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1. Introduction

The German Committee Future Earth (Deutsches Komitee für Nachhaltigkeitsforschung in Future Earth, DKN) is an independent scientific advisory body of the German Research Foundation (DFG). At the same time, it is the national contact point and platform for developments and activities within the international research program for global sustainability "Future Earth" and the "World Climate Research Programme" (WCRP).

The DKN fosters interdisciplinary, integrative sustainability research in both a national and international context and thus promotes cooperation between the disciplines. It also offers to the German scientific community a platform for exchange and networking related to sustainability research and promotes its further development.

With this position paper the DKN highlights pertinent research gaps and suggests forthcoming fields of research. It combines insights from global environmental change research and the environmental social sciences and humanities. This programmatic framework will form the basis of the future work program of the committee itself. Furthermore, it is hoped that it will motivate other scientists to engage across disciplinary boundaries with the manifold epistemological, theoretical, and methodological challenges of sustainability science. This contribution addresses agents in science, science management, and science funding in a national and an international context.

An earlier version of this paper was discussed at the German Sustainability Science Summit 2021 (German Committee Future Earth, 2021). Comments from these discussions are added as an appendix of this publication.

The paper consists of six chapters on different research areas, each followed by open research questions (RQs). Chapter 2 (“Approaches and goals of sustainability research”, RQs on page 9) discusses the foundations for sustainability research as an essential takeoff point of the work within DKN. Following this discussion of the different conceptual approaches, chapter 3 (“How to attain sustainable development? Transformative change is key”, RQs on page 12) focuses on different trajectories regarding how to attain sustainable development. Chapter 4 (“Scales as challenges in climate change, adaptation, and sustainable development research”, RQs on page 15) discusses challenges regarding spatial, temporal and functional scales as cross-cutting topics. Chapter 5 (“Extreme events and resilience: relations to human health, well-being and social cohesion”, RQs on page 20) treats interlinkages, synergies and tradeoffs between extreme events, societal resilience, individual health and well-being, and social cohesion for designing pathways towards the Sustainable Development Goals. Linkages between biodiversity, food production, human nutrition, dietary behavior and health are discussed in chapter 6 (“Food systems, biodiversity, and health”, RQs on page 22) and in chapter 7 (“Dietary transformations towards sustainability”, RQs on page 24). The paper closes with a chapter on conclusions and outlook.

2. Approaches and goals of sustainability research

Sustainability implies a notion of the future as it ought to be ("the future we want", according to the final document of the UN Summit on Sustainable Development in Rio de Janeiro 2012). Such a future should be a common one, as the World Commission on Environment and Development (WCED) document "Our common future" emphasizes (Brundtland, 1987). This suggests a consensual conceptualization of "mankind". The slogan "the future we want" stipulates a global "we" which is not a given, but rather a postulate being supposed by the Sustainable Development Goal (SDG) process. Skeptics may see this postulate as being overly idealistic or simply illusionary. Others bemoan that the global "we" conveniently glances over major differences in power and economic wealth and opportunities to articulate ideas in a global future-making process. We regard the assertion conveyed by "we" as an empathetic, caring, and responsible shorthand for "humanity", and link this with norms and values that are foundational for sustainability research as an essential take-off point for our work within DKN. Its normativity is firmly based on environmental ethics, theories of intergenerational justice, and future ethics (Ott, 2014) – philosophical traditions with deep roots in Western thinking and pertinent parallels in non-Western philosophies. Reflective scrutiny with respect to evaluations, recommendations, and policy advice is required to transparently distinguish between facts and values as well as between academic aspiration and political standards.

Sustainability research develops the scientific basis for solutions to real-world problems, for transdisciplinary collaboration with societal actors, and for participatory research. It can also contribute to practically and empirically substantiating ethical concepts for dealing with sustainability problems. Participatory research formats, such as citizens' juries or stakeholder workshops, make use of local and indigenous knowledge, both factual and normative. Such knowledge is localized, embodied, based on trial and error, and often stored in narratives and rituals. As yet, it is an open question how to translate indigenous knowledge and bring it into dialogue with Westernized scientific bodies of knowledge. Sustainability research has to engage in formats that aspire to understand epistemic differences and sameness (Verran, 2002; IPBES, 2019) between Western knowledge claims at the one end and indigenous ones at the other. At the same time, we have to be sensitive to the pitfalls intrinsic to trans-cultural communication about nature, about sustainability, and about environmental futures.

The normative orientation becomes especially relevant if sustainability research studies the sustainability transformation demanded by the "UN Sustainable Development Agenda". Here, sustainability research is about nudging, incentives, and motives, but also about structures and societal inertia due to habits and customs. It asks how a transformation toward sustainable development might be implemented, mainstreamed, and accelerated. It supposes some theoretical assumptions and framings of the fabric of modern society. But are these ideas adequate to understand socio-ecological challenges in the 21st century? We argue that many theoretical framings of modern societies ("risk society", "knowledge society", "event society", "multiple option society", "acceleration society") remain too shallow and need to be further developed towards a socio-ecological understanding of modern societies, and following established standards of theory-building. Coupled models of environmental and societal human systems are economically biased. Culture, gender, religion, community life, customs etc. are habitually absent from these models. Studies in cultural anthropology and archaeology are under-represented. The broad discourse in cultural anthropology has not found yet its way into sustainability research. Hence, theoretical reflections on a transcultural and transdisciplinary approach to a holistic understanding of sustainability are deemed necessary. As much as it is necessary to reflect upon the phenomenological dimensions of sustainability research, it is also mandatory to critically engage with its history.

The idea of sustainability has a long tradition. The word "Nachhaltigkeit" was coined in 1713 in a book on forestry, written by von Carlowitz (Carlowitz, 1713). According to von Carlowitz, harvesting timber should be allowed only within the limits of the natural growth of trees. Such a constraint was justified with respect to the legitimate interests of future generations. Thomas Jefferson made a famous statement in 1789: "The Earth belongs in usufruct to the living". Jefferson only considered current living humans in

this respect. The concept of "usufructus" (German: "Nießbrauch") indicates the same basic idea: to hold a substance intact over time while consuming only the flow of resources stemming from such substance (Soentgen, 2016). Sustainability has been conceived as an ethical idea for the economics of natural resources. Thus, sustainability was seen as a conceptual constraint over the long-term use of natural resources, seen as living funds. In the 19th century, the sustainability concept was applied to fertile soils by Justus von Liebig and to marine resources by Karl August Möbius. Later it became a key idea within the many environmental movements in Germany before 1914, as "Naturdenkmalpflege", "Wandervogel", "Lebensreform", "Gartenstadt", and "Heimatschutz". The idea of sustainability was then lost during the decades of warfare, revolution, civil wars, and genocides. It was marginalized in the post-war decades of GDP growth, consumerism, and welfare states. Its renaissance originated in the environmental movements of the 1960s. Recognizing limits to growth (Club of Rome) implied the idea of living (well) within natural limits (today: planetary boundaries).

In 1987, WCED launched its report "Our Common Future" as the outcome of several years of inquiry and debate (Brundtland, 1987). The WCED mission was to reconcile growing environmental concerns (pollution, extinction of species, desertification etc.) with the ideas of progress, development, wealth, and growth in a postcolonial age and within a "Cold War" between competing super-powers. Members of this commission were deeply divided ideologically on almost all matters of substance. Finally, the WCED reached a common moral denominator: basic needs of poor humans should be fulfilled first. From this "basic needs" approach the most famous definition of sustainability was coined: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs". The term "compromising" refers to risks and to the precautionary principle. This uncompromised ability might constitute a constraint on present overuse of natural resources. Under this "needs" constraint, however, the WCED favored an even more intensive utilization of natural resources in order to meet human needs and aspirations. WCED shifted the idea of sustainability from a more conservationist paradigm to a more humanitarian and social-justice paradigm. The WCED definition was prominent within UN circles and it was adopted at the Rio summit in 1992. The SDGs are clearly in line with the WCED's definition. They combine a "green" version of "catch-up" development with a recognition of global environmental threats such as the extinction of species. While the WCED clearly posits poverty as a major cause of ecological degradation, the SDGs state the need to halt climate change and terrestrial as well as maritime biodiversity loss. Seite

The divide between the old tradition and the recent history of sustainability is also reflected within the more theoretical debates. In theory, there are several conceptual approaches (or framings) which go beyond this dichotomy. We focus on three of them: the first builds on strong sustainability, the second is a refined economic concept of inclusive wealth, and the third is the SDG approach.

Strong Sustainability

At the level of ethical grounding, strong sustainability adopts three sources of normativity, as a) environmental ethics, b) theories of justice, and c) cultural belief systems that posit an interdependence between humans and the rest of the living and non-living natural world. While a) and b) are based in theoretical ethics, c) refers to moral convictions and cultural traditions. All three sources are seen as paying special attention to environmental legacies within an infinite chain of generations. An axiologically robust and richly textured ("deep") anthropocentric environmental ethics can be combined with a Rawlsian approach to justice because Rawls included a principle of fair inter-temporal legacy in his theory. If this principle is chosen "behind a veil of ignorance" (Rawls, 1971) but substantiated with respect to environmental values (or ecosystem services) a case for a constant natural-capital rule can be made. A Rawlsian approach postulates a safe minimum for each member of a system of cooperation ("principle of difference").

At the conceptual level, strong sustainability focuses on stocks (or funds) of natural capitals as they change over time, for better or worse. Since strong sustainability casts doubts on the economic hope that natural capitals might be substitutable by human-made or human capital, it adopts the rule of holding natural capital (at least) constant over time. This constant natural-capital rule is specified to a set of management rules. This set includes a rule that we should invest in natural capitals if such capitals have been depleted in the past. This investment rule demands recovery and restoration of degraded ecosystems, protection of viable populations of species, and even the creation of new wilderness areas. It demands a physical degrowth of the industrial throughput. Strong sustainability is rule-based. The rules

are reflected in the moral guidelines of a) consistency of economics within boundaries, b) resilience of land-use systems, and c) (more) sufficiency in cultural lifestyles and patterns of consumption. Strong sustainability is close to the original idea of Aldo Leopold's "land ethics" (Leopold, 1949), as it seeks to sustain the fertility/productivity, resilience, and diversity/richness of terrestrial and marine systems for the sake of future generations (and, perhaps, for the flourishing of sentient beings within their habitats). Strong sustainability is open to non-anthropocentric concepts of inherent moral values in nature. It might ban whaling, while allowing fisheries. Probably, there are deep cultural differences in beliefs about how humans should treat non-human beings properly, whether grading moral values is permissible, and where to draw the lines of the moral community. One should note that any natural being to which inherent moral value is attributed counts as an individual being and not just as unit within a fund of living natural capital.

The concept of inclusive wealth

The concept of inclusive wealth distinguishes different kinds of capital, based on the general notion that capitals are stocks that yield flows, which provide direct or indirect services to humans. The concept of capital does not imply specific property-rights regimes. Various kinds of capital include a) human-made (produced, manufactured) capital, b) human capital, c) natural capital. To these are sometimes added: d) health capital, e) social capital (e.g. beneficial social networks) and/or f) institutional capital (social cohesion, governance etc.). Different capitals change over time via production, renewal, consumption, and depreciation. In modern times, human-made and human capital have been developed, often at the expense of natural capital (UNEP, 2018) (see Fig. 1).

