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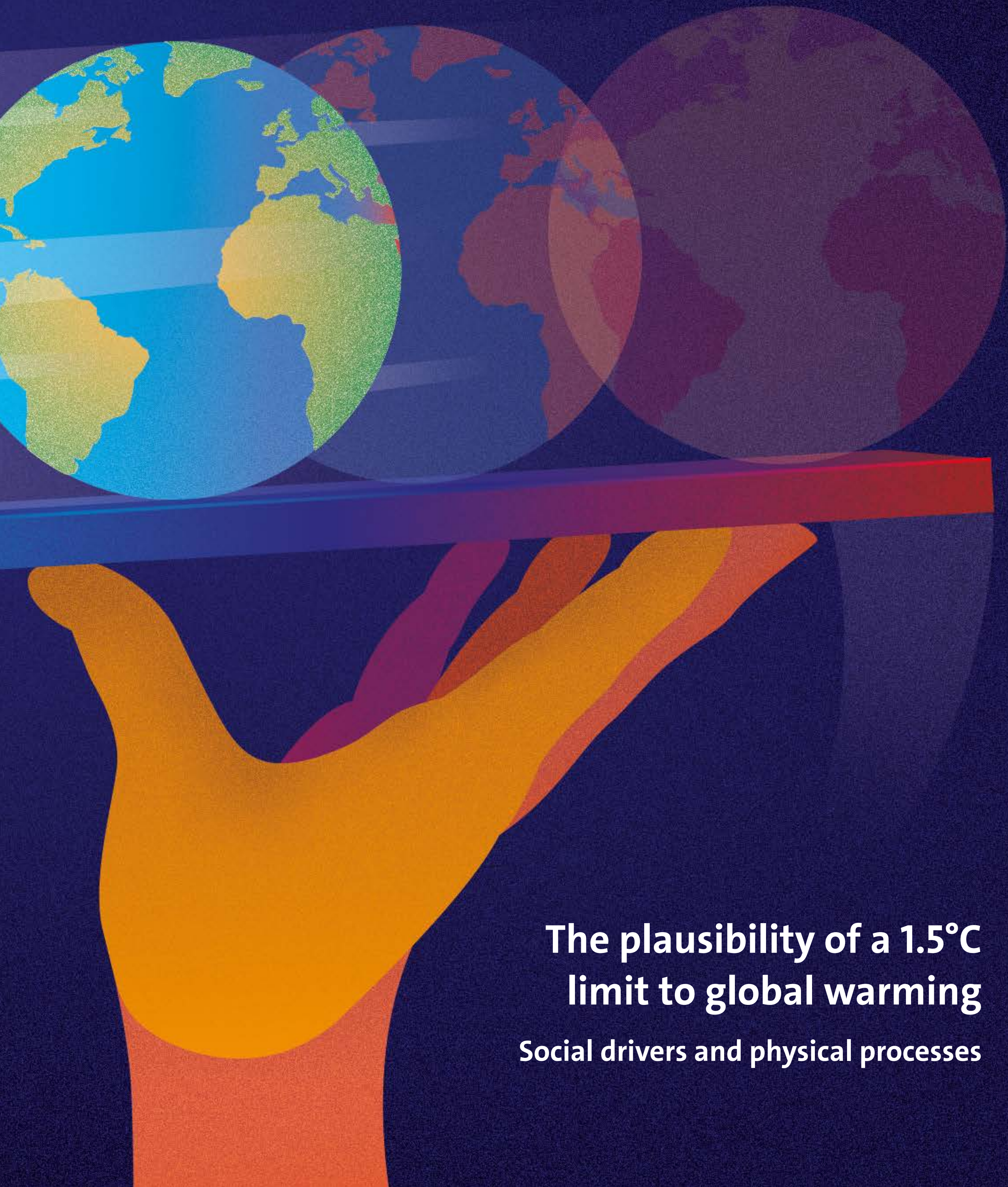
HAMBURG CLIMATE FUTURES OUTLOOK



The plausibility of a 1.5°C limit to global warming

Social drivers and physical processes

2

CLICCS Plausibility Assessment Framework

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CLICCS Plausibility Assessment Framework

2.1

An integrative approach to assess the plausibility of climate futures scenarios

Our understanding of climate futures combines changes in the physical climate system with how society changes with these. The social and physical worlds are inextricably intertwined as society influences the physical environment in countless ways. And simultaneously, physical processes create the frames in which social actors and drivers are able to evolve. We define these frames as *physical boundary conditions* for society. They are dynamic, and their changes are responses to human activities, the internal dynamics of physical processes, and climate sensitivity. Thus, we analyze climate futures in an integrative and interdisciplinary approach, which encompasses both the social and physical worlds. The central goal of our *Outlooks* is to identify climate futures that are not merely possible but also plausible, and this goal is even more demanding and requires a completely novel approach. The 2023 Outlook edition establishes a methodological framework that reflects both social and physical dynamics and discusses their interconnections and their implications for climate futures scenarios: the *CLICCS Plausibility Assessment Framework*.

Here in Chapter 2 we start by explaining what we mean by plausibility (Section 2.1.1), and to do so we briefly introduce the building blocks of the CLICCS Plausibility Assessment Framework (Section 2.1.2)—the Social and Physical Plausibility Assessment Frameworks—and describe the scenario context of the current Outlook (Section 2.1.3). In Section 2.2, we recall and update the Social Plausibility Assessment Framework (Aykut, Wiener et al., 2021). We introduce the concept of densification of the global opportunity structure as an analytical category that indicates the accumulation of resources and the formation of repertoires for climate action (Section 2.2.1). Then we present guiding questions for assessing the plausibility of one particular climate future scenario (Section 2.2.2). In Section 2.3, we present the novel Physical Plausibility Assessment Framework, which focuses on the dynamics of physical processes that may affect the plausibility of the climate future scenario defined in the current Outlook. To this end, the section presents the selection criteria of the physical processes assessed—we chose six processes that have a high impact on the physical boundary conditions for society, receive a large amount of public attention, or are difficult to assess due to fundamental uncertainties (Section 2.3.1). Finally, we present guiding questions for assessing these physical processes (Section 2.3.2).

