintain or disrupt the system.

~~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 &~~and ~~Ossewaarde, 2018; Dryzek &~~and ~~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 established systems (such as energy systems) and their governance arrangements. On the other hand, agents who hold power thanks to such arrangements typically use

tactics of repression and criminalization, particularly in the extractive sectors of the Global South (Szablowski ~~&~~and Campbell, 2019). Research focusing on the different fields of forces in various political contexts may discover how differences in system adaptation and reconfiguration relate to particular administrative capacities and governance arrangements (cf. Blühdorn, 2013; Fischer, 2017; Davoudi, 2018; Köhler et al., 2019; Mummery ~~&~~and Mummery, 2019). It can also generate insights into the (possible) connection between particular resilience policies and models, on the one hand, and ~~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 of systems under pressures of climate change comes with~~ new forms of power inequalities, polarization, injustice, and ~~battle for resources,~~ democratic deficits ~~and post-democratic tendencies~~, on the other hand. ~~climate change denial tactics, attacks on legal rights, 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 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 &~~and Mummery, 2019). Bierbaum and Stults (2013, p. 18) point to the ~~'~~"growing recognition of the need for a new model of deep and long-term stakeholder engagement~~'~~". Such a model ensure that all (local) stakeholders are involved in determining a ~~'~~"vision of resilience, impediments to achieving that vision, and contextually relevant actions for achieving that vision~~'~~" (Bierbaum ~~&~~and Stults, 2013, p. 30). It can safeguard both the effectiveness and equitability of solutions.

A fourth~~third~~ promising topic for future resilience research is the interplay ~~concerns the relationship~~ between adaptive resilience and transformative resilience and transformational adaptation ~~in the reactive and proactive governance responses to anthropogenic climate change~~ (Clément ~~&~~and 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~~ The focus can be on the ways in which 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 ~~&~~and 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 ~~&~~and Konrad, 2019). It is likely that stakeholder engagement (including resistance) in transformational politics and tentative governance varies, and manifests itself differently, across different policy fields. For instance, the sustainable energy transformation may include multi-layer governance challenges, many pro-active stakeholders, new investment opportunities and job opportunities. ~~Given that multiple public and private actors are responsible for the performance of different parts of a system, tentative governance comes with transformational adaptations that must be arranged. Hence arises the question which adaptations allow for transformation?~~ In contrast with the sustainable energy transformation, sea level rise and the disruption and relocation of coastal cities may trigger a more limited transformative politics, despite inevitable transformation of systems due to shocks and disturbances (metamorphosis). Yet, in the coming decade, transformational politics and tentative governance – including anthropogenic topics like population displacement, privatization of climate adaptation, conflict organized around scarce resources (like water resources), intergenerational environmental conflict, and the closing of old infrastructures that are too costly to maintain – becomes a more urgent research topic.

~~A fourth topic for future resilience research~~The fifth research theme concerns the relationship between the phasing out of unsustainable systems and societal transformations. In other words, what are the implications of the disintegration of old systems for societies, that is, for their cultures, collective identities, traditions, economies, political-administrative power constellations, class structures, etc.?; and which societal transformations promote such disintegration?

~~The sustainable energy transformation is a most obvious phasing out of old systems (like coal energy systems) and change of worldviews, middle-class consumerism, lifestyles, etc. towards new energy systems, given that burning fossil fuels has such a major impact on climate change. Adaptative and transformational responses to climate change are intermingled with responses to many societal and ecological developments. A response like investment in transportation systems that aims to address increasing transportation demand must accordingly include possible climate change impacts. In the Anthropocene epoch, systems typically face pressures to change, to establish new (less unsustainable) interactions between society and ecology. Pressures on existing systems not only emerge from ecological adversity, over-exploitation, resource depletion, etc., but particularly from counter-discourses and new ways of thinking, new lifestyles, and new contestations (like the Fridays for Future, the Anti-Mining, the Transition Towns, Black Lives Matter, and Degrowth movements) that increase the positive vulnerability of undesirable systems (Bergmann &and Ossewaarde, 2020). At the same time, anthropogenic climate change comes with the development of a multi-trillion market of the emerging green economy, which proves new climate investment opportunities. Given such societal pressures and opportunities, new r~~Research topics encompass ~~include~~ the governing and accelerating of the decline of existing systems and their adaptive cycles (Stegmaier, Visser ~~&~~and Kuhlmann, 2014; Hoffmann, Weyer ~~&~~and Longen, 2017; Stegmaier, Visser ~~&~~and Kuhlmann, 2020); the particular circumstances in which accelerations can manifest themselves; the identification of, and coping with, uncertainties in processes of adaptation and transformation and transformational adaptation; and the construction of new incentive structures, for accelerating sustainable transformation (cf. Clément ~~&~~and Rivera, 2017; Warmink et al., 2017; Köhler et al., 2019). This branch of discontinuation research