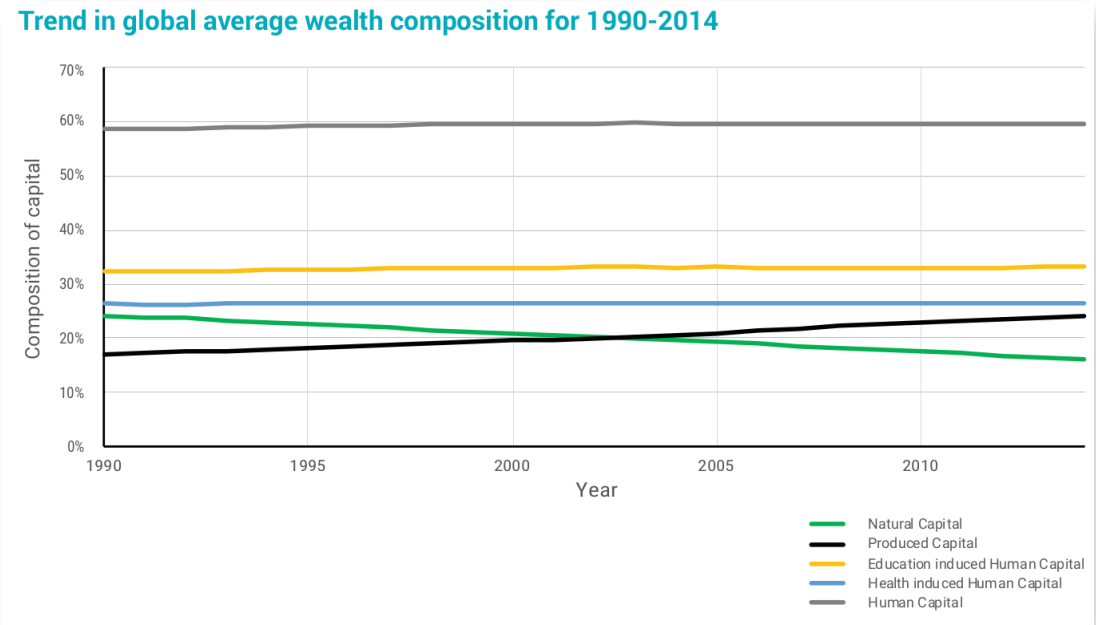

Fig. 1: Trends in different forms of capital, expressed as shares of the total social value of all capital stocks (UNEP, 2018).

From such theoretical assumptions on different forms of capital the program of sustained inclusive wealth emerges: use and invest in capitals as to maximize the inclusive wealth of all humans over time (to infinity). This program is usually based on discounted utilitarianism as an underlying ethical theory (Arrow et al., 2003), and sometimes on maximin (Cairns & Martinet, 2014). Its strength (according to proponents) is that it allows a substitution between different kinds of capital if such substitution would increase human welfare. Sustainability requires that the overall stock, in terms of social value, of capital should not diminish over time, allowing for substitution and compensation across different types of capital. The inclusive-wealth approach can be operationalized by the measure of inclusive (also termed genuine, or comprehensive) savings. For this, the social value of each capital stock is determined as its marginal contribution to aggregate social welfare, and conditional on the assumptions about future patterns of

consumption and investments into the different capital stocks. Quantification of these values is often based on economic valuation studies that explore people's actual preferences for ecosystem services, climate protection, and other conservationist objectives. According to the inclusive-savings measure, a country is sustainable if the aggregate net savings are always positive. If a precautionary principle or basic (subsistence) needs are adopted with respect to critical natural capitals, the inclusive-wealth concept converges towards strong sustainability (Baumgärtner et al., 2017). If the degree of substitutability, however, is assumed to be high, and if the rate of discount remains high, the inclusive-wealth concept collapses into the original concept of weak sustainability that allowed the depletion of natural capitals if investment rates into human-made and social capital remain high. Factories, airports, hospitals, and universities can compensate the loss of nature.

The SDG Approach

The SDG approach supposes a series of entitlements for all present and future humans. All humans are entitled to the basic prerequisites for a decent and flourishing human life. The SDG approach is grounded in theories of social justice, such as are found in Martha Nussbaum's and Amartya Sen's capability approach. The capability approach is grounded in an ethics of moral entitlements of all human beings to actualize their specific capabilities. On such ethical grounds, the SDG concept asks questions about prerequisites for and obstacles to universal human well-being. Such "entitlements to prerequisites" are specified by SDGs targeting the eradication of (absolute) poverty, malnourishment, illiteracy, and insufficient water provision and sanitation. Access to health services and to modern energy supply shall be provided. Other SDGs refer to desirable objectives, such as reduced inequality (within and in between nations) and just gender relations, and also economic growth, employment, decent work, improved infrastructures etc. Nature-related SDGs are seen as being just as crucial as the social ones because nature is a prerequisite for human existence. If access to freshwater supply and sanitation schemes are regarded as a humanitarian SDG, then three SDGs refer directly to nature: SDGs 13 (Climate action), 14 (Life below water), and 15 (Life on land). SDG 6 (Clean water and sanitation) integrates social and environmental goals, since it mentions protection of aquatic ecosystems and provision of freshwater for humans. With some generosity, such integration may also hold for SDG 12 (Responsible consumption and production).

The 17 SDGs are specified in more than 100 targets and sets of indicators. The relationship between different SDGs and their targets may be a) supportive, b) neutral, or c) contrary. By way of example: universal access to affordable modern energy (cheap electricity worldwide, SDG 7) clearly contradicts ceteris paribus the goal of limiting mean global warming to well below 2°C (SDG 13). Improvement of infrastructures impairs restoration of coastal ecosystems. Other targets look inaccessible, such as that of halving the number of traffic casualties worldwide within a few years. The SDGs continue the classical promise of modernity on the global scale: "improved life prospects for all". They demand that no human being should be left behind on the way towards sustainable development. The time span given within which to reach the many targets is very short (by 2030). Future research should not only address single SDGs individually, but focus on the many conflicts between and synergies across SDGs and theoretical concepts of sustainability.

Research questions

- What is the relation between specific SDGs and theoretical concepts of sustainability? Can strong sustainability, inclusive wealth, and the SDG approach be synthesized and reconciled, or must one decide between competing paradigms?
- How can the many conflicts between and synergies across SDGs and theoretical concepts of sustainability be identified and assessed? Which ethical theories of moral conflicts and dilemmas apply to this relationship? Do different cultures and levels of wealth allow for different priorities?
- How can matters of distributive justice be integrated in the maintenance, restoration, and utilization of natural capitals? Should justice search for ideal solutions ("ideal global justice"), or solutions which are regarded as being "fair enough" by most participants?

3. How to attain sustainable development? Transformative change is key

Given the quite different concepts of sustainability, it is not surprising that highly divergent approaches are discussed regarding how to achieve sustainable development. The SDGs are formulated in the United Nations 2030 Sustainable Development Agenda, which is titled "Transforming our world". The agenda reflects the strong influence of the idea of transformative change towards sustainability (Patterson et al., 2017). The idea is that societies will have to undergo a radical transformation, including major technological and social innovations in order to reach a path of sustainable development. The idea of a system shift is linked to the concept of complex socio-ecological systems that can cross thresholds into completely new development trajectories (Folke et al., 2010). A transformation means an enduring and substantial change of basic societal institutions, technologies, and cultural patterns. Historical examples of such transformative system shifts were the Neolithic Revolution, the decline of the Roman Empire, the colonization of America, Africa and vast parts of Asia, the Industrial Revolution and the Great Acceleration. Environmental history and historical ecology may contribute to sustainability science by asking how the harsh, repressive, and violent sides of historical transformations have been avoided in past settings, in order to address the forthcoming necessary transformation towards sustainability.

An important aspect of transformative change is the vision of a new social contract with global dimensions and a new common identity of humankind. Part of this is the idea of a new contract of generations that includes ecological sustainability as a key element (Dao et al., 2017). Such noble ethical ideas, however, must be implemented under non-ideal conditions. As a matter of brute fact, "humankind" is not a large family, and states do not form a global community ("Staatengemeinschaft"). From an ethical point of view, the tradition of contract theories (Hobbes, Locke) is at some pains to explain why rational agents should enter contracts which are not advantageous to them. Fictional ideal contracts do not bind real people. How, then, may ideals of international justice be actualized in the face of geopolitical strategies of competing powerful states, as the US, China and Russia and unions of states struggling for internal cohesion (the European Union, the African Union) on the one hand and failed states and/or utterly impoverished states on the other hand?

The ideas of degrowth and sufficiency belong to the transformative dimension. They focus on material consumption, with the gross domestic product (GDP) as the main indicator, and call for an end to economic growth (Dasgupta, 2021). Ott (2012) distinguishes four variants of degrowth (DG). The first variant (DG-1) scrutinizes GDP as a measure for wealth, happiness, and successful politics. DG-1 wishes to replace GDP with synthetic indicators of human well-being. The second variant (DG-2) is based on strong sustainability. DG-2 argues that it is mandatory to reduce the material and energetic throughput of the economic system. The third variant (DG-3) emphasizes the need for deep cultural change in terms of lifestyles, habits, and recognition. The fourth variant (DG-4) claims that capitalism and sustainability are incompatible. Under this assumption, transformation toward sustainability requires that we overcome essential features of capitalistic modes of production. DG-4 opposes concepts of "green growth". All concepts of sustainability (SDG, inclusive wealth, strong sustainability) can endorse DG-1, DG-2, and DG-3. A nuanced and critical debate about DG-4 is beyond the scope of this paper.

The proponents of the inclusive-wealth framework suggest that the focus on degrowth in terms of GDP is not the right point of reference, but that the aim should rather be to achieve positive, inclusive net investments (Dasgupta, 2021). As a point of reference, the "United Nations Inclusive Wealth Project" computes the total value of capital stocks for the world and for individual countries (UNEP, 2018). The United Nations are also working on the System of Environmental Economic Accounting to include non-market values of environmental goods and services in national accounting procedures (https://seea.un.org). According to both strong sustainability and inclusive wealth, one must distinguish between physical and economic degrowth. Empirical research into how physical degrowth is related to GDP and how strong rebound effects really are is necessary. The prospects for "decoupling" strategies should be researched more closely because degrowth theorists rigidly reject them as illusionary (Paech, 2012). If they are right, inclusive wealth is not sufficient for a transformation to sustainability. If so, a

transformation must affect lifestyles and habits deeply and a cultural revolution towards decommercialized ways of life is mandatory. Such a revolution, however, might compromise current systems of social security (health, pensions, social transfers). Research is needed into how transformations support the establishment and maintenance of resilient social-security systems.

Conceptually in line with the inclusive-wealth approach to sustainability are the ideas of the "green economy" and the "green new deal", according to which policy measures such as taxing pollution should help to push the world's economies toward a more sustainable path. A key element in this regard is the call for a price on greenhouse gas emissions, for example by means of a carbon tax or by a comprehensive emissions trading system. As there is no global governance system, however, such approaches face serious limitations for global sustainability issues such as climate change or biodiversity loss.

Despite their conceptual differences the proponents of the outlined three paradigms should strive for agreement on important specific aspects of how to achieve a sustainable society and economy, nationally and globally, that require specific research. We highlight five examples that all refer to different aspects of organization of policy action to achieve sustainability (understanding that this is a process with no foreseeable end point that aims at substantial and lasting rather than incremental improvements). In all five examples research on transformation or transformative research – i.e. research that is directly involved in transformation processes via participation or innovation – are key elements of sustainability research.

First, (non-)sustainability is a result of local and global socio-ecological processes and their interactions. From the perspective of transformation, policies that influence or shape these processes and interactions need to be better understood. Research is needed therefore on the interactions between policies at the local, the regional and the global level; on the effects of inconsistent or openly contradictory policies at these levels; and on the effects of policy voids at the global, regional or local level. Examples of this are the bottom-up approach adopted to mitigate climate change under the Paris Agreement, and the implementation process of the 2030 Agenda, including the importance of the mechanisms and fora introduced for reporting, evaluating, and reviewing.