2.1.1 Assessing the plausibility of climate futures under conditions of deep uncertainty

The CLICCS Plausibility Assessment Framework is a theoretical model to assess the plausibility of a selected climate future, based on empirical evidence. In this second Outlook, the framework is used to assess the plausibility of a climate future scenario that combines achieving the emissions goal and the temperature goal contained in the Paris Agreement (Section 2.1.3). The emissions goal is translated into the scenario of deep decarbonization by 2050 and is addressed by the Social Plausibility Assessment, whereas the temperature goal requires an additional Physical Plausibility Assessment. Combining social and physical plausibility assessments involves several epistemological challenges (Stammer et al., 2021a). The integration of social and physical assessments rests on very different and sometimes contrasting disciplinary approaches to probability and to climate futures. For example, traditionally, as in the IPCC, climate research refers to the probability that a certain climate future will occur, usually conditioned on a particular emissions scenario (e.g., Lee et al., 2021). In these cases, the physical plausibility can often be expressed probabilistically. Both possibility and plausibility are assessed in physical climate sciences on the basis of knowledge of deterministic and stochastic behavior of the climate system, the latter due to the fact that the climate can vary without any external influence (Stammer et al., 2021a). This approach, however, reaches its limit in the presence of deep uncertainty, which is a common challenge in physical and social sciences research. A sound engagement with assessments of climate futures has to acknowledge at least two different layers of uncertainty that are inherent to researching climate change and future dynamics both in the social and the natural sciences.

On the one hand, social and natural sciences address uncertainties arising from incomplete knowledge or a lack of information. This uncertainty can be reduced by learning, for instance, by gaining a better understanding of a process, collecting an ever larger amount of data, and improving methodologies. An example of this kind of uncertainty, which in the natural sciences is called *epistemic* uncertainty (e.g., Marotzke, 2019), is the equilibrium climate sensitivity (ECS). In the social world, this applies, for example, to the calculation of risk, which involves logical deduction and references to observed empirical patterns.

On the other hand, some uncertainties are insurmountable. In the social world, many types of incidents cannot be predicted at all, and this leads to situations of *deep*—in the sense of radical (Keynes, 1937) or fundamental (Dequech, 2000)—*uncertainty*. This lack of anticipatory capability does not stem from limited cognitive capabilities or from immature scientific tools, but from the recognition that social structures and processes are inherently contingent (Beckert, 1996). In situations of deep uncertainty, no objective and quantifiable methods exist to determine the probability of occurrence (Knight, 1921). “Uncertainty is understood as the character of situations in which agents cannot anticipate the outcome of a decision and cannot assign probabilities to the outcome” (Beckert, 1996, p. 804). The essence of this argument is that in situations of deep uncertainty, a probabilistic formulation is not possible, so that individual decision-making, and even more so assessing futures, need to be based on other methodologies.

The natural sciences define deep uncertainty in a similar way. In the IPCC WGI AR6 Glossary, a situation of *deep uncertainty* is defined as the state in which “experts or stakeholders do not know or cannot agree on: (1) appropriate conceptual models that describe relationships among key driving forces in a system; (2) the probability distributions used to represent uncertainty about key variables and parameters; and/or (3) how to weigh and value desirable alternative outcomes” (IPCC, 2021a, AR6 WGI Glossary, p.2253). Unlike deep uncertainties in the social sciences, deep uncertainty in the natural sciences can be reduced by learning. Examples of deeply uncertain processes in the Earth system are the Marine Ice Sheet Instability and the Marine Ice Cliff Instability, which both affect the Antarctic ice sheet (e.g., Fox-Kemper et al., 2021; see Section 6.2.3).

The natural sciences also have to deal with a type of uncertainty that is insurmountable or, as it is sometimes called, *irreducible* (e.g., Marotzke, 2019). This *aleatoric* uncertainty arises from chaotic processes in weather and climate, processes that are deterministic but that so sensitively depend on the prior state of the weather or climate system that they are unpredictable beyond a certain time horizon and can thus be treated as if they were stochastic (e.g., Marotzke and Forster, 2015). It is this *internal climate variability* that leads to aleatoric uncertainty, which cannot be reduced by further learning but can at best be accurately quantified (e.g., Marotzke, 2019; Lee et al., 2021).

The complexity of deep uncertainty of climate futures is enshrined in the entanglement of physical processes and probabilities. At this point, it may, for example, be impossible to estimate when a tipping point is reached, and possible futures of social dynamics cannot be assigned a probability value but only be analyzed on the grounds of past and present contexts. Even though social dynamics and some physical elements of the climate system are veiled in deep uncertainty, using the CLICCS Plausibility Assessment Framework we can still assess the plausibility of specific climate futures. The distinction between possible and plausible climate futures, which was developed in the 2021 Hamburg Climate Futures Outlook, has now been extended. The Social Plausibility Assessment Framework of the 2021 Outlook edition took the methodological step to develop and make explicit a theoretical model of change (transformation), against which available evidence can be held to assess the plausibility of a predefined scenario (deep decarbonization by 2050). In the 2023 Outlook, we have extended this methodological step to deeply uncertain physical processes. We explicitly formulate and as such communicate our mental models of relevant processes at play. If we can both formulate these models and find empirical confirmation, we can state the plausibility of a certain outcome.

Our focus on plausibility contrasts with many assessment frameworks (Box 1), in particular those that were developed by the IPCC in its WGIII. There, the focus lies on *feasibility*, which “refers to the potential for a mitigation or adaptation option to be implemented” (IPCC, 2022b, Footnote 71). We hence think it appropriate to equate *feasible* in the AR6 WGIII with *possible* as used here for climate futures. The AR6 WGIII comprehensively assesses potential enabling conditions for and barriers to the feasibility of mitigation measures, especially in Chapter 3 (Riahi et al., 2022). However, the AR6 WGIII does not assess empirical evidence for the extent to which social dynamics will plausibly shape these enabling conditions or barriers, and as a result the AR6 WGIII does not assess the plausibility of these mitigation measures being implemented in the future. By contrast, we assess social processes, their past and present dynamics, and their context conditions. Not all possible climate future scenarios can be considered equally plausible, because past events and emergent dynamics in the present are central for the direction these dynamics take toward or away from a particular future scenario (Bas, 2021; Pulver and VanDeveer, 2009; Staman et al., 2017). Our assessment of plausibility inevitably involves a certain positionality (see Section 2.1.2 on decentering climate science), and the same empirical evidence might therefore be interpreted differently in the future since the context—and therefore the basis for the assessment—might have changed.

