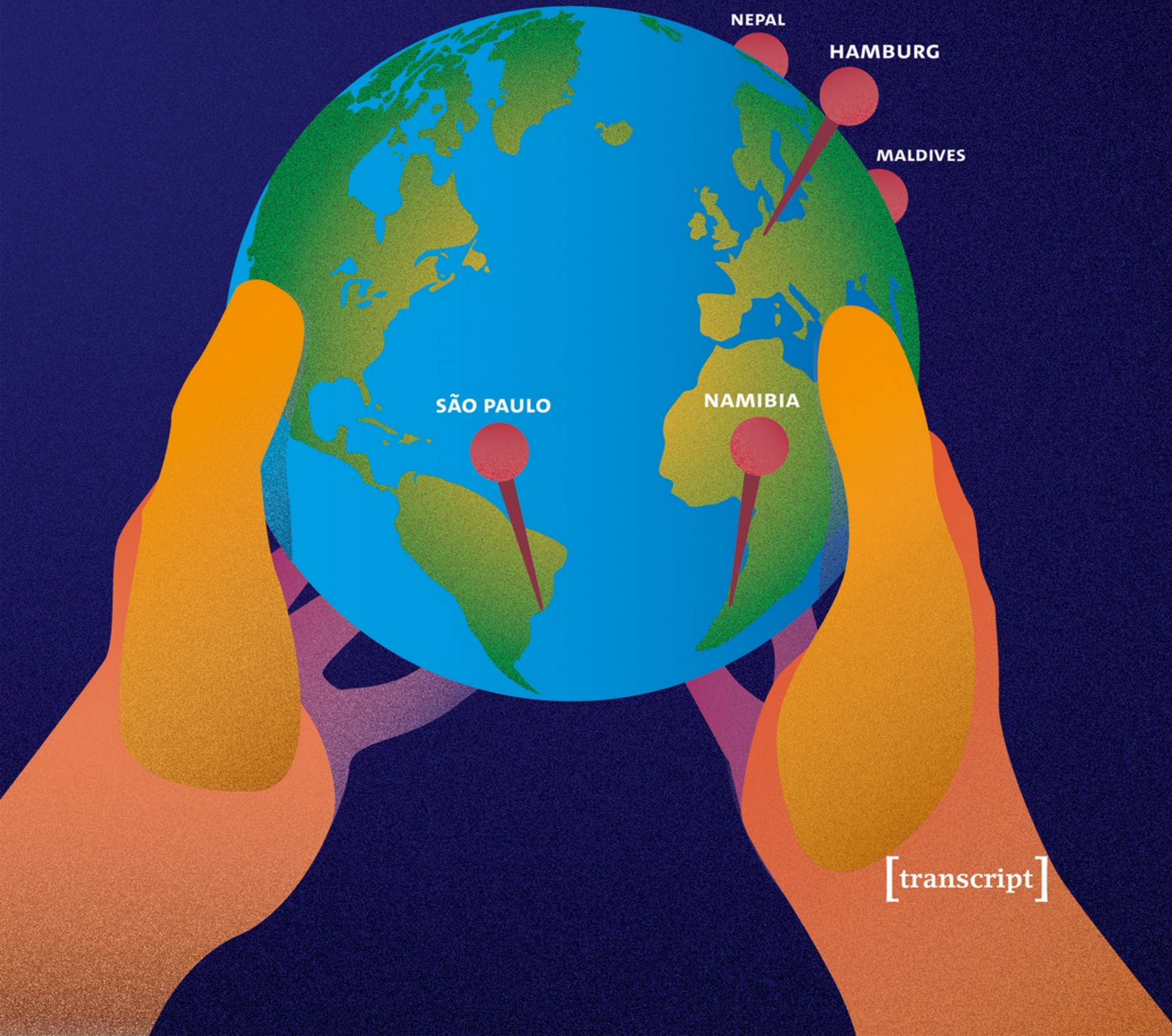
2024

HAMBURG CLIMATE FUTURES OUTLOOK

Conditions for Sustainable Climate Change Adaptation



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CLUSTER OF EXCELLENCE
CLIMATE, CLIMATIC CHANGE, AND SOCIETY (CLICCS)

About CLICCS

Researchers from a wide range of disciplines have joined forces at the Cluster of Excellence CLICCS (Climate, Climatic Change, and Society) to investigate how climate and society co-evolve. The CLICCS program is coordinated through Universität Hamburg's Center for Earth System Research and Sustainability (CEN) in close collaboration with multiple partner institutions and is funded by the Deutsche Forschungsgemeinschaft (DFG), EXC 2037 „CLICCS – Klima, Klimawandel und Gesellschaft" – Projektnummer: 390683824.