Second, transformation processes as such need to be better understood. The question is what pushes them, what slows them down, and what prevents them from emerging at all. It is vital to investigate when disasters, extreme events or prolonged extraordinary situations such as the COVID-19 pandemic turn into "windows of opportunity" for change, and when they severely reduce a society's or a polity's capacity to act. Research is needed on the importance of social cohesion for a society's vulnerability, its resilience, and its capacity to engage in change. Also, the specific influences of natural factors (such as exposure to climate change), socio-economic levels of development, and institutional capacities need to be taken into account. It would be sensible, for example, to analyze the contrast between Costa Rica, the first country to commit to becoming a zero-carbon society, and Australia, which has much larger scientific and financial resources but chooses to ignore climate change. To address such comparisons, suitable comparative methodologies need to be developed.

Third, research is needed to discern valid ethical criteria for designing policies and other "solutions" for achieving sustainability, how these criteria relate to people's ideas of attractive futures, who needs to agree on such criteria, and how they can be achieved. Furthermore, we need to better understand how these criteria accommodate notions of universal distributive justice or fairness (in terms of time and space, humans and other living species) and how they can be incorporated into local, national, and global processes of decision-making and action. Other questions also need to be addressed, such as: what traditions of thought and practice exist regarding collective action, the relationship between the individual and the collective, and boundaries of the collective? And: which traditions of thought and practice across the world can show a way forward to answer the previous questions practically? Furthermore, it is vital to discover how the more theoretical top-down approaches to sustainability be reconciled with local (and indigenous) knowledge, cultural and religious traditions which follow a "bottom-up" logic ("local agendas").

Fourth, a characteristic feature of sustainability problems is their complexity: they have multiple roots, and their solution requires systemic approaches. However, such systemic approaches are at loggerheads with the current division of labor between policy fields and ministries (and scientific disciplines). The rationale for policy-making in a modern state is based on a specific and narrow understanding of effectiveness which governs each policy field: the best societal impact, so the assumption goes, results

as a whole if each policy field and its main institutions pursue a reduced set of goals and rational action that relate to specific sectors of society, and use specific instruments to achieve them. From this perspective, coordination and cooperation across policy fields (as required by 21st-century real-world problems) is considered pointless, onerous, and cumbersome. Research is therefore needed to gain a better understanding of where coordination is most relevant and productive, and to identify approaches that build on and reform existing patterns of division of labor. Thought models that have attempted to do this with regard to implementing the 2030 Agenda and its 17 SDGs include the 2019 Global Sustainable Development Report (Independent Group of Scientists appointed by the Secretary-General, 2019) and an approach developed by a team of authors associated with SDSN and The World in 2050 initiative (www.twi2050.org) (Sachs et al., 2019).

Fifth, there is the question of how to distribute the burdens of transformations. Any substantial transformation will imply opportunity costs and it will affect the entire system of relative prices. This would be true even if prices were politicized. Higher prices for specific consumption goods (energy, meat, transport etc.) affect the budgets of low-income households unevenly. This effect runs counter to all concepts of justice which oppose burdening the poor. If it is taken for granted that it is unfair to burden persons living in absolute poverty, it is less clear whether it is always unfair to burden relatively poor people in a transformation. Would it be fair if the relatively poor were to be relieved of (all or most) burdens which would then have to be borne disproportionally by the wealthier strata of global society? This problem occurs at different scales. There should be more macro-economic research on proposals as to whether and, if so, how burdens borne by the poor might be compensated by additional transfers, tradable permits etc.

Research questions

- What are the social and economic opportunity costs associated with different approaches to sustainability policy and how are they distributed? What are criteria for distributing costs fairly (over time and space)?
- What are the impacts of national sustainability policies on other countries, and globally? What requirements does globalization place on sustainability policies; to what degree is globalization compatible with sustainable patterns of production and consumption? What opportunities reside in reducing globalization?
- Natural capitals are collective goods, but the collectives are mostly particular states and communities. Are persons morally entitled to enjoy collective natural goods of other political entities? Are there duties to share collective goods with the rest of humanity? Might this repeat the “tragedy of open access”?

4. Scales as challenges in climate change, adaptation, and sustainable development research

Spatial, temporal, and functional scales have been a prominent topic in transformation research. However, less attention has been given to these issues as a cross-cutting topic. We argue that attention to scales is a key issue for better research on global environmental change and sustainability transformation. In brief: global problems cannot be understood let alone addressed without an intimate understanding of local dynamics. Nor can local problems be addressed without an in-depth understanding of multi-scale linkages.

Within the broader scientific discourse regarding climate change, vulnerability, and adaptation, including issues of resilience-building, transformation, and green recovery (after COVID-19), scales are not a priority topic yet. Concepts, assessments, and tools, however, are often directly and indirectly linked with questions of spatial, temporal, and functional scales. While there is evidence regarding the fact that present levels of greenhouse gas emissions pose a threat to human security, and increasing global warming increases climate-related risks to unique and threatened systems as well as to food security, health, and biodiversity, little information exists about shifts in risk, vulnerability, and exposure patterns linked to different spatial and temporal scales. Even though global assessments and models confirm that an increase in the global mean temperature of 2°C will push many ecological and socio-ecological systems towards tipping points beyond their adaptive capacity (Coninck et al., 2018), there is still a knowledge gap regarding the speed of potential changes at different spatial and temporal scales and their mutual interdependencies.

In addition, concepts such as " planetary boundaries" (WBGU, 2011) often focus on physical or natural systems, while sustainability research in the context of climate-change research requires a deeper understanding of different types of tipping points also linked to social, environmental, and coupled social-environmental systems. Thus, research on the nexus of climate-change mitigation, adaptation, and sustainable development needs a more integrative perspective that accounts for boundaries and tipping points of both natural/physical systems and human/social systems, including those of coupled socio-ecological systems. The discussion of boundaries or even tipping points also needs to be addressed for different temporal, spatial, and functional scales.

Furthermore, investigating synergies and tradeoffs between climate-change mitigation and adaptation strategies as well as sustainable development goals is an emerging research field, particularly the context regarding enabling conditions and tools that help to reduce vulnerability and risk. While synergies and tradeoffs between mitigation, adaptation, and sustainable development can be assessed with an abstract approach at the global level, there is also a need to examine how these synergies and tradeoffs materialize at different spatial scales, for example within larger geographic regions, nations and communities, and with regard to different temporal scales. This scientific discussion is also linked to research that examines the feasibility and effectiveness of different strategies and tools in the context of climate-change mitigation, adaptation, and sustainable development (e.g. Singh et al., 2020). Even though this research field is still emerging in the context of climate-change and sustainable-development research, there is a need to complement this research with a stronger understanding on how different spatial and temporal scales influence feasibility and effectiveness.

While, for example, one effective individual adaptation strategy to reduce increasing heat stress in cities is the installation of air-conditioning, this strategy – once applied at a large scale – could lead to a significant increase in greenhouse gas emissions and to increasing outdoor temperatures within cities (intensification of the urban heat island effect). Thus, the discourse about enabling conditions and the feasibility and effectiveness of different strategies and tools in the context of climate change and sustainable development needs to address the knowledge gap regarding scales.

More research is also required on how to link different knowledge types, data, and methods between scales. At present, global models and local models often remain in their respective niches, and coupling processes and dynamics between natural/physical phenomena and social or societal aspects still remain fragmented and disconnected within most research approaches.

In the last decades modeling approaches in sustainability and climate research have made significant progress concerning the sensitivity to cross-scale linkages. In many cases, however, these approaches focus on physical or human systems only, and often at a specific spatial scale. Knowledge gaps and mismatches remain, for example, with regard to how to better link questions of climate-change mitigation, adaptation and societal development – including sustainable development considering and acknowledging different scales. For example, in climate-change adaptation research, scenarios for climate change are used to estimate future consequences of climatic change for people or land-use systems, e.g., examining consequences of such change in 20, 30, 50 and 100 years at different temperature levels. These scenarios do not sufficiently account for socio-economic or societal changes within the same period, which makes conclusions about risks or resilience and the feasibility and effectiveness of specific strategies and tools difficult. It is very unlikely that demographic, socio-economic, or physical structures within a nation or city will remain the same, hence future assessments about impacts of climate change need to account for such societal developments in addition to physical climatic changes. More exchange is needed between research communities working on different spatial scales.

To correct such shortcomings, new methods have been developed to better link climate change and greenhouse-gas emission scenarios with socio-economic development patterns that affect the adaptive capacity of societies (pathway narratives, indicators, and new models) (O'Neill et al., 2017). For pathway narratives that focus on or remain primarily at the global scale, such as the Shared Economic Pathways, downscaling is in part possible, but raises concerns and reveals various limitations. Hence, integrated assessment models are important and can bridge gaps, but more research is needed on how to develop new tools and how to combine different methods that can complement these global assessments and models with more local or meso-scale information considering different types of knowledge (including participatory approaches at the local scale).

Linking different spatial and temporal scales also requires a special focus on urban regions, since urbanization will significantly influence sustainable development, adaptation options, and human vulnerability and risk. Particularly in the context of climate change, new dependencies and emerging shifts of functional scales between cities and their hinterlands, e.g. in terms of environmental services such as water or cold air streams, need to be considered as important research objects to better understand different interactions and challenges between scales (local–provincial). Assessments and models that aim to inform urban development or urban design and infrastructure policies of cities in a changing climate therefore need a better link to micro-, meso- and macro-scale approaches.

Against this background sustainability research needs to strengthen an integrated perspective linking societal and environmental perspectives and assessment and modeling approaches, especially in cross-cutting research fields (e.g. resilience of urban regions, settlement and transport development or specific tools, as well as freshwater supply, forestry, and biodiversity) that are able to connect climate-change mitigation, adaptation, and sustainable development.

Consequently, sustainability research has to improve our understanding of how physical phenomena and environmental change manifest within a changing climate, but at the same time it must provide more knowledge regarding the differential consequences at various spatial and temporal scales and on how societal changes (e.g. issues of inequality, adaptive capacities) influence future impacts on societies.

Scales and justice or just transitions

While there is a high level of agreement and evidence that the bulk of greenhouse gas emissions has been emitted by industrialized countries in the Global North, the most severe adverse impacts of climate change are felt at present, and most likely will continue to be felt in the future, in less-developed countries or countries in transition in the Global South. However, there is less agreement when it comes to the question of how to measure and operationalize environmental or climate justice and how questions of justice are related to spatial as well as temporal scales. Climate justice, for example is a wicked problem, because it includes duties to curb domestic emissions, principles of how to divide remaining carbon budgets, duties to assist poor nations to adapt ("adaptation financing"), duties to compensate loss and

damage, duties to comply with the Paris agreement, and duties to remove carbon dioxide from the atmosphere.

Furthermore, next to the global discourse about climate justice and just transition in the context of climate change, there is a need to further enhance assessment tools to account for such aspects at national or sub-national scales. For example, in Germany the concept and goal of equal or just living conditions in all parts of Germany (Gleichwertige Lebensverhältnisse) is an important norm for the provision of federal financial support for regions that show a significantly lower level of development or infrastructure provision. The principle of equal living conditions has to face many societal and economic inequalities, cultural diversity, and even natural heterogeneities at national and sub-national level. Indicators used do not sufficiently account for environmental qualities, environmental pollution, or negative consequences of climate change. Thus, the ethical profile of different approaches in the field of environmental justice must be reflected and assessed. How can egalitarian principles be specified at different scales with respect to different resources, capabilities, and cultures? How to account for cultural diversity?

At the global scale, living conditions have slightly improved according to the Human Development Index and SDG sub-targets (at least before the COVID-19 pandemic). However, the wealth gap within societies also increased in many countries and regions. Thus, new assessment types are needed to account for these differences at various scales.

Overall, ethical issues and issues of justice or just transitions with a scale-sensitive perspective need to be integrated in interdisciplinary research on how to better account for climate-change mitigation, adaptation needs, and sustainable development at different spatial and temporal scales.