2.1.2 Building blocks of the CLICCS Plausibility Assessment Framework

Although physical and social worlds are intertwined, for the purposes of the assessment in the Outlook we address the dynamics of social and physical processes separately. This analytical differentiation allows us to synthesize key findings in the various issue areas as a first step to systematically develop an integration based on various approaches, concepts, and data. The goal of the current Outlook is to bring together social and physical assessments that bridge concepts, similarities, and differences in order to initiate a unique integrative plausibility assessment.

In this integrative framework, social drivers and physical processes constitute the conceptual building blocks of the Social and Physical Plausibility Assessment Framework, respectively. *Social drivers* are broadly understood "as overarching social processes that generate change toward or away from a given scenario and its characteristics" (Aykut, Wiener et al., 2021, p. 34; see also Section 2.2.1). If the drivers continue their current trajectories, they might either support or inhibit social dynamics toward a selected climate futures scenario (e.g., deep decarbonization by 2050). *Physical processes* are defined here as processes that occur in the physical world and are governed by the laws of nature; thus, they encompass the application of concepts from climate physics, biogeochemistry, and ecology. These determine the response of the climate system to anthropogenic and other perturbations.

The concept of enabling and constraining conditions works as a bridging concept for social drivers and physical processes. *Enabling and constraining conditions* are circumstances and factors affecting the dynamics of these drivers and processes toward or away from a specific climate future scenario. This means that these dynamics may be affected by enabling or constraining conditions that are either social or physical in nature. A physical process (or elements of it) may constitute an enabling or constraining condition affecting the dynamics of a social driver. Conversely, a social driver (or aspects of it) may constitute an enabling or constraining condition that affects the dynamics of a physical process. A social driver such as climate litigation, for example, may enable or constrain a physical process such as the Amazon Forest dieback. Likewise, a physical process like Arctic sea-ice decline may enable or constrain the dynamics of a social driver such as media or climate protests. The upshot of such an approach is that there is a two-way, but not necessarily symmetrical, interaction between social and physical dynamics.

Tipping points: Deep uncertainties in the climate system often veil processes that characterize proposed *tipping elements*, which could cross potential *tipping points*. The IPCC AR6 defines a tipping point as "A critical threshold beyond which a system reorganizes, often abruptly and/or irreversibly", and a tipping element as "A component of the Earth system that is susceptible to a tipping point" (IPCC 2021a AR6 WGI Glossary, p.2251). Originally intended as a metaphor for policymakers and to reframe climate governance as risk management (Russill, 2015), tipping points have become a concept used in various contexts and by numerous stakeholders (van der Hel et al., 2018). Note that natural scientists often use the terminology of "abrupt changes" and "irreversibility" instead of "tipping point" (e.g., Lee et al., 2021).

While we apply the concept of tipping points in the assessments of physical processes, we refrain from using the concept of *social tipping points* (Milkoreit, 2022; Winkelmann et al., 2022). Following the introduction of the tipping point metaphor in the physical climate sciences, social tipping points are broadly conceptualized as nonlinear and mostly irreversible processes of transformative change in social systems (e.g., Lenton et al., 2008; Milkoreit et al., 2018). However, the concept markedly departs from its physical counterpart in assuming that social tipping is both desirable and that it can be intentionally activated (Moser and Dilling, 2007). The latter assumption, in particular, expresses a "curious degree of confidence in our collective ability to initiate and control rapid and radical change in social systems" (Milkoreit, 2022, p. 4) that seems to be motivated less by theory-informed or evidence-driven reasoning but by wishful thinking. While a normative motivation is not problematic per se, there are a number of issues with the social tipping point approach in its current form. First, we already argued in the last Outlook that foregrounding tipping points as enablers for decarbonization without explaining by which social forces and mechanisms these can be enabled, entails the risk of mistaking desirability for plausibility (Aykut, Wiener et al., 2021, pp. 31–32). Second, in a recent critique, Milkoreit (2022) adds a number of important shortcomings of social tipping point research, such as using the label without giving evidence for the possibility of tipping with regard to both past and future social change, not defining system boundaries and scales of analysis, not providing evidence for tipping criteria, and not using social theory. While the most convincing analyses study socio-technical systems such as financial markets (e.g., Tan and Cheong, 2016), there is as yet no empirical evidence of a major social tipping point that supports decarbonization (Milkoreit, 2022). Rather than placing our hopes on hitherto unknown levers that would quasi-mechanically set transformative changes in motion at the speed and scale required, our approach focuses on well-established and emergent drivers of social change and how they are observed using scientific methods and data. That said, identifying possible amplification mechanisms that would speed up social changes—a major goal of the social tipping point approach—is useful for the exploration of both tipping and incremental processes (Milkoreit, 2022).

Decentering climate change research: Global assessments typically risk being conducted from an unspecified, seemingly neutral, benevolent, and omniscient standpoint. The risk concerns biases that might be very influential for the outcome of the assessment: Eurocentric problem definitions and technocratic solutions might exclude diverse ways of knowing and therefore produce overly homogenizing assessments that ignore divergent positions and thereby reinforce unjust conditions. We adopt several strategies to decenter climate change research, and we consider this an ongoing process, which will be further evolved in each new Outlook. For the time being, our assessments seek to implement the following strategies by indicating in which ways and to what extent social drivers require a decentering and recognition of diverse ways of knowing:

(i) Address Eurocentrism: The notion of decentering refers to postcolonial scholarship on the problem of universal claims in the social sciences that are often rooted in Eurocentric assumptions about global structures, dynamics, and modes of knowledge production (Castro Varela and Dhawan, 2020). In the context of climate change, universal categories such as the human in human-induced climate change, the globe in global warming, and a focus on global averages carry the risk of glossing over fundamental issues regarding the agency and responsibilities of the various actors (Newell and Paterson, 2010). Addressing social inequalities also includes reflecting on who creates specific climate goals and on whose knowledge and understanding these are based. For example, observational data in climate research are largely underrepresented outside highly industrialized countries. These data might be fed into regional climate models or be used to decide on adaptation measures. Thus, research must also acknowledge social inequalities and justice in data distribution, which are often hidden behind averages. It is therefore important to stress that what we conceptualize as physical boundary conditions is neither a stable nor given setting, but subject to diverse ways of knowing, understanding, and interpretation that are shaped by societal and cultural background knowledge.