assumes that technologies influence socio-ecological systems. Some technologies threaten resilience to climate change, while others enhance it (Smith ~~&~~and Stirling 2010), which brings us to another, related research topic, namely, the implications of the so-called ‘~~“~~AI Revolution~~”~~’ and the (top down and politically steered) making of the alleged ‘~~“~~Age of Artificial Intelligence~~”~~’ for resilience research and SES (Berendt, 2019).~~.~~

~~Such research informs that political objectives like drastic reduction of CO2 emissions (as can be found in the European Green Deal (2019) will hardly be achieved by using single cleaner (green) technologies alone, but structural system metamorphosis is needed to qualitatively alter established systems (Vögele, Kunz, Rübbelke &and Stahlke 2018; Rogge &and Johnston, 2017; Stegmaier 2019). One of the challenges for the coming decade is to reverse the negative, alarmist, catastrophic, apocalyptic or paralyzing image of climate change: transformational adaptation comes with stakeholders taking a pro-active and positive view on climate change and on positive vulnerability, with new opportunities emerging from responses to climate change. How can climate change and vulnerability of established (and typically unsustainable) systems be regarded as an opportunity rather than as a risk in the governance of transformational adaptation to climate change?~~

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

of local communities (Bierbaum ~~&~~and Stults, 2013; Pfeffer ~~and&~~and Georgiadou 2019). A recent example of the integration of different sources of knowledge 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 (unhabitat.org, 2019)~~–~~. This example illustrates the importance of embedding AI technologies in particular contexts so that the needs of particular communities, for instance, are served, and fairness and transparency are safeguarded. Resilience research and models must therefore include an evaluation of AI technologies: how has data been acquired and by whom?; what are the implications of particular AI technologies for the SES in question?; which new power relations are established through the reliance on AI technologies?; which stakeholders are being included and which ones excluded during the whole process beginning with the problem definition to the formulation of solutions that involve an intensive application of AI? (Rajan ~~&~~and Saffiotti, 2017; Taddeo ~~&~~and Floridi, 2018; Khakurel et al., 2018; Vahedifard, et a.l, 2019; Miller, 2019; Saravi et al., 2019)~~.~~

A sixth ~~fifth~~ theme for future resilience research concerns the role of environmental, energy and climate justice in theorizing, modeling, interpreting, and explaining resilience to climate change (cf. Skillington, 2015; Fazey et al., 2018; Mummery ~~&~~and Mummery, 2019). What kind of research results from the integration of ~~For future research,~~ theories of environmental justice, energy justice and climate justice into ~~can be conducive to helping furthering comprehension of~~ adaptive and transformative resilience and transformational adaptation models? ~~. How can justice claims be made more responsive to newly unfolding ecological and societal circumstances and uncertainties?~~ Future resilience research will somehow have to confront wicked problems: given unstable political contexts, scarcity of ~~'~~"resources~~'~~" and struggles for survival and power, how can ~~How can~~ principles of equity, fairness and access to resources and services be secured?; ~~in a toxic political environment? And how can ~~li~~~~n the problematic context of climate-induced migration and a political environment marked by anti-immigration policies, how can ~~—~~~~the wellbeing of migrants be ensured and, in general, human

rights be safeguarded?; how can the disparity and inequality in the distribution of risks, locally and globally, be tackled? Equity in this regard will mean much more than equality. ~~Theories of environmental, energy and climate justice are also highly relevant for developing understanding of how adaptive and transformative resilience and transformational adaptation are perceived and experienced in everyday life by different stakeholders that face anthropogenic challenges. Constructivist enquiry into perceptions, experiences and prioritizations of resilience constructs is a promising topic for future resilience research. In this regard, insurance decisions of citizens against the risks associated with climate extremes can gain further research attention. As addressed by O'"~~ Hare et al. (2016), citizens are faced with an increasing responsibility to make decisions to ~~'"~~insure~~'"~~ themselves and their assets against the possible damages of climate change. Such decisions can have diverse justice implications in different political and economic contexts that influence how citizens perceive, experience, and prioritize climate risks. Similarly, Other challenges include the incorporation of ~~the~~ cross-sectional dimensions of justice, particularly gender and racial relations, ~~is becoming increasingly relevant and yet challenging to understand and integrate~~ into climate justice (Terry, 2009), and energy justice (Feenstra and Özerol, 2018) frameworks. And in the Global South, addressing issues of corruption, violence, poverty and lack of access to resources (and violent battles for resources) and services (like education and sanitation) may have a higher priority than global environmental considerations (Köhler et al., 2019).