More integrative research is needed to inform the assessment of feasibility and effectiveness of different tools to prevent adverse consequences of climate change and to improve knowledge on how to best achieve the SDGs. There needs to be more research that aims at downscaling and which incorporates different knowledge types and methods to capture these dynamics. Also, questions regarding how to better account for the persistence of certain structures – for example, within the built environment, or in terms of structural inequality in societies – have to be raised. A purely theoretical-conceptual discourse about transformation or transformative adaptation will not be sufficient for research for sustainable development in the light of climate and societal change.

Research questions

- What are the differential consequences of climate and societal change at various spatial and temporal scales, and how can we approach cross-scale dynamics productively?
- What is the role of spatial, temporal, and functional scales in terms of determining the feasibility and effectiveness of strategies?
- How to methodologically address mismatches between scales in present model and assessment approaches that aim to inform adaptation and sustainable development? How can top-down approaches in research (global models) and bottom-up knowledge and methods about particular environments be synthesized and linked?
- How to consider issues of justice in different approaches to deal with climate change and adaptation at (and across) different spatial and temporal scales?

5. Extreme events and resilience: relations to human health, well-being and social cohesion

Climate-change projections indicate that climate extreme events will become more frequent and/or more intense (IPCC, 2012). Recent research shows that the preparedness to respond to extreme events is intensely linked with social cohesion. Hence, it is essential to ask how extreme events, individual health and well-being, and social cohesion are linked in a systemic way. Reaching SDG 3 (Good health and well-being) requires dynamic processes of socio-ecological transitions across different interlinked scales of social and ecological organization. Often such transitions are challenged by extreme events, as e.g. evidenced by recent hurricanes, droughts, floods, and certainly also by the current COVID-19 pandemic. We specifically ask how sustainable socio-ecological transformation is affected by interactions between four entities: extreme events, societal resilience, individual health and well-being, and social cohesion (see Fig.2).

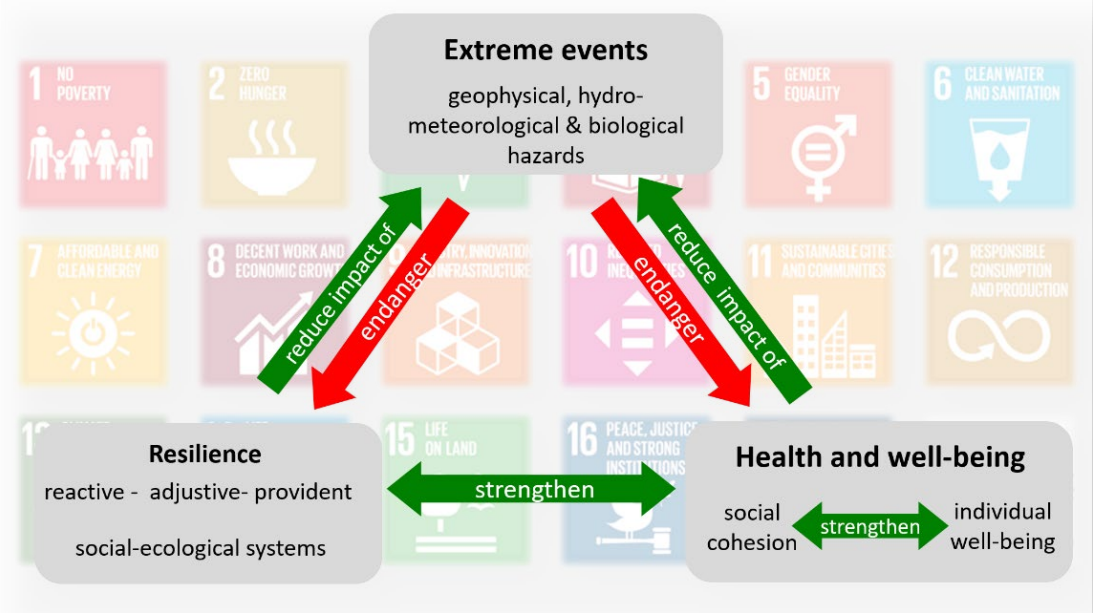

Fig. 2: Interactions of extreme events, resilience, social cohesion and individual well-being. Hypothesized direct effects of one element on the others are indicated in the arrows, while indirect effects can be derived as corollaries.

Research has shown a close linkage between socio-ecological resilience and a range of capacities, from knowledge to technology and finance. We hypothesize that social cohesion is an essential but grossly under-researched further condition to provide resilience in the face of extreme events. The essential source of social cohesion is a common belief in the legitimacy and trustworthiness of the central normative institutions (constitution, input-legitimacy, output-legitimacy, jurisprudence, administration). Extreme events can either weaken or strengthen social cohesion. They can also be used to support authoritarian policies in the name of the common good. Further, extreme events probe the vulnerability of social cohesion and unveil further vulnerabilities (relating to inequality, marginalization, elite isolation, lack of political participation etc.) that may lead to damage or (partial) collapse.

It is important to recognise that dynamics unfolding between extreme events and health and well-being may be sudden and fast in, e.g., catastrophic events, but may also be reached through slow processes through a variety of behavioral/psychological and social pathways that involve increased exposure to stressors, diminished coping resources, and constrained possibilities for restoration (Hartig et al., 2003)

Yet extreme events may also open the opportunity for transformational change. Dynamic adaptaptive processes may help to strengthen linkages between health and well-being and resilience in a changing climate. We also suggest that societies with a high degree of social cohesion may react in more resilient ways when challenged by extreme events.

Extreme events

We define extreme events generally as temporarily extraordinary conditions, which have a strong impact on the functioning or behavior of a system (Broska et al., 2020). The time scale of "temporarily" can range from minutes (e.g. tornado, earthquake) to multi-decadal (e.g. megadroughts). The latter are often called slow-onset events. Spatial scales affected can also vary from local to global scales (Fig. 3). The abnormal conditions can be internal or external to the system. An atmospheric heatwave is an external extreme event affecting ecosystems, or e.g. the health system of a city. System-internal events could range from pathogen outbreaks within a forest to a financial crisis within an economic system. While the differentiation between internal and external is useful, it is not always sharp and depends on the definition of the system boundary. In addition, external events can trigger internal events (Frank et al., 2015). Last but not least, an apparently external event can become more likely via internal processes; e.g. an atmospheric heatwave is external, but has become more likely through anthropogenic climate change.

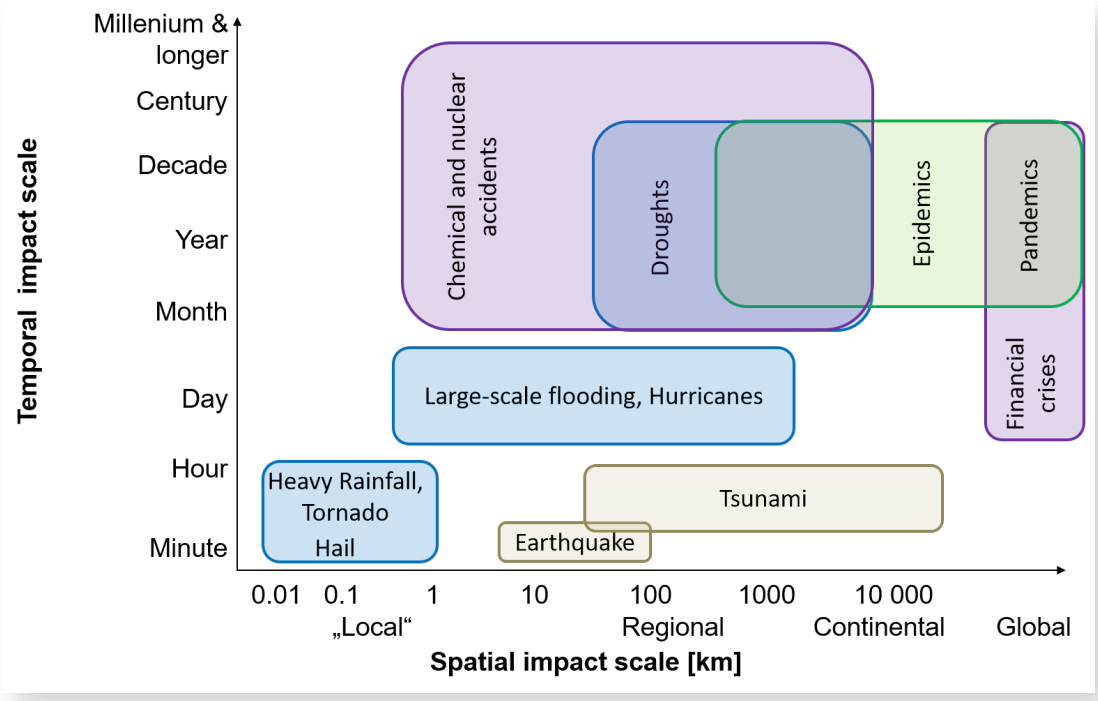

Fig.3: Examples of extreme events across temporal and spatial scales.

We consider extreme climate events, disasters, and emergent risks in the context of global climate, environmental, and societal change. Such extreme events are becoming increasingly critical and a potential major threat to sustainable development (Reichstein et al., 2021). Climate, environmental and societal change alter the frequencies and intensities of extreme events, rendering acquired knowledge less useful. In addition, also societal exposure and vulnerability are changing given socio-cultural transformations and developments. We further allege that extreme events, or rather our perceptions

thereof, are culturally framed. Cultural codes, religious beliefs, and historical experiences influence pathways of analysis, evaluation, and meaning to actors experiencing such events as social and personal crises.

Resilience

We define resilience as the degree to which a system is able to continue on a targeted path towards sustainable development after an extreme event. Resilient socio-ecological systems are well-buffered against consequences of extreme events, ensuring the well-being of actors within those systems (Bollig, 2014). Resilience mechanisms have recently been characterized across three distinctive decision contexts and time horizons (Weise et al. 2019):

1. reactive, when threats are imminent and there is a high pressure to act (e.g., when a climate extreme has struck);
2. adjustive, when the nature of the threat is known in general and appropriate time is available to adapt management, e.g. projected increased flooding due to heavy rainfalls or alternatively increased likelihood of heat waves and droughts and effects on agriculture; and
3. provident, when the threats are not well understood, or are even unknown, and long-term horizons have to be considered, e.g. thawing of permafrost soils or potential reversal of ocean currents.

Resilience as such is deeply rooted in the material infrastructure and the socio-cultural framing of socio-ecological systems. Environmental and social capacities and capabilities are decisive for the resilience of social collectives and individual actors. This comprises the willingness to plan and act for resilience. This willingness can be high for reactive decision contexts in critical short-term situations, but is often low for provident long-term decision contexts. It is crucial, for transformation processes towards resilience, to include the learning from experiences in future scenarios and informed decision-making processes.

Individual health and well-being

The WHO (1948) defines health as “a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity”. According to this definition, there was hardly any healthy person ever. In the philosophy of medicine, this definition is widely rejected. To include “social well-being” in the definition does not make sense from a medical perspective. The most common approach to human health sees a healthy state as a range between critical points which should be defined according to evidence-based medicine. A bedrock of such the WHO’s definition of health is not only the focus on factors that cause disease (pathogenesis), but also those factors that promote health and well-being (salutogenesis), where individual well-being relates to physical, mental and social conditions (Naci et al., 2015). Abiotic extreme events can impact severely on both ecosystems and societies and thereby on health and well-being. Here, biodiversity and nature-based solutions can play a role in mitigating and adapting to e.g. climate change (Kabisch et al., 2017) and foster both individual and public health (Marselle et al., 2019). Here, we will focus on the determinants and outcomes of social health and well-being, with a focus on the linkages of social cohesion and individual well-being (Fig. 4).