(ii) Account for diverse ways of knowing: The concept of diverse ways of knowing refers "to diverse scientific or everyday practices and technologies for accessing the world, including different approaches within the same epistemic system, such as observations and models, and different epistemic systems, such as local, traditional, or indigenous knowledge systems" (Petzold, Wiener et al., 2021). As a result of cultural differences, assessing climate futures needs to draw on the diversity of interpretations and understandings in order to analyze human practices, behaviors, and explanations vis-à-vis changing climate (e.g., Schnegg et al., 2021). A plurality of approaches is required to identify and observe the variety of settings and dynamics with various kinds of data, empirical work, and diverse epistemologies as the basis of driver assessments. An assessment framework that focuses on the plausibility of social transformation needs to critically engage with human agency and changing physical boundary conditions that are elsewhere described as decentering the human.

(iii) Decenter the human: Decentering the human recognizes that nature and climate change cannot be "seen as a constant and unchanging background to human stories" (Chakrabarty, 2021, p. 7), but that the social and physical world are interconnected in a multiplicity of ways. Hence, humans are not only an active and interfering part of the physical world, but the changing states of the physical world also create new boundary conditions that affect human practices at the same time. It is this understanding of the physical realm as boundary conditions that shapes our integrated assessment of climate futures. A decentered approach also addresses the challenge of time and timescales as central references and concepts that cut across the analysis of physical and social dimensions of climate change. The limited timescales of social science involve the analysis of how diverse ways of imagining, reflecting, and integrating pasts and futures into current practices shape social dynamics. Earth system science and physical assessments, on the other hand, work with very different timescales that substantially exceed the history of humanity and rather belong to the "inhumanly vast timescales of deep history" (Chakrabarty, 2021, p. 4).

While some key aspects of diverse ways of knowing have already been summarized in the 2021 Outlook edition (Petzold, Wiener et al., 2021), the current Outlook edition sheds light on diversity and multiplicity as central and cross-cutting aspects that shape global societal dynamics (Rosenberg, 2016; Rosenberg and Tallis, 2022). This edition extends the focus of decentering by more systematically integrating the issues of, for example, justice, inequality, and diverse ways of knowing climate change. The plurality and diverse set of justice and inequality issues can potentially shape social drivers of deep decarbonization in different directions. Additionally, accounting for diverse ways of knowing allows the discussion of ethical complexities and existing priorities that guide climate-related policies (Wilkens and Datchoua-Tirvaudey, 2022). This helps researchers to understand the many ways in which actors respond to climate change and make sense of it.

2.1.3 The overarching question and the climate future scenario of the 2023 Outlook

In the current Outlook, we use the CLICCS Plausibility Assessment Framework to address the following overarching question:

What affects the plausibility of attaining the Paris Agreement temperature goals?

To do so and following the procedure of the 2021 Outlook, the updated social plausibility assessments evaluate social driver dynamics toward or away from deep decarbonization by 2050 (Section 6.1). In turn, the physical plausibility assessments elucidate physical dynamics and their role in limiting global warming to well below 2°C or, if possible, to 1.5°C relative to pre-industrial times (Section 6.2). The guiding questions of the social and physical assessments support the integrative process in searching for common ground (Sections 2.2.2 and 2.3.2).

It follows that the scenario context of the current Outlook builds on two interrelated scenarios: (i) achieving deep decarbonization by 2050 and (ii) staying within the Paris Agreement temperature goals (Figure 1). (i) Deep decarbonization describes a scenario of social transformations that lead to net-zero carbon emissions by 2050 (Held et al., 2021, pp. 25–26). Our deep decarbonization scenario is mainly qualitative in nature insofar as it does not include details about exact emissions levels and focuses instead on the approximate magnitude of societal change that is required to drive the transition toward net-zero climate futures at a rapid enough pace. This climate future scenario is thus tailored to the analysis of social dynamics (Held et al., 2021, pp. 25–26) and serves as a basis for the Social Plausibility Assessment Framework. (ii) The temperature scenario builds on the central goal of the Paris Agreement, the effort to hold global warming to well below 2°C and, if possible, to 1.5°C, relative to pre-industrial levels (UNFCCC, 2015, Article 2 paragraph 1a). The global warming levels of the Paris Agreement are calculated relative to a pre-industrial reference period (1850–1900), which establishes a