~~A sixth theme for future resilience research comes with a changing (geo)technological environment, that is, the so-called '"AI revolution'" in the making. Given worldwide investments and top-down AI strategies that global governance actors and national governments have recently published, AI will most plausibly become a major force that shapes resilience to climate change by means of monitoring, forecasting and learning. A relevant example of big data is the G-Earth Engine and the vast amount of satellite imagery made available by space agencies, which opens up an unprecedented dataset of satellite images for scientific research. Such extensive datasets, marked by high spatial and temporal resolution, are essential for monitoring a changing earth system. In the past~~

decade, resilience discourses have increasingly incorporated phenomena like big data, AI, cybersecurity and smart city. In the coming decade, resilience discourses may increasingly become algorithmic technology discourses. New interplays between automation, (un)sustainability, and adapting and transforming systems trigger new questions for future resilience research (cf. Köhler et al, 2019). For instance, in the near future, not only the number of climate disasters is expected to rise. Also the data – satellite data, drone data, sensor data, social media data, volunteer geographic information (VGI) data, Internet of Things data, etc. – available on such disasters is expected to increase in size and resolution, amounting to vast volumes of climate disaster data. However, AI, due to the unstructured nature or coverage of input data, may omit those phenomena, places and social groups that are not present in the data (Hoefsloot et al. 2019). Alternative ways of knowing can refine or contribute complementary insights to the precise measurements and data gaps (Pfeffer and Georgiadou 2019). New research questions for naturalist and constructivist research emerge from challenges of organizing big data and how to make it available and usable, given the variety of public and private stakeholders, workflows and incentive structures involved in the (social) construction of big data (Wright, 2016). How can AI be augmented with alternative ways of knowing to strengthen adaptive/transformative resilience? How to incorporate the socio-spatial dimension in resilience research, to pronounce the different capabilities of different groups and places? And what role can AI play in creating a dialogue between the naturalist and constructivist resilience research? In the coming years, AI tools – mainly tracking (for instance, tracking of deforestation tracking or energy/water consumption) and machine learning techniques – are expected to be widely used. Among other things, for detecting and predicting how climate disasters probably develop, for locating areas or communities at risk, for analyzing the consequences of climate disasters, and for assisting in climate disaster responses. Working with AI for purposes of learning from data – for instance, via the use of data mining or deep learning techniques for dissecting patterns in satellite images – comes with the design of procedures for data analytics, forecasting and intervention (Rodríguez González, Zanin &and Menasalvas Ruiz, 2019) and requires domain and local knowledge as well as a dialogue between

naturalist and constructivist researchers. In contrast to the official national statistics of the past, which diffused societal controversies, big data analytics create myriad parallel realities, stand in the way of achieving a minimal consensus about basic facts and amplify controversies. A recent example where AI and alternative ways of knowledge came together is the resilient settlement program led by UN HABITAT which brought together a multitude of actors (policy, private, academic, community organizations) and data and algorithms and local knowledges to identify settlements at risks. In sum, next to technologization of resilience discourses, social processes of big data construction, the inclusion and exclusion of diverse stakeholders, the embeddedness of AI in everyday practices, the various uses of AI in the exploitation of data, fair, transparent and accountable (FAT) AI, as well as the integration and inclusion of alternative knowledges are promising fields of resilience research.

In the coming decade, several AI challenges are most likely to increasingly come to the fore in resilience research. First, monitoring systems (for instance, monitoring the status and behavior of infrastructure or human settlement dynamics) that incorporate machine learning make that systems are automatically checked rather than regularly inspected by experts. When AI is integrated with knowledge of how systems work, expertise is outsourced to AI, which implies that expert knowledge may get lost or become obsolete. Moreover, AI classifications may have unintended consequences for certain places or communities. For example, by labelling areas at risks, property prices may go down or insurance agencies are not willing to provide an insurance certificate. Second, the digitalization of SES makes systems vulnerable to, for instance, breakdowns, power outages and cyberattacks – hence resilience strategies and digital strategies are intertwined (Wessel, 2019). '"Digital resilience'" has recently become a key concept in resilience research that refers to strengthening resilience of digital systems to potential cyberattacks, including the adaptive capacity to respond to such attacks (Wright, 2016). The making of digital resilience typically implies bringing in tech firms for the protection of SES, whose algorithms are typically opaque. Third, because of the reliance on AI and associated data, other realities are neglected, excluding certain places or communities from digital resilience strategies. Fourth, AI systems facilitate governing at a distance, with governing becoming more invisible and