Social Cohesion

Research on social cohesion, and theorizing about the causes and consequences of social cohesion have a long history in the social sciences. Such earlier research and theory development is currently re-evaluated and connected to the manifold challenges of a rapidly globalizing world (Chan et al., 2006; Dragolov et al. 2016; Fonseca et al. 2019). What holds societies together and what guarantees their transgenerational existence in the face of multilevel shocks and crises has been of keen concern for generations of sociologists, and is of crucial interest once again at the beginning of the 21st century. In recent decades, research on social cohesion has culminated in an interest in cooperation. While social cohesion asks for a societal-system perspective, interest in cooperation is focused on individual motivation to cooperate and on institutions that facilitate or hinder such cooperation. While the question of how social cohesion is generated and maintained has been a central concern of the social sciences, the question of how resilience and social cohesion are related is innovative, and inextricably related to concerns about our path towards well-being and health.

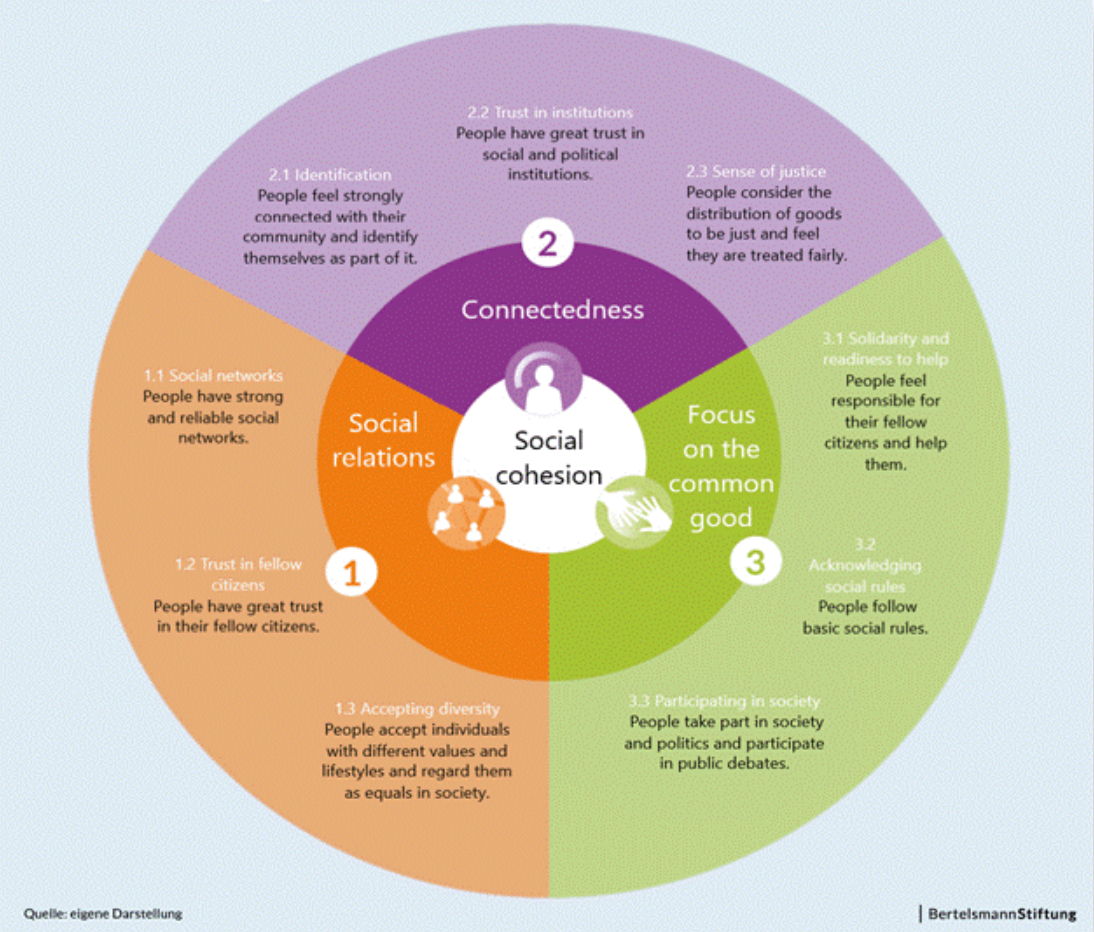

Fig. 4: Aspects of social cohesion in different dimensions (Bertelsmann Stiftung, 2017)

Three key aspects of social cohesion are differentiated (Fig. 4) (Bertelsmann Stiftung, 2017):

1. relatedness: degree of identification with society, trust in social institutions, sense of justice;
2. connectedness: social relations including strength of social ties, trust in fellow human beings, acceptance of social diversity;
3. focus on a public good: solidarity and cooperativeness, acceptance of social norms, social participation.

Research questions

- What impacts on social and individual well-being are expected to be caused by extreme climate events, including risks emerging from compound events and cascades of impacts and feedbacks across ecosystems, infrastructures, and society?
- What are key challenges to resilience across different sectors and SDGs, while facing extreme events?
- How are resilience and social cohesion mutually interlinked, and how does this change in the case of extreme events?
- How to compare and measure degrees of social cohesion and resilience across countries?
- Resilience mechanisms entail costs and benefits. Is it essential that such costs and benefits are distributed in a just manner to provide for social cohesion ("resilience justice")?
- How do extreme events, resilience and tipping points relate to each other? Can tipping points be identified for a complex compound concept such as social cohesion at all?

6. Food systems, biodiversity, and health

Food systems on the one hand and individual dietary behavior on the other hand are two sides of the same coin. They are paradigmatic cases for studying the conceptual connectivities between sustainability, scales, social cohesion, health, well-being, and extreme events. Food provision is fundamental for human health and well-being. At the same time food production is a key driver for the deterioration of biodiversity in terrestrial, aquatic, and marine ecosystems. Food production, human nutrition, and biodiversity management are intricately linked across different local and global scales. The linkages between biodiversity, diet, and health are little understood, and management of biodiversity conservation and food production often seems decoupled (Phalan et al., 2011; Tscharntke et al., 2012). Too often, recommendations for a sustainable diet are related to single issues, such as an agricultural production system (for example, organic farming versus conventional farming) or to a specific type of food. It is evident that the global food system, including food production and its impact on biodiversity, water and soils, and consumption is in a crisis and transformation toward sustainability is urgently needed to maintain or restore both human health and productive, resilient, and diverse ecosystems. A holistic approach to decent environmental conditions, animal welfare, and proper human nutrition across systems (e.g. One Health, Schneider et al., 2019) allows for the development of sustainable solutions to maintaining functioning ecosystems that support life on earth and our human population.

In their recent report, the German Advisory Council on Global Change (WBGU, 2020) recognizes a "trilemma" of land use where three global and interlinked crises are involved: the climate crisis, the crisis of biodiversity, and the crisis of the global food system. The destruction, degradation, and fragmentation of terrestrial ecosystems accelerate climate change, trigger the loss of biodiversity, and affect food security. Already 20% of the global area under cultivation is experiencing decreasing or stressed productivity (Cherlet et al., 2018). Moreover, Huang et al. (2020) find that with continued global warming the total area of land facing increased risk of desertification will strongly increase. The global loss of biodiversity and associated losses of nature's vital contributions to people, which together embody biodiversity and ecosystem functions and services (Díaz et al., 2018; Pascual et al., 2017), have been highlighted by the recent Global Assessment of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2019). We live in an era of mass extinction of species and unprecedented loss of biotic diversity. The most important direct and indirect drivers of biodiversity change are land-use changes, climate change, and environmental contamination. The efforts that have to be undertaken to cope with one of the above-mentioned three crises can lead to unintended effects that impact upon the others.

Current land use is a main contributor to global biodiversity loss as well as climate change. Greenhouse-gas emissions in agriculture have increased over decades, mainly because of the increase of livestock farming, enhanced fertilizer utilization, and the spatial expansion of rice production (IPCC, 2019). Also in Europe, agriculture contributes significantly to land-based greenhouse-gas emissions, two thirds of which are generated through livestock production. The Common Agriculture Policy (CAP) of the European Union so far does not sufficiently contribute to the achievement of climate goals (Pe'er et al., 2019; Pe'er et al., 2020). Sustainable use of terrestrial, aquatic and marine systems, however, can also contribute to providing major greenhouse-gas sinks in soils, biomass, and oceans. Land-use systems should therefore strive to achieve zero net emissions to halt further climate change (Rogelj et al., 2018).

Much of the current land use is driven by food production. The prevailing global nutrition system requires excessive water use, and results in increasing water pollution, deforestation, and consumption of ecologically valuable areas as well as loss of biodiversity. Despite extremely resource-intensive agro-industries, a sufficient and healthy diet is not available for everybody. A diversification of diet, which is desirable for health reasons, would, however, lead to a further increase in the demand for agricultural land, since comparable yields of fruit trees or vegetables require more land areas than similar yields of grain (WBAE & WBW, 2020). The "Lancet Commission on Obesity" describes a systemic relationship between problems of overeating and malnutrition on the one hand and environmental problems on the other hand (Swinburn et al., 2019). Against this background some authors (Garnett & Godfray, 2012; Pretty & Bharucha, 2018) call for a "sustainable intensification" of land use. The WBGU (WBGU, 2020)

recommends a systemic turn-around of land use that focuses on restoration, expansion of protected areas up to 30% of the global land surface, diversification of agricultural systems, transformation of dietary styles, and strengthening of bioeconomy. Fostering maintenance and creation of a mosaic of natural habitats, supporting small-scale farming (including 2 billions of smallholders, i.e. 83% of all farmers, who form the pillars of food security), as well as promoting a diversity of cultivated crops agricultural landscapes, while enabling responsible supply chain control respecting human rights and biodiversity conservation for imported goods, can support biodiversity-friendly farming landscapes and sustainable food production systems (Tscharntke et al., 2021; Grass et al., 2021).

Sustainable management of land and soils, including the transformation of land-use systems, is therefore key to sustainability. Conservation, sustainable use and restoration of ecosystems are the necessary preconditions for protecting biodiversity and climate and for building sustainable nutrition systems (IPBES, 2018).

Research questions

- What transformations of land-use systems will enable us to cope with the climate crisis, the biodiversity crisis, and, linked to this, the crisis of the global food system?
- How can transformation combine biodiversity conservation, restoration, and sustainable use and sustainable intensification of land use to maintain functioning ecosystems and sustainable food provision?
- Since the Common Agriculture Policy (CAP) is a main driver of land use in Europe: how can the CAP be adapted to the objective of making the EU a net-zero-emissions system in 2050, and what role can nature-based solutions play within such adaptation processes?
- How can we design governance processes to guide the transformation such that land-use conflicts and socio-economic conflicts can be resolved to foster sustainable diets, biodiversity conservation, and climate-change mitigation and adaptation?

7. Dietary transformations towards sustainability

Fostering global human nutrition and associated food production across the globe plays a central role in reaching the SDGs (Grosso et al., 2020). In addition to food production, major changes in human food consumption are necessary to stop degradation of biodiversity and soils to remain within the planetary boundaries (Willett et al., 2019). There are a number of aspects qualifying for a sustainable dietary approach, most important the move to a more plant-based diet (Burlingame et al., 2012). The planetary health diet for the first time described a hypothesis-driven dietary pattern to serve as a healthy diet across the world, which should also support sustainable land use (WMO, 2020). However, adherence may not support all aspects of a sustainable diet for all population groups and regions in the world (Zagmutt et al., 2019; Tuomisto, 2019). Sustainable diets are plant-based, yet the suggested dietary patterns are not suitable and practicable or easily adoptable for everyone and every region in the world. For instance, the triple burden of malnutrition means over-nutrition, but also under-nutrition and micronutrient deficiencies in low-income countries calling for dietary shifts meeting environmental and nutrient requirements under conditions of climate change to be further differentiated. Thus, research is needed to identify sustainable diets for different specific target groups. The practice of developing food-based dietary guidelines incorporating aspects of sustainability and individualization could help to come up with recommendations balancing nutrient requirements, disease prevention, and environmental health for target groups and regions across the globe (Tuomisto, 2019; Brown et al., 2020; Gazan et al., 2018).