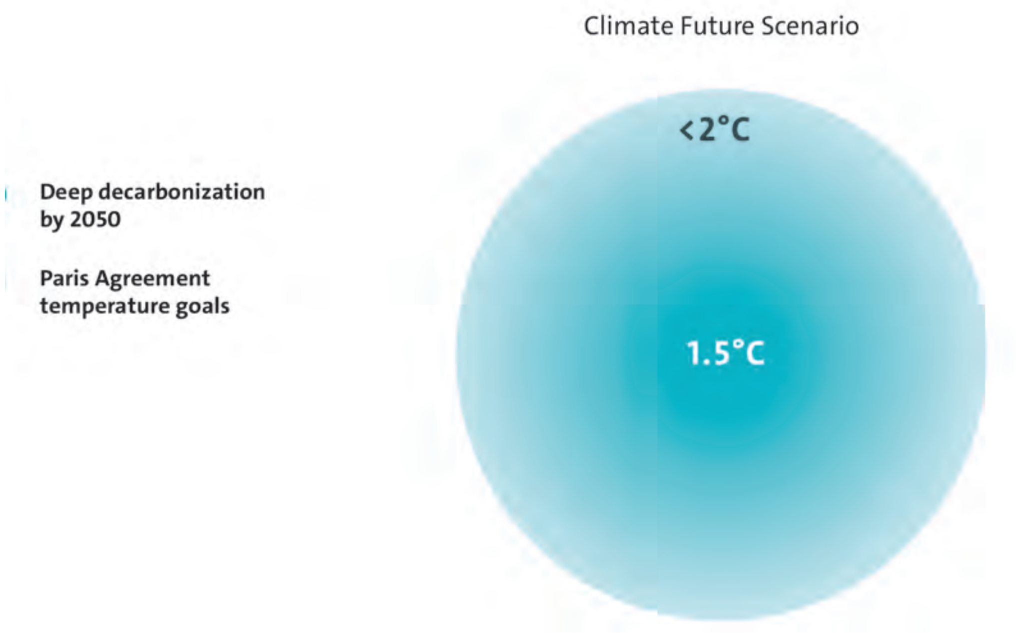

Figure 1: Climate future scenario. The circle represents the climate future scenario of the 2023 Outlook, which combines deep decarbonization by 2050 with the Paris Agreement temperature goals. The social plausibility of deep decarbonization is central to limiting global surface temperature increase to 1.5°C above pre-industrial times, whereas the physical plausibility is assessed also with respect to a global surface temperature increase of below 2°C.

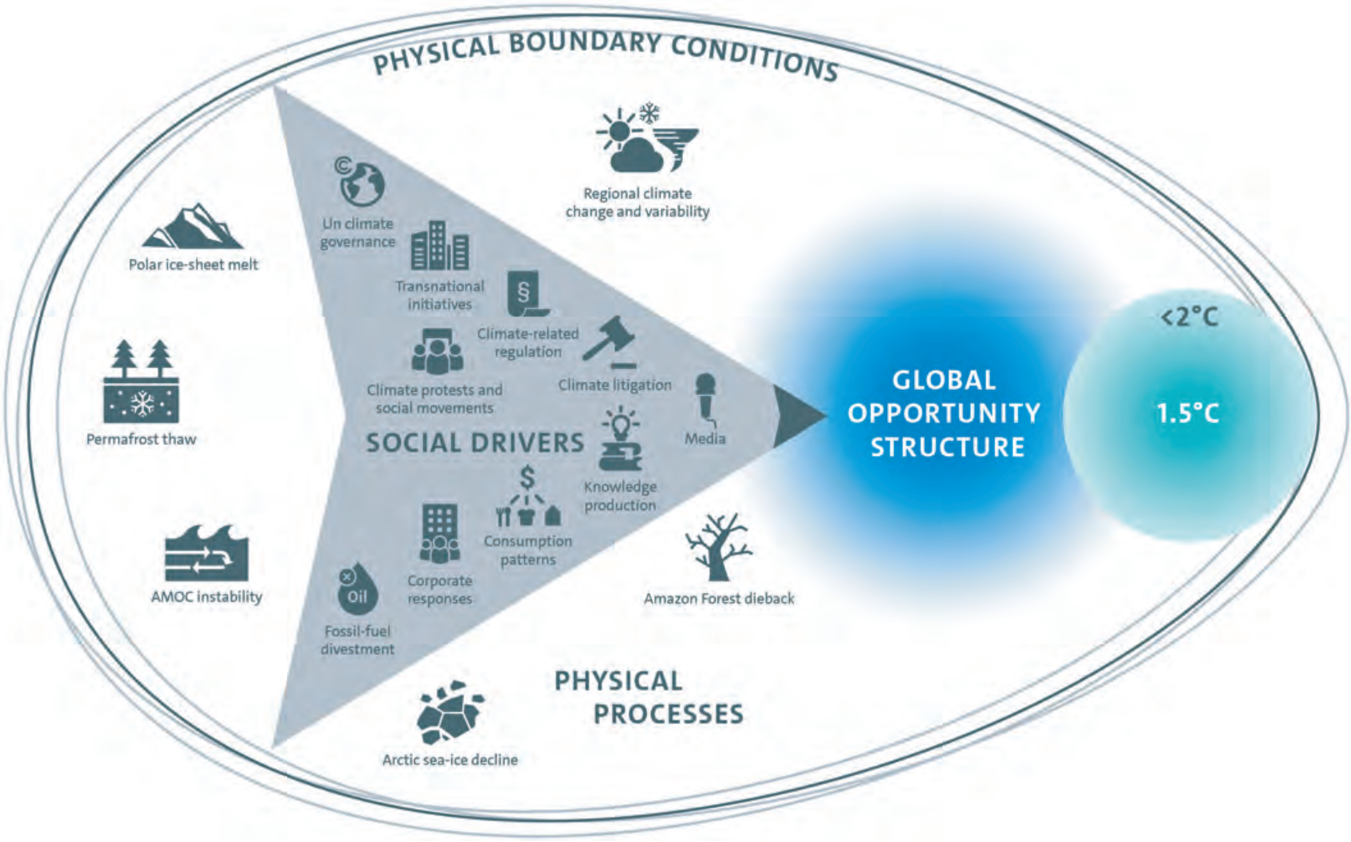

Figure 2: Components of the integrated CLICCS Plausibility Assessment Framework. The figure illustrates how social drivers of decarbonization (in the gray arrow) and physical processes (all around the arrow) are embedded, act, and exist within the physical boundary conditions (encircled in the lines). Social drivers and physical processes influence each other and affect both the global opportunity structure (blue area in the center) and the physical boundary conditions. Thus, both are not static but dynamic. On the right side, the figure shows the chosen climate future scenario, which combines deep decarbonization by 2050 with the Paris Agreement temperature goals. The assessment of the social drivers' and physical processes' dynamics, and their enabling and constraining conditions, leads to a conjecture about the plausibility of the selected climate future scenario (for details, see Section 6.1 and 6.2).

baseline of global mean surface temperature (IPCC, 2021a).

The temperature and emissions scenarios are deeply connected. For example, assessing the plausibility of reaching deep decarbonization by 2050 is essential for assessing the plausibility of complying with the 1.5°C climate future scenario. However, social and physical worlds affect the plausibility of staying within the Paris Agreement temperature limits in very different ways. We will therefore integrate the social and physical plausibility assessments with respect to their role and interaction. On the one hand, we look at the anthropogenic impact on the carbon cycle, in terms of greenhouse gas emissions as well as changes in carbon sources and sinks. Social drivers may possibly lead to wide-reaching social change, leading to rapid emissions reductions by 2050. On the other hand, we consider the effect that some physical processes—which already today are responding to anthropogenic emissions—have on global temperature and their interactions with society. Thus, we assess their potential to influence the plausibility of the climate future scenario reflected in the Paris Agreement temperature goals.