~~possibly unaccountable. For instance, when disaster management (for instance, in the context of an extreme weather event) becomes '"~~digital humanitarianism~~'", the distance between the saviors and survivors becomes big, with survivors becoming reified abstract entities that inspire limited empathy. In fact, survivors are confronted with the risks of AI systems, in terms of privacy breaches and identity frauds. In other words, while AI is expected to become a key theme in resilience research, a promising topic for future resilience research concerns the challenge of uncovering resilience traps and neutralizing the ecological and societal damage and injustice done through the reinforcement of AI technologies in governance processes like digitally based service provision or humanitarian interventions in the Global South.~~

5. Conclusion

In the social sciences, resilience to climate change is a concept that is incorporated in different theoretical approaches that are linked to contrasting scientific approaches. Holling originally reinterpreted and incorporated the ~~good old~~ notion of resilience in his SES approach, which was then picked up by naturalist scientists and embedded ~~who incorporated Holling'"s reinterpretation of resilience in their own~~ in cybernetic complexity theory, for instance. The complexity theory was for a very long time the preferred approach to resilience to climate change in the social sciences. ~~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.~~ This situation changed as resilience increasingly became the theme of political discourses and policies some decade ago, especially ~~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, and ~~climate crises,~~ pandemics~~, governance failures, and the breakdown of infrastructures,~~ - The instrumentalization and decontextualization of resilience by

local and global governance actors invited the critical response of scholars who often had recourse to constructivist approached. The diversification of resilience research and expansion of the social scientific jargon resulted from this development. The question of whether resilience should operate as a unifying paradigm is not yet settled. However, it may well facilitate interdisciplinary dialogue and even transdisciplinarity. Such cooperation or dialogue is arguably necessary given the extremely complex nature of our socio-ecological predicaments.

~~constructivist approaches developed to take resilience research far beyond complexity theory and associated methods. And it introduced a variety of new concepts for resilience research, such as the resilience discourse, myth of resilience, just resilience, resilience trap, transformative resilience, and transformational adaptation. Resilience cannot operate as a unifying paradigm, but it can facilitate the reconciliation of naturalism and constructivism. Thereby, the two contrasting scientific approaches can provide a liberating perspective on each other (without the one repressing the other) and brought into a theory-energizing tension with each other. Such reconciling – igniting theory-energizing tension – is needed for reimagining resilience to climate change and for specifying how.~~ New light may be shed on how new political-administrative institutions (including panarchical self-organization) and practices can respond in legitimate ways (taking~~en~~ justice and vulnerability considerations into account) to the challenges of climate change, in different ecological, political and technological contexts (cf. Johnsson et al., 2018).

The six themes for future resilience research that we have identified combine naturalist and constructivist insights and approaches so that human agency, reflexivity and considerations of justice and equity are incorporated into research that predominantly involves system thinking. In fact, further cooperation is the first identified research theme. Interdisciplinary and multidisciplinarity between naturalist and constructivist approaches and the many varieties of these approaches can prove to be challenging, not only because of clashing methodologies and conceptual frameworks, but also because of institutional factors. Yet, there have been attempts to reduce the gap between these approaches, without destroying a fruitful tension. The second research area could be called ~~'~~"critical resilience~~'~~"

research. It includes questioning the very concept of resilience and proposing alternatives or supplementary concepts. Such critical resilience research will most probably be a complement to, or necessary component of, other resilience research. The third theme consists in the contextualization of resilience research, which serves the multiple purposes of effectiveness (of measures), sustainability and justice. The interaction between, as well as the blurry line, between adaption (adaptive resilience) and transformation (transformative resilience) is the fourth research area. Related to the latter topic is research focusing on the two-way relationship between the phasing out of unsustainable systems and societal transformations. Given the increasing incorporation of AI technologies in resilience research and policies, a fifth research topic pertains to the implications of AI technologies for societies, and more specifically, for sustainability and justice. The final theme is the integration of various forms of justice (such as inter-racial) and theories of justice into resilience research.

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