The identification of key aspects suitable for change in dietary behavior as well as the identification of target population groups, along with the estimation of the influence of these changes on sustainability (environment and health) could be targets towards dietary transformation. Modelling research shows changes in diet only to be expected in parts of the population, and at the same time, that exchanging meat with other sources of protein in the diet can then only lead to moderate attenuation of the environmental impact of dietary intake (Gazan et al., 2018). Life-cycle assessment (Jones et al., 2016) measures the environmental impacts of foods, but the adoption of this approach to estimate the environmental impact of individual, self-selected diets is so far only feasible to a limited extent.

Little is known about how to achieve changes to more sustainable dietary patterns (Grosso et al., 2020). Here, an approach centred on individual behavioral choices, traditionally focusing on nutrition education, needs to be supplemented by more systemic approaches. As such, recent research shows that a particular focus needs to be placed on the facilitation of the “sustainable” choice as the “easy and default” choice for the consumer. A range of behavioral interventions must be offered, and simple awareness-raising falls short of exploiting the range of measures to engender behavioral change (Michie et al., 2014). A recent report emphasized the anchor points for action to achieve more sustainable nutrition in Germany (WBAE & WBW, 2016; Spiller et al., 2020) Here research is needed on measures to improve public facilities, develop land-use systems, and implement integrated policies across sectors for a more sustainable diet.

Discussion and research on the connection of environmental crises and nutrition to date often focuses on food security. Little is known about the relevance of crises for risk awareness and dietary patterns, both at the population and the individual level. Of interest is the effect of different spatio-temporal patterns of environmental changes in crises, e.g. of slow, long-term environmental change, as in climate change, versus sudden environmental changes, such as with regard to pandemics such as COVID-19. A greater understanding is needed of how different environmental changes or crises can catalyse short- and medium-term changes, particularly with respect to the individual and systemic alterations of diet and health patterns. From a point of view of land use and environmental planning as well as socio-ecological resilience, it would be of interest to investigate if specific socioeconomic groups identify the necessity for change (risk awareness) and options for change (capacities) – for instance, vulnerable groups like overweight individuals, individuals with disease, or the elderly. Here again, the individual level versus the systemic level needs to be differentiated to explore their potential to serve the transformation.

Research questions

- What governance systems and policy, planning, and practical instruments can serve a sustainable food production, sustainable storage and transportation, sustainable food consumption patterns, and associated reduction in food waste?
- What are the most effective starting points for transformation towards sustainable diets in different regions? How does a focus on individual behavior change compare in effectiveness to more systemic approaches at the population level?
- How can sustainable diets be tailored for different target groups? Which population groups should be addressed and how can different groups be reached properly?
- What are the potential synergies or trade-offs of sustainable diets and sustainable food production on other aspects of human health and well-being, such as quality of life in cities or social cohesion, as well as on biodiversity restoration and climate-change mitigation and adaption?
- What are the visible starting points for sustainability transformation via nature-based solutions (e.g. urban gardening) and their effects on the triangle of diet, health, and biodiversity?
- How can crises lead to a transformation in diet and health, e.g. via change in individual behavior or political restructuring?

8. Conclusions and outlook

This position paper has been developed over the past two years. It reflects discussions within the German Committee Future Earth and debates on the contents of the paper during the course of the German Sustainability Science Summit 2021 (German Committee Future Earth, 2021). Hence, the paper is conditioned by disciplinary biases of the committee members as much as it is framed by challenges brought about by the Coronavirus pandemic and a series of extreme, climatically induced events. We pinpoint a number of topics here that we consider to be of the greatest importance for research in the decade to come. Certainly, alternative topics would have been possible, and perfectly meaningful. Transitions towards alternative energy supply and transformations of mobility systems are key topics that need in-depth interdisciplinary research. On a global scale, alternative visions of a sustainable future (e.g. ecological civilization, conviviality) will be discussed with more fervor in future.

Notwithstanding these considerations we argue that key concepts relating to sustainability require constant reflection and probing. To what extent are they conditioned by political motivation and cultural background? Our paper offers a first insight into pertinent discussions on key concepts. It reflects upon the historical origins of key concepts and their development when taken into the context of the politics of global environmental governance. Above all, questions of justice (transgenerational, transnational etc.), now considered to be a key challenge of transitions towards sustainability, must be debated. There are a good number of promising approaches that directly address questions of justice. These need to be weighed and their practical impact requires evaluation. Perhaps too often we design new approaches towards sustainability without properly evaluating existing ones for their merits and weaknesses. We argue that the sustainability sciences at large should engage in both evaluation of existing theories and the development of new concepts at the same time. This effort must be addressed by international interdisciplinary consortia engaging scientists from the natural sciences, the social sciences and the humanities, arguing simultaneously from vantage points in different spatio-cultural settings. The capacity to both reflect and to aspire is crucial, as is a sensitivity to challenges related to scale. None of the issues raised in this position paper are strictly local or national. Key challenges to be addressed by communities and nations are necessarily embedded in global environmental changes and global social, economic and cultural dynamics. Cross-scalar linkages still present pertinent challenges to the sciences. Problems seem overtly complex when we need to research the details of multi-scalar linkages. While conceptually such linkages are well integrated into modeling approaches, to address them in empirical research and political action is still a key task of the sciences.

The paper then singles out three fields of research that address key challenges of sustainability research. Extreme events progressively challenge individual health and well-being as well as social cohesion. The resilience of coupled socio-ecological systems is probed by climatic perturbations, the effects of bioversity loss, and pollution. We need further research that seeks in-depth interdisciplinary understanding of the socio-ecological processes underlying transitions from extreme events to crises and catastrophe. In order to limit damage to both human and more-than-human well-being we need to reflect upon existing practices and patterns of resilience first of all. Our approaches to conceptualizing and designing socio-ecological resilience in the face of climate change must begin with a sober account of existing efforts, as much as these aims also require ambitious attempts to address the manifold challenges of the 21st century. In its two final paragraphs the position paper emphasizes that changes in food systems and dietary transformations are of crucial significance to address anthropogenic perturbations, steep biodiversity declines, and health. The key challenge here is to conduct research on these very issues, taking into account cross-scale interlinkages, impactful extreme events, and debates on justice at the same time. The position paper singles out a number of crucial and forward-looking questions that may guide research.

We hope to see concrete interdisciplinary programmes and projects arising from discussions sketched out in this paper. Such endeavors are necessarily interdisciplinary, involving scientists from different epistemic communities, and also transdisciplinary and participatory, involving decision-makers and civil society from the early phases to the reflection upon resulting theories.

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Comments

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TH Köln

Certain events are extreme not only on the hazard side but also in the sense that they can exhibit extremes within society. Many such events are rather creeping processes with a preparation phase long before an initiating event can reveal underlying root cause problems, nested interconnections, or impact chains. It is vital to analyse extreme events from the side of impact chains, too.

Certain impact chains can include escalation steps similar to the cascading effects of interdependent critical infrastructure failures. These escalations are a combination of an ongoing hazard process, coupled with a social amplification of a risk process. One example scenario of an escalation development is climate change as a creeping risk that is identified as a threat when extreme events emerge from droughts that trigger wildfires. When this hazard or threat development is then coupled with a societal escalation development such as, for example, a social unrest phenomenon, it can exhibit escalation steps similar to linear or complex cascading effects – for example, when a wildfire occurs in an area where people are already dissatisfied with the risk- and response management of their government in terms of COVID-19 measures. A first escalation step can occur when officials such as firefighters or paramedics are hindered in their wildfire operations by protests, road blockages or misinformation. This actually happened recently in Europe, for example, when COVID-19 patients were transported to another region or in the pluvial flood response operations in Germany in July 2021.

Based on this, I argue that more awareness, research and communication measures are necessary for a more reflective, risk-informed society. Extreme events must also be analysed concerning the societal impact chains and escalation steps. Regarding communication, the social amplification of the risk model can help to decode how a risk measure such as prescribing face masks for COVID-19 protection can lead to deferring reactions. Reactions can range from support and acceptance to competition and social unrest. Amplification and attenuation effects including feedback loops and additional ripple effects in this model show how these different impacts are generated, and offer leverage points for taking measures. Terminology and theoretical background are similar to research in the natural sciences and offer opportunities for integration and advancing research.

However, some caveats must be mentioned, too. Social cohesion should be included more consistently in research and in reactions mitigating extreme events. However, enforcing a streamlining of disaster-risk reduction could also inadvertently invoke social coercion or herd behavior, which then could trigger protests, especially when personal freedom is at stake. Unintended consequences must be observed when promoting „societal resilience“, such as stirring up societal resistance against official measures. One example is vaccination measures against a pandemic; while they increase society's overall resilience, some parts of society may protest against this measure. Hence, some concluding summaries on the caveats:

1. There is still a lack of scientific discussion on mal-resilience.
2. Likewise, critical reflection on cooperation and participation is missing.
3. Different political regimes may perceive “social cohesion” as a useful buzzword.
4. Calls for “transformative action” must be aware of political connotations.

But overall, it is an important call to unite research on extreme events with social cohesion aspects and focus on societal impact chains, too.

Helena Freitas

University of Coimbra

Despite the brutal expression of the pandemic and the evidence of its causes, an effective change in the global political and economic system is unlikely. But change is imposed and this perception has been reinforced by the effects of a year that has also been characterized by prolific dramatic climate news: a long heatwave in Siberia, record-breaking smoke clouds in Australia following major forest fires, the largest tropical storms ever recorded in the Atlantic, devastating fires in Brazil's Pantanal, the largest floods in Africa; devastating cyclones in India, the Philippines and Indonesia; the hottest summer in Northern-Hemisphere history, and temperature records in Antarctica and the Arctic. The relationship between world crises is obvious. Epidemiologists and conservationists argue that outbreaks of diseases such as the one we are currently experiencing - resulting from deforestation, global warming, the degradation of natural ecosystems - are increasingly likely to be at the origin of new epidemics.

The complexity of the global challenges we face is enormous, imposing a systemic, collaborative, and innovative approach. The well-known economist Mariana Mazzucato wrote that the pandemic has made more evident a structurally flawed economic system, in which jobs do not protect workers in difficulty and inequality is increasing: an absurd and transitive system that allows the rich to become richer and ignore impacts on life on the planet. Mazzucato challenges us to rethink the role of the state in the economy and society and, above all, to regain the sense of the public interest – a mission economy capable of responding to major global challenges. Global warming, pollution, dementia, and obesity are environmental, social and health problems, the complexity of which requires the design of equally complex solutions. It is essential to mobilize resources in a manner as bold and inspiring as the Apollo program did, but this time to respond to the problems of our time. This new mission – like the successful moon mission – will involve a profound change in institutions and governments, creating new models of corporate governance, and ensuring that companies, society, and governments come together to build solutions for common goals.

My hope is that the pandemic will change our collective priorities. We have the chance to prioritize what has proved truly important and necessary. Each of us will keep our memory, but as a society, it has become evident that there is a great need for a sound public-health system capable of responding to all; the pandemic has also highlighted the importance of supporting science, of recognizing climate change and addressing its consequences through a global approach, and of increasing effective political and social interest in reducing inequalities.