2.2

The Social Plausibility Assessment Framework: from social drivers to the plausibility of deep decarbonization

In the 2021 Outlook edition, we assessed the overarching question "Is it plausible that the world will reach deep decarbonization by 2050?" Given the importance of social dynamics for understanding changes toward and away from low-carbon climate futures, we have developed the Social Plausibility Assessment Framework (Aykut, Wiener et al., 2021). This has guided the analysis of past, present, and emergent dynamics of ten overarching social drivers of decarbonization (Aykut et al., 2021c; Engels et al., 2021a; Gresse et al., 2021b; Guenther and Brüggemann, 2021; Johnson and Busch, 2021; Perino et al., 2021a; Perino et al., 2021b; Scheffran et al., 2021; Wiener et al., 2021; Zengerling et al., 2021).

Similar to other assessment frameworks and scenario-driven modeling, our existing assessment framework is subject to refinement based on observation from our initial analysis in the 2021 Outlook. In the following, we provide a brief summary of key Social Plausibility Assessment Framework concepts (i.e., social drivers, enabling and constraining conditions, global opportunity structure, and societal agency), and we explain the new concept of densification and an extended concept of the global opportunity structure.

2.2.1 Main concepts and theoretical underpinnings of the Social Plausibility Assessment Framework

The Social Plausibility Assessment Framework allows us to analyze social processes that work as social drivers of decarbonization. The drivers' respective composition differs according to the central type of agency that engages within the context of a driver. While we conceive of drivers as social processes that are malleable and change over time, at any given time drivers entail structural and institutional contexts that represent enabling and/or constraining conditions (e.g., rules of engagement, resources, and repertoires) that have an effect on driver dynamics. As agents interrelate with these structures and institutions, dynamics toward or away from deep decarbonization can be identified with regard to the plausibility of this scenario. In order to provide a systematic assessment of how these context conditions change over time, we employ the concept of *global opportunity structure*, which allows us to identify two types of change: first, the changing enabling or constraining conditions, and second, the shift from visible resources to useful, or material, repertoires of climate action. Over time, this may lead to a *densification* of climate action resources and repertoires within the global opportunity structure. The following paragraphs introduce these concepts, beginning with social drivers, then turning to the type of agency that moves these drivers and, relatedly, the agency's interaction with enabling and constraining conditions of the drivers in the global opportunity structure. Here, we turn to the generation of resources and their global use as they develop into recognized repertoires of the global opportunity structure. In the final section, we look at the subsequent final empirical step of assessing the densification of climate repertoires.

Social drivers: The notion of social drivers rests on a heuristic that does not presuppose complete knowledge of social systems and mechanisms. Instead, it foregrounds specific aspects of the social world that are considered relevant with regard to a given issue or question. We conceive these drivers as social processes, that is, as patterns of social interaction in which the actions and experiences of social agents continuously interlock (Elias, 1994; Krieken, 2001), and as temporal phenomena that develop a dynamic momentum of their own (Stinchcombe, 1964, p. 103). According to neo-institutionalist approaches, social drivers exhibit self-reinforcing elements (Pierson, 2004; North, 1990), but also openings for path departure (Garud and Karnøe, 2001). They are constituted by, and also constitutive of, social agents and organizations and are embedded in structural and institutional environments that constrain or enable them (Tilly, 2008; McAdam et al., 2003; Giddens, 1984). In other words, social drivers represent a certain internal logic and dynamic in which outcomes of previous changes alter the conditions for future changes (Sabatier, 2007; Tilly, 2008). They are characterized by a historic trajectory and specific contextual conditions that enable or constrain specific forms of societal engagement or activism.

In designing the 2021 Outlook, we identified ten relevant social drivers of decarbonization: UN (United Nations) climate governance, transnational initiatives, climate-related regulation, climate protests and social movements, climate litigation, corporate responses, fossil-fuel divestment, consumption patterns, journalism, and knowledge production (for more details on the identification of social drivers, see Gresse et. al, 2021a). The drivers represent (emergent) social processes that are identified in relation to a given scenario, namely deep decarbonization by 2050. They cover social dynamics that span various sectors, including the state, business, and civil society, and scales of social order, including global, national, and subnational processes. As outlined above, each driver is in turn characterized by process-specific context conditions. While social processes hence provide conditions that enable or constrain climate-related engagement, societal agents also continuously shape these context conditions (Vanhala, 2020). They create climate action *resources* that can be used by other agents, and which thereby facilitate future climate action by obtaining visibility as resources of the global opportunity structure. Such resources include, for example, climate-friendly business models, contentious practices, scientific knowledge, legal texts, social norms, and network capacities. When used by other agents in new contexts, these resources acquire global materiality and as such become part of a global climate action *repertoire* that is increasingly used in a strategic way by societal agents (Aykut and Wiener, 2021).

Societal agency: The current struggle to mitigate climate change and decarbonize global economic activity is spearheaded by a diverse range of agents, including governments and administrations, but also protest movements, civil society organizations, think tanks, consultants, firms, scientists, municipalities, and transnational legal networks (Chan et al., 2015; Jernnäs and Lövbrand, 2022). This sheer diversity of agents and activities transcends familiar descriptions in global governance research (Aykut, 2016). We therefore introduce the notion of *societal agency* to capture, alongside classical forms of climate activism (Fisher and Nasrin, 2021), a wider spectrum of civic engagement that can take the form of legal activism (Peel and Osofsky, 2020; Ganguly et al., 2018), transnational private initiatives (Chan et al., 2021), or city networks (Bernstein and Hoffmann, 2018) as well as climate-related advocacy in national policymaking (Kukkonen et al., 2018) and international administrations (Saerbeck et al., 2020). This focus on societal agency is combined with larger structures, institutions, and historical dynamics. The objective is to account for disruptive change through social movements or radical innovations, but also incremental change driven by markets, reforms, and organizational learning.