Human pressure on Earth is undermining and challenging the fundamental processes that support a habitable biosphere and the Earth system's resilience at a growing scale and increasing speed. It is not possible to continue promoting development at the expense of the destruction of nature. The 2030 agenda should inspire the way, responding to poverty, inequalities, human rights, education, health, and also ecosystems. We must be able to build other paradigms of progress, safeguarding a relationship of respect between the human being and life in general. Advancing human development while respecting planetary boundaries is now the most important challenge for humanity, and for science.

Christian Günner

Hamburg Wasser

Municipal utilities of general interest like HAMBURG WASSER continuously invest in long-lasting quality of service. This includes continuous repair and maintenance of existing assets for water and sewage, adapting plants and waterworks to new technical and ecological standards, and developing completely new services for surface-water management, energy self-sufficiency, watering of municipal and private green areas, and cooling of urban public spaces. A public company like HW manages assets of around 4 Bil. € and invests up to 150 Mio. €/a. In view of these huge sums, excellent services with qualified personnel are only possible because of very long depreciation rates for the assets of up to 100 a (e.g. sewers).

Along with the increasing population (2.1 Mio. inhabitants) and the continuous sealing of urban surfaces within the boundaries of Hamburg (~1 km²/a) over the last 200 years the length of pipes and sewers (~11,000 km), as well as the total value of assets has greatly increased. Due to this the continuous need for maintenance and repair has increased. Furthermore, climate change causes growing sea-level rise, endangering the central sewage treatment plant on the river Elbe, and also increases the probability of heavy rainfall events, causing devastating storm-water run-offs; the occurrence of heatwaves, dry periods and increasing soil temperatures can also be observed.

During the company's history over the last 170 years, global surface-temperature change has been very moderate, but if we consider the same time span starting from the present day and continuing into the projected future, we are confronted by a global temperature rise between 2° to 6°C depending on how successful the world's community is in de-carbonising all its living activities. Cities should become much more resilient and adapt to climate change before then. If we take into account that buildings, cities and infrastructures are built to last for at least 100 years, we should already have begun changing processes and procedures for planning and building of new development areas (e.g. Science City Bahrenfeld). We have to think about sustainable utilities right now! What does this mean for research approaches?

The future of water services in cities is very much dependent on the local political will and the ability of government administrations to accelerate their change processes and their decision-making. We are not able to predict what might happen in Hamburg in the year 2100, but we can develop realistic scenarios, taking into account all actual scientific knowledge (e.g. the IPCC report) and the next year's political goals of the local and national government in terms of climate protection, mitigation and adaptation. Additionally we use e.g. the worst- and the best-case scenarios. There is also a basic need for good services by utilities of general interest in the future. To make the right decisions for the transformation of these utilities, we would like the following questions to be answered:

- How should big cities like Hamburg (re-)organize co-operation and networking of cross-sectoral administrations and utilities for municipal services like power, heat, water, sewage, waste, public transport, data management and so on?
- How can material- and energy flows be simulated and managed from a common municipal point of view? What would be more suitable decision-making processes in German cities?
- Urban labs should be used for cross-sectoral R&D activities to be subsidized by local, regional and central governments; the focus should be on quick transfer and application.
- What does the national water strategy (from 2021/22) mean for the priorities of local governments and administrations in terms of decision-making and action?
- Scenarios should focus on necessary adaptations and change in services as well as the future legal, organizational and financial framework for these changes.
- One basic field of activities is the necessary change in dealing with data. Actual data about both the built world and about future plans, possible developments and future needs should be available across faculty boundaries. There is urgent need for holistic thinking and city-wide data management. Methods for participation based on improved data exchange are crucial.

Terry Hartig

Uppsala University

As I recall our discussion during the event, and building on the slides used during my presentation, I have three main comments on the paper. First, links between extreme events and health and well-being are not only as direct as suggested in the figure, but will work in pathways through aspects of everyday life in a residential context. These pathways will variously involve increased exposure to stressors, diminished coping resources, and constrained possibilities for restoration. For example, during a heatwave, family members may feel trapped together in a house, get on each other's nerves, and not take a walk in a nearby park as they would usually do when needing time alone.

Second, some extremes will be reached through slow rather than fast processes, and these will also work through a variety of behavioral/psychological and social pathways that involve increased stress, diminished coping resources, and constrained possibilities for restoration.

Third, the figure needs to communicate more clearly the understanding that resource dynamics are not limited to one component of the model strengthening the other. Our session moderator thought that the green arrows with reference to "strengthen" alone suffice for your purposes. I disagree. See adapted figure 5.

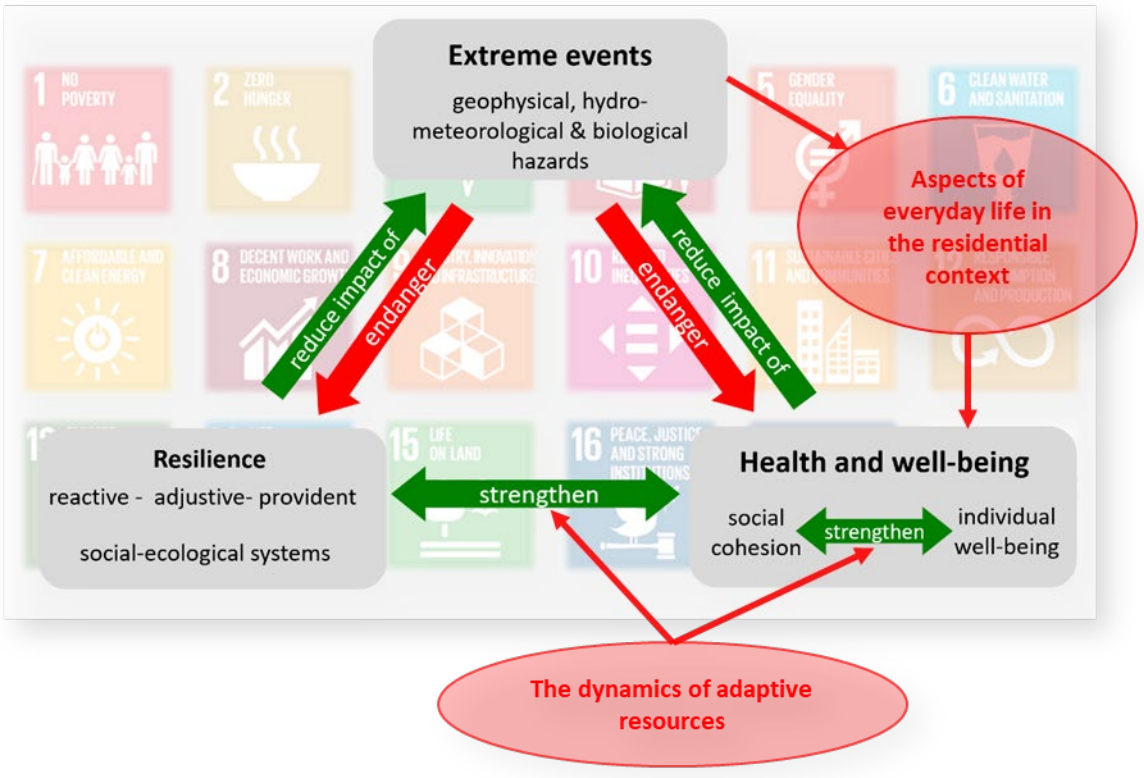

Fig. 5: Interactions of extreme events, resilience, social cohesion and individual well-being. Hypothesized direct effects of one element on the others are indicated in the arrows, while indirect effects can be derived as corollaries.

Melissa Leach

Institute of Development Studies

Sustainability is inherently a normative concept. If we are to take this seriously, and as recognised in the 2020 HDR on Human Development in the Anthropocene, we need to give further elaboration and attention to questions of equity in sustainability research and action, and to differences of wealth and power in future-making.

In Leach et al. (2018) we built on analysis in the 2016 World Social Science Report "Challenging Inequality: Pathways to a just world" to argue that there is both a moral and a pragmatic case for why equity matters to sustainability. The moral case is about fairness as a feature of a "good society" (the future we want); there may be different societal and cultural versions of this, although also a broad universality in terms of human rights. The pragmatic case is about inequity compromising the achievement of other societal or sustainability goals. Equity has seven dimensions: economic, social, cultural, political, spatial, environmental, and knowledge-based. They intersect to shape the experiences of particular groups toward marginalization or its opposite. Further, justice needs broader conceptualization beyond distributive justice to consider procedural and recognitional justice, all of which can operate intergenerationally, but also within generations. So in a sustainability policy process, we should ask: whose perspectives are recognized? Who has voice in decision-making? And therefore what are the distributional outcomes? And how does this feed back to shape recognition?

An integrated perspective considers how equity intersects with sustainability from small-scale to systems levels. "The future we want" can be conceived as a broad space of "equitable sustainability". There are many interactional dynamics through which sustainability may be achieved at the expense of equity (of different kinds), but also through which they may be pursued together, staying within the space. And there are multiple possible pathways within a broad space of equitable sustainability, which prioritize different versions of sustainability and equity (sustainability of what for whom).

Pathways (following Leach et al. 2010) are alternative trajectories of intervention and change, supported by narratives, entwined with politics and power. Choosing amongst these pathways is itself a normative act but also a political one, and a deliberative one. The implications are that sustainability research needs to:

- Challenge unsustainable and unjust pathways, appreciate and seek out alternatives
- Seek out equity-sustainability synergies, beware of and compensate for trade-offs
- Recognise multiple pathways, bottom-up as well as top-down, and across global, national, regional, local settings
- Attend to plurality – to respect and respond to diverse perspectives and contexts
- Foster inclusive debate around goals, and means to get there
- Challenge political and knowledge inequities – in debates and approaches that foster cognitive justice and leave no-one behind; i.e. equity and justice also in the process of research.

Furthermore, getting into and staying within a space of equitable sustainability will often require transformative, not incremental change. But how to conceptualize such transformations? Work by the STEPS Centre argues that this needs to combine perspectives on transition, and incentives, with deeper attention given to structural causes and power, and attention also to "enabling transformations" involving care and conviviality. Separately and together, these approaches offer opportunities and challenges for sustainability research which will need to be interdisciplinary, and often transdisciplinary and co-produced, and can draw on an ever richer methodological repertoire for normatively-oriented sustainability research aimed at building transformative pathways to equitable sustainability.

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Nynke Schulp

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The DKN position paper highlights that "A holistic approach to decent environmental conditions, animal welfare, and proper human nutrition across systems allows for the development of sustainable solutions to maintaining functioning ecosystems that support life on earth and our human population." I very much agree that such a holistic, or systems approach is key to solving the three crises (the climate crisis, the crisis of biodiversity, and the crisis of the global food system) that are addressed in the position paper. Several recent studies indeed emphasize that solutions across the food system are needed. For example, Clark et al. (2020) explore the contribution of plant-rich diets, reducing global per-capita consumption to a healthy level, closing yield gaps, reducing food loss and waste, and modifying management regimes to reduce their greenhouse-gas emission intensity. Through this analysis, Clark et al. (2020) show that meeting the 1.5-degree-Celsius target from the Paris Agreement, which is considered a prerequisite in dealing with the global climate crisis, requires ambitious changes throughout the global food system. With regard to the global biodiversity crisis, Leclère et al. (2020) show that an integrated strategy is needed to halt biodiversity loss. Only scenarios that address food supply, food demand, and increased conservation were, in their model simulation, able to bend biodiversity trends, and less holistic solutions fell short. Lee et al. (Lee et al., 2019) simulated the role of the European food system in land-based mitigation and found that meeting Europe's afforestation and reforestation targets can only be achieved with large-scale transformation of the European food system.

However, these solutions come with uncertainties and trade-offs. Biodiversity conservation for example might conflict with the rights of indigenous communities, (Leclère et al., 2020), and if action isn't taken on the right scale, consequences might be offshored (Fuchs et al., 2020). Also, sustainable agricultural strategies such as organic farming come with trade-offs regarding food access (Seufert and Ramankutty, 2017). Nevertheless, we have an approximate idea of the path towards a sustainable food system (Fig 6).

Fig. 6: Eefficient, mid-scale agriculture that follows the characteristics of the landscape and supports a plant-based diet.

A key avenue for future research is therefore how lifestyle change at the individual scale links to the global-scale challenges. But even more important is the question of how we can effect the changes required in the hearts and minds of the people. How can actors in the value chains be stimulated to prioritize deep sustainability goals over costs and profit? How can we move towards a food system that doesn't, as it has over the past 30 years, structurally overshoot the planetary boundaries (Fanning et al., 2021)? Stewardship for local food systems might contribute (Enthoven and Van den Broeck, 2021), or raising awareness about impacts and educating consumers and value-chain actors about their responsibility in global society (Bak-Coleman et al., 2021) and their impact on distant landscapes (Laroche et al., 2020). But most importantly, it requires a policy change. The recently proposed law that aims to reduce the EU's global impact on deforestation (https://www.europarl.europa.eu/legislative-train/theme-international-trade-inta/file-eu-driven-global-deforestation) is promising and might help to level the global playing field. Integration and alignment with the CAP is needed to keep the playing field level.

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Despite many regional and global initiatives in the last decades, global biodiversity losses are still dramatic, and agricultural intensification remains the main reason for this. We just left the UN decade on Biodiversity, started the decade on Ecosystem restoration (2021-2030), and we got behind COP15 in Kunming and COP 14 in Nagoya with, again, only very vague declarations of intent (COP 15 in Kunming 2021, after the COP 14 in Nagoya 2016). This is due to the contrasting interests of the involved parties and the conflicting challenges that must be overcome to achieve sustainability. Agriculture is a major driver of biodiversity losses, but global food demands are expected to double by 2050 due to population growth and increasing meat consumption. Further, the high level of natural-resource use by the Global North cannot be a model for the Global South (Steffen et al. 2015, Science), as the Planetary Boundaries have been already crossed (in particular for climate change, environmental pollution, loss of genetic resources). Aiming at "a good life for all" (Hickel 2019, Third World Quarterly), not only for the Global North, needs at least to halve our ecological footprint (and living standard). If all the people on earth were to live like US citizens (or Germans), we would need five (or three) planets respectively.

The EU is importing agricultural goods grown in an area of the size of Germany, but does not care abou the social, economic and ecological conditions of production. We do not care about importing soy from Brazil based on rainforest destruction and human-rights violation, or textiles from Ethiopia produced with famine wages despite the signed "UN Guiding Principles on Business and Human Rights" (2011), which are still not respected. We are accomplices in crimes perpetrated during the agricultural production of our import goods. Interestingly, and as a marginal note, we may rather look back towards Alexander von Humboldt, who lived in the Age of Enlightenment (enrolled as a student in Göttingen 1789/1790) and was the globally best-known scientist of his time. He was a citizen of the world and an anti-nationalist, was admired by Simon Bolivar for his commitment to freedom movements and for saving the unique biodiversity of South America, and he met Thomas Jefferson to criticize his racism. This makes him a convincing role model even for today.

In terms of sustainable biodiversity conservation in Central Europe, we should focus on creating a mosaic of natural habitats (>20%), small-scale farming (with fields far below 6ha) and a diversity of cultivated crops in our agricultural landscapes. This is key to promoting large-scale biodiversity in both conventional and organic agriculture. Landscape-wide biodiversity-friendly measures should be certified, which is unfortunately not the case under organic farming. Global responsibility means that we need to halve our ecological footprint, reduce food waste, support the 2 billion smallholders (83% of all farmers), who are the backbone of food security, and develop a responsible supply-chain control respecting human rights and biodiversity conservation for imported goods.

For more detail see Tscharntke et al. (2021) and Grass et al. (2021).

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Rafael Ziegler

HEC Montréal

This is a rich and detailed paper, bravo! In seven minutes of commentary, I cannot cover the many points it raises. In response to the question, I would like to 1) propose a distinction between political and scientific approaches to sustainability and its relevance for the discussion of "normativity of sustainability science"; and 2) based on this make some suggestions for research questions in relation to ethics of research and innovation in the Anthropocene.

1. Distinction between scientific and political approaches to sustainability

"Normativity" is not defined in the paper. In philosophy, "normative" refers to operators such as right or wrong, ought and may, typically associated with justice (whereas "evaluative" includes concepts and predicates such as good or bad, better or worse, desirable or undesirable, typically associated with well-being and the good life) (Christian and Valentini, 2016). The position paper seems to refer to "normativity" mostly in the justice sense, and I thus take it that "normativity of sustainability science" is primarily about the place of justice in sustainability science. "Sustainability" is a contested concept that brings together different societal actors who advance their interest using the concept (or arguing against it) and who propose sustainability conceptions and policies (Michael, 1999).

Distinguishing scientific conceptions of sustainability and political sustainability discourses. Conceptions of sustainability originate from science, for example economics and philosophy. For instance, the theory of strong sustainability (see page 7) draws on philosophical resources to justify intergenerational justice and the preservation of natural capital. Another example is inclusive wealth (page 8 ibid.). A political sustainability discourse is debated and legitimated by political actors and is typically a compromise. For example, the SDG are a set of 17 goals agreed on by the United Nations. While the boundary between scientific conceptions and political discourses is blurry, the position paper (in section 3) should more strictly differentiate between these two – since the distinction creates space for the "normativity of sustainability science" and the various roles it can take:

a) The role of critique: Scientific conceptions of sustainability are important to scrutinize and critically accompany political discourses and their compromises: are the SDG justified, coherent etc. (for example SDG 8 "promote… economic growth" is according to theories of justice a confusion of ends and means)? This helps to keep the SDG discussion critical and dynamic, an important role not least in the light of selective "SDG washing". Research questions are: what would be a critical reading of the SDG (including as a whole) from Rawlsian-strong sustainability, utilitarian, and, further, not only Western philosophical perspectives? What are the critical issues they highlight? What are areas of convergence and overlapping consensus? A methodological question is how to do this well: political discourses are by their nature compromises, so it makes little limited sense to judge them by the same criteria as other scientific conceptions, to present them in an unqualified manner as a matter of "competing paradigms" (page 9) or to claim that the SDG are grounded in the capabilities approach of Sen and Nussbaum (page 9, since already these two philosophers have quite different views; and capabilities scholars more generally vigorously debate pros and cons of SDGs, see for example the special issue of the International Journal of Human Development and Capabilities (2019)).

b) The role of technical knowledge: The position paper works with the Weberian fact-value distinction. Weber noted: "The question of the appropriateness of the means for achieving a given end is undoubtedly accessible to scientific analysis" (Weber, 1994). "Given" political "ends" (such as the SDG) and associated policies etc. can be explored, improved, criticized etc. – all in a way that does not cause headaches for social scientists who are usually afraid of being "normative"!

c) The role of reflexive sustainability scientists: but even if sustainability "goals" or "ends" are politically legitimated (and many of them are prima facie morally plausible and urgent), there will always be a need to reflect on the positionality and performativity of sustainability science (also in the light of the critical points in a) above). We need more space and recognition for scientists to leave their "value-neutral" comfort-zones. Better bringing together the first two roles (a and b) in reflexion could be a key outcome of this paper and its associated processes.

d) For reasons of space, I ignore further roles of sustainability science (Wittmayer and Schäpke, 2014) and the questions they raise (including adverse effect on career options of young scientists).

2. Suggestions for research questions on "normativity of sustainability science":

2.1. Further exploring normative conceptions

The Anthropocene and "beyond sustainability"? My impression is that increasingly researchers are rejecting "sustainability" as a "failed" concept, not worth the time, instead suggesting that "we should rather focus on a regenerative economy", etc.. There is an important, and also intergenerational, discussion, about the uses and limits of sustainability beyond comparing sustainability paradigms. Consider for example that the talk of planetary boundaries and staying in "safe space" sits oddly with the fact that in terms of biodiversity the evidence points in the direction of a 6th "mass extinction". I am personally not convinced by such critics so far, but I think it is an important discussion to be had.

Sufficientarian justice as an intrinsically and instrumentally important starting point: The discussion of planetary boundaries quickly leads to the point that these boundaries need to be complemented by an "inner" "social foundation" or "threshold" (for meeting basic needs, life in dignity, human rights). This resonates with the established basic-needs focus in sustainability discussion (page 7). A more recent addition is to put more focus on the fact that the wealth of some undermines the basic needs of many others (instrumental consequences of economic, political and environmental inequalities, see Robeyns (2017)) Such a renewed, sufficientarian starting point also might help to avoid problematic "progress" assumptions (ever more for all forever) that the position paper notes.

2.2. Overcoming consequences of normative bias

Values in sustainability science are also a matter of **the choice of objects/research focus** (another Weberian point) . . .

Transformation for structural change is called for but there is a danger that this reproduces prevailing categories. Examples from innovation research and economic development:

More research on **social innovation** as change in social practices is needed to make sure that the call for transformation becomes more than a repetition of ideas that have proven insufficient (e.g., technical innovation for green growth, see IPBES, (2019)).

More radically, social science can contribute a less biased stance beyond the prevailing pro-innovation bias by also seriously exploring **technical and social exnovation - that is, ending the use of some technologies and practices** (Ziegler, 2020)

Also, both conceptions presented in the paper put the emphasis on "capital" – but primarily as an outcome category, not a social category of **ownership**: Who owns various forms of capital? And how is this structural and organisational question linked to alternatives to the capitalist firm (starting with cooperatives)? Such questions seem practically absent from the paper.

Global dialogue: The paper cites two "Western" (by origin) conceptions of sustainability and the SDG. There is a need for more descriptive ethics to understand alternative visions of sustainability around the world, and (based on that?) a normative dialogue about overlaps and differences. The position paper makes this point at several instances. I just want to emphasis its importance (and the link to descriptive and normative ethics).

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Transdisciplinary research has become a central research approach and principle in the sustainability sciences. The aim is not only to understand the complex interrelationships of real-world problems and the major societal challenges of our time. Sustainability research is also motivated by a design mission, shaping a socio-ecological transformation. Science is not only expected to explain phenomena but also to provide orientation to handle sustainability challenges. Knowledge production in sustainability research is requested to interrelate descriptive, normative and practice-oriented forms of knowledge, therefore relying on approaches of science-practice collaborations. In addition to the search for and negotiation of "socially robust orientations", which are important results of transdisciplinary research processes, there is a great demand for knowledge on how a sustainability-oriented transformation can succeed in concrete terms.

As a consequence, more interventional and transformative approaches have been established alongside the transdisciplinary research approach, such as the "real-world labs" approach (e.g. Wanner et al. 2018) or transition management (Loorbach, 2007). These forms of transformative research aim to co-develop concrete solutions for real-world issues, implement, test and improve them and thus seek to create transformative impact. However, these modes of knowledge production are also accompanied by a changed role of science, new expectations, and various dimensions of normativity (see Scholz, 2017). More than ever, science embraces the role of a change agent. While in transdisciplinary processes science acts as a "public good" and "honest knowledge broker" or facilitator of societal learning, in transformative approaches, science has an accelerating function seeking to catalyse societal transformation and learning processes. Scientists directly intervene in real-world situations, purposefully changing processes and action and empowering local actors. In research practice, we increasingly observe that scientists are taking on activist roles, when they specifically and selectively work only with a very specific stakeholder group or bring in their own strongly normative world views.

So far, this shift in roles has received little critical consideration. In the future, it will be important to reflect on these different roles of scientists in sustainability research, to make them transparent, but also to critically question their legitimacy, to build up “normative competencies” and develop new approaches to deal with these normative dimensions.

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