Global opportunity structure: As we developed in the 2021 Outlook and in subsequent work (Aykut and Wiener, 2021; Aykut et al., 2021d), the *global opportunity structure* for climate action is constituted by relevant context conditions for climate-related societal agency, climate action resources that have acquired global visibility, and climate action repertoires shared among social agents. This notion draws on research focusing on contentious politics that identified relatively stable institutional conditions for claims-making vis-à-vis national states (Kitschelt, 1986; Della Porta, 2013). By extension, the global opportunity structure approach examines context conditions for societal agency in a much less structured global context (Schulz, 1998; Vanhala, 2020). While social processes do provide specific context conditions for various forms of climate-related engagement, societal agents also continuously create new narratives and resources that facilitate future climate action (Paiement, 2020; Aykut et al., 2022b). The global opportunity structure hence forms and evolves through societal interaction on and across multiple sites. Climate action repertoires, for instance, are constructed through local activities and struggles, but acquire global relevance when scripts and resources are visible and become accessible for protagonists of climate struggles worldwide. In the current Outlook, we extend and further specify how the global opportunity structure changes, for example, regarding the expected shift from resources to repertoires, which we identify as an effect of enhanced societal agency.

Densification: The 2021 Outlook pointed to an accumulation of climate action resources such as new social norms, media frames, policy instruments, and legal precedents that are generated through practice by social drivers. Once these resources acquire global visibility among societal agents worldwide, they can become part of new climate action repertoires. This material change from resource to repertoire occurs through iterated interactive use by societal agents. Climate change litigation, for instance, "takes place in a rapidly evolving *scientific, discursive* and *constitutional* context, which generates new opportunities for judges to rethink the interpretation of existing legal and evidentiary requirements" (Ganguly et al., 2018, p. 841, emphasis in original). This implies that scientific findings, shifting cultural norms, growing transnational support networks, and new international treaties constitute potential resources for new types of climate litigation cases. We therefore expect that a growing dynamic toward decarbonization would also entail, and build on, a strengthening of links between processes, for example, by "establishing normative links between transnational partnerships and treaty implementation" (Streck, 2021, p. 493), or by integrating litigation risks in financial risk models used by investors and regulators (e.g., Thomä et al., 2021).

To probe this expectation, research in the current Outlook begins to examine a possible densification of the global opportunity structure for deep decarbonization, as climate action resources multiply, gain visibility, and materialize in the form of new climate action repertoires. The notion of densification builds on different research traditions. Political scientists have introduced policy density as a proxy for measuring policy ambition in large cross-country comparisons (Knill et al., 2012), including in the climate field (Le Quéré et al., 2019; Eskander and Fankhauser, 2020). For example, Schaub and colleagues hold that ”policy density captures the policy activity level and internal differentiation of a policy field in terms of the policy instruments it comprises” (Schaub et al., 2022, p. 227). By contrast to such purely quantitative approaches, qualitative uses of the notion find that increases in policy density often interlock with a densification of legal norms, social interactions and political authority (Althammer and Lampert, 2014, pp. 103–114). Moreover, legal scholars have identified normative densification as a major feature of contemporary transformations in world society (see the wide range of contributions in Thibierge, 2014b). According to this tradition, densification describes a multiplication of norms of all sorts—legal, moral, cultural—but also changes in their domain and form of application, for instance when an undefined and abstract norm becomes gradually more concrete and operational in social situations (Rousseau, 2014, p. 41). In other words, densification in this sense combines quantitative and qualitative elements (Thibierge, 2014b, pp. 52–53). It is more than a simple increase, because it also includes one or more dimensions of qualitative change. These can entail an extension of the domain of applicability of a norm, a clearer definition of its conditions of validity, or an intensification of its normative power (Thibierge, 2014a, p. 58).

Against this backdrop, we hold that a densification of global opportunities for climate action can take different forms, and different intensities. In its most basic form, densification consists in a purely quantitative increase of climate-related activities in one or several drivers, for instance, of national climate laws, protest events, and corporate carbon reports. It further intensifies through a qualitative shift in resources and activities, for example, when activism shifts from online petitions to street demonstrations, when new policy paradigms are adopted, and when soft norms of international law are hardened in national legislation. And it may finally result in an increased interaction between drivers such as when scientific knowledge is produced with an explicit view to supporting climate litigation cases or when social movements adopt contentious strategies that directly target company behavior. In its most advanced form, densification therefore points to interlinkages between transnational societal dynamics that indicate more fundamental changes in global society.

2.2.2 Guiding questions

Deep decarbonization by 2050 remains central for staying within the Paris Agreement temperature limits. Assessing the dynamics of social drivers and the global opportunity structure for deep decarbonization is therefore key to explore emerging or changing conditions for the attainment of the Paris Agreement temperature goals. The same is true for the systematic account of inequalities and climate justice issues as well as the analysis of observable densification of societal agency toward climate action. Taking these aspects into account and to guide the social driver assessments, we have refined the previously established guiding questions (cf. Aykut, Wiener et al., 2021a, p. 37). For the current Outlook edition, the social plausibility assessments addressed the following guiding questions:

- If the driver continues its current trajectory, will it support or undermine social dynamics toward deep decarbonization?
- Do currently observable enabling or constraining conditions support or undermine driver dynamics toward deep decarbonization?
- Are there signs that the direction of this driver is or will be changing?
- Under which conditions (e.g., changes in enabling conditions and interaction with other drivers) would you expect a change in the direction toward deep decarbonization?
- Does the driver show signs of densification and in this way provide global resources that are visible and accessible to other social actors and drivers, and how are these resources changing or showing signs of changing?

The main insights of the individual driver assessments are brought together, and their implications for staying within the 1.5°C global warming limit are discussed in Chapter 3. Comprehensive answers to these questions are given for each social driver in Section 6.1.

2.3

The Physical Plausibility Assessment Framework: from physical processes to the plausibility of tipping points

The Physical Plausibility Assessment Framework provides a methodological framework for plausibility research in the field of natural climate sciences. Following common guiding questions, the framework can be applied to assess the plausibility of a specific future scenario, even in the presence of deep uncertainty (Section 2.1.1). We use the Physical Plausibility Assessment Framework to assess a selection of physical processes with respect to the climate future scenario presented in Section 2.1.3.

2.3.1 Main concepts and theoretical underpinnings of the Physical Plausibility Assessment Framework

The following paragraphs introduce a scenario storyline approach that helps to link heterogeneous lines of evidence and to combine physical and social processes. We then turn to feedback mechanisms in the physical world and their role in changes of specific tipping elements. Finally, we address public risk perceptions and how alarmist scenarios dominate public discussions. The section ends with a complete set of criteria we use to select those physical processes that enter our physical plausibility assessment and the resulting choice of six physical processes.

A storyline approach to climate futures: In climate science, scenario storylines (Moss et al., 2010) have a long tradition of being used to describe various emissions and socioeconomic pathways that will shape the future climate and society. In the context of deep uncertainty, in particular, storyline approaches have been highlighted as useful approaches that bring together various lines of evidence and link social processes (Chen et al., 2021; New et al., 2022). Supporting such scenario storyline approaches with tailored information from physical climate model simulations has recently gained popularity in the climate modeling community (Doblas-Reyes et al., 2021). Physical climate storylines are the physically self-consistent unfolding of past events that can explicitly address physically plausible, but low-likelihood, high-impact outcomes (Doblas-Reyes et al., 2021; Sillmann et al., 2021). If we know that something is unlikely to happen in the future (large uncertainty), and even if we cannot quantify that low probability (deep uncertainty), we can develop plausible storylines based on a set of assumptions and explore their consequences. Often these consequences in the tails of statistical distributions carry the highest risks (Sutton, 2018). Thus, physical climate storylines can be used to communicate uncertainties, provide a physical basis for partitioning uncertainties, and explore the boundaries of physical plausibility (Shepherd et al., 2018).

Process dynamics—feedbacks beyond tipping points: The plausibility of attaining the Paris Agreement temperature goals depends not only on future anthropogenic emissions and hence on plausible societal changes as enablers for decarbonization, but also on how sensitively the climate system responds to the emissions. This sensitivity relates to feedback mechanisms and their role in potentially crossing tipping points of specific Earth system elements. In climate sciences, feedbacks can amplify climate change and thus have a destabilizing effect, or they can dampen climate change and have a stabilizing effect (Box 2). In the context of the current Outlook, stabilizing feedbacks in the climate system enable the attainment of the Paris Agreement temperature goals, whereas destabilizing feedbacks constrain it.

Risk perception in the public discourse: Risk perceptions are shaped by an awareness and understanding of what is discussed as the objective threat of an uncertain event in scientific discourse. However, these socially objectified risk definitions, in combination with several exogenous factors as well as ethical and moral considerations, can be interpreted to form a subjective judgement on the probability that this event will occur and on the severity of the harm the event could cause (Wachinger et al., 2013; Bradley et al., 2020). Exogenous factors involved in this process include the degree of informedness, sociodemographic factors (e.g., nationality, age, education, income), and identity feeling and ideology (e.g., political ideology, religiosity), as well as trust in media and confidence in scientific institutions (e.g., Xie et al., 2019; Van der Linden, 2015; Engels et al., 2013; Kellstedt et al., 2008). Additionally, emotions intrinsically affect the perception of risk (Roeser, 2009).

Media constructions of scientific knowledge are influential in society. However, journalistic practices and dependencies—selling stories, the news value, the public attention, and the news judgment—result in story selection and framing that highlight certain factors and thereby promote particular interpretations and shape public policy as well as public attitudes (Entman, 1993, 2004; Leiserowitz, 2005). Thus, public perception of global climate change is influenced by how scientific knowledge is transferred, for instance, by the media (Section 6.1.9). The most striking findings and the most alarmist predictions often have a resounding success in the media and dominate public discussions on climate. In some climate change media reporting, there is a preference for negative, apocalyptic scenarios (e.g., O'Neill and Nicholson-Cole, 2009). Crossing tipping points certainly belongs to the category of alarming news that is of public interest (Pidgeon, 2012; Antilla, 2010). One goal in the current Outlook is to assess the scientific knowledge of some elements of climate change that receive broad public attention, as well as the plausibility of abrupt or drastic changes of these.

Selection criteria and selection of processes: To be included in the assessment, these physical processes must fulfill one or more of the following criteria: (i) the process is veiled in deep uncertainties, (ii) the process is a potential tipping element, (iii) or the process receives much attention in the public discourse shaping climate risk perception. The physical processes included in the assessment are the thawing of permafrost in the northern high latitudes (all criteria; Section 6.2.1), the decline of the Arctic sea ice (criteria ii and iii; Section 6.2.2), the instability of polar ice sheets and the resulting additional sea-level rise (all criteria; Section 6.2.3), a future collapse of the Atlantic Meridional Overturning Circulation (AMOC; all criteria; Section 6.2.4), the dieback of the Amazon Forest (criteria ii and iii; Section 6.2.5), and the change in regional climate variability with relevance for extreme weather events (criterion iii; Section 6.2.6).

Assessing the enabling and constraining conditions that might affect the plausibility of attaining the Paris Agreement temperature goals or the plausibility of drastic changes in physical processes of social relevance links the Physical Plausibility Assessment Framework to the initial Social Plausibility Assessment Framework, as well as to specific social drivers.

2.3.2 Guiding questions

The following guiding questions are the basis of the physical plausibility assessments and address the enabling and constraining conditions for attaining the Paris Agreement temperature goals. Since the processes considered can have widespread effects on the global climate and the carbon cycle, assessing their past and future evolution is crucial and includes the plausibility that drastic or abrupt changes will occur.

Guiding questions for the physical processes' assessments are:

- How did the physical process evolve in the past?
- What would a continuation of recent dynamics under increased global warming mean for the prospect of attaining the Paris temperature goals?
- What are the consequences of failing to attain the goals of the Paris Agreement, and what would be the consequences for these physical processes of exceeding given global warming levels?
- In which way is this physical process connected to other physical and social processes?
- Is it plausible that drastic or abrupt changes in basic process dynamics are triggered within the 21st century?

The main insights of the individual process assessments are brought together, and their implications for the attainment of the Paris Agreement temperature goals are discussed in Chapter 3. Comprehensive answers to these questions are given for each physical process in Section 6.2.

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