About the Outlook

In the annual Hamburg Climate Futures Outlook, CLICCS researchers make the first systematic attempt to assess which climate futures are plausible, by combining multidisciplinary assessments of plausibility. The 2024 Hamburg Climate Futures Outlook addresses the question: Under which conditions is sustainable climate change adaptation plausible?

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Key Findings

In a world with global greenhouse gas emissions still on the rise, higher temperatures, more extreme weather and climate events, and multiple impacts of climate change, communities face big challenges. Adaptation to climate change is needed, but not all adaptation measures are sustainable; some even worsen conditions, especially in the long run. Sustainable climate change adaptation cannot be taken for granted since whether and how local communities succeed in enhancing resilience depends on a variety of social conditions. Based on nine case studies, the Hamburg Climate Futures Outlook 2024 identifies key conditions that influence the plausibility of achieving sustainable climate change adaptation and their connections to mitigation goals. The current Outlook provides a realistic assessment that sets expectations straight and helps to identify social conditions for effective climate action.

▶ The *Social Plausibility Assessment* confirms our previous finding that achieving deep decarbonization, that is, net-zero CO_2 emissions by 2050, is not plausible. No overall shift can be observed since the previous assessment in 2023. Therefore, meeting the Paris Agreement goal of limiting the temperature increase to 1.5°C remains not plausible. Currently, none of the 10 social drivers supports deep decarbonization by 2050, with only six social drivers supporting decarbonization. These are: UN climate governance, transnational cooperation, climate-related regulation, climate activism and social mobilization, climate litigation, and knowledge production. The media driver remains ambivalent as it sometimes supports and sometimes inhibits deep decarbonization. Since 2023, fossil-fuel divestment showed a significant change, from a social driver that supported decarbonization to one inhibiting deep decarbonization. This, along with corporate responses and consumption trends, makes three drivers that currently inhibit deep decarbonization by 2050.

▶ Social drivers relate to and affect each other in different ways. All social drivers offer empirical evidence for an increase in their dynamics contributing to climate action. This happens also by creating new resources for other drivers, for instance new court rulings, new forms of knowledge, and increased political pressure. Nevertheless, despite the plethora of new resources, there is less change affecting key structural and institutional context conditions of drivers, and therefore no qualitative transformative shift toward deep decarbonization can be observed. Some driver dynamics highlight that available resources may also be used to undermine or counteract climate action.

▶ Internal climate variability arises spontaneously and randomly within the climate system. The assessment emphasizes that it is essential to explicitly consider internal variability to better predict changes in extreme events. The quality of these predictions is affected by the uncertainties and limitations of climate models. Knowledge and understanding of these uncertainties and limitations are crucial for communities facing adaptation challenges to climate change. They need to adapt to extreme events, which are strongly influenced by internal climate variability. Such knowledge can make a difference in effective and sustainable climate change adaptation strategies to high-impact events with respect to time-horizons, plans, or expenses.

▶ The interplay of climate change and internal variability can lead to ecosystem and socio-economic disruptions with potentially devastating consequences. Adaptation strategies are needed, for example in compound extreme events in crop-growing regions that may threaten local and global food security, in costly precipitation extremes and severe floodings that damage infrastructure and cause fatalities, and in marine heatwaves that are powerful catalysts of ecosystem disruption, with severe consequences for local communities.

▶ The analysis of nine case studies emphasizes key conditions that affect the plausibility of achieving sustainable climate change adaptation. Long-standing political conflicts, social inequalities, and other structural problems ought to be addressed for sustainable adaption to become plausible. The same is true of increasing socio-cultural embedded capacities so as to bridge the gap between adaptive capacities and local climate vulnerabilities. Establishing climate-friendly laws, regulations, and adaptation plans are not sufficient unless the people who have to implement adaptation are involved, unless the measures are actively put into practice, and unless the plans are connected to clear indicators and measurable goals based on both scientific assessments and climate justice principles. It is essential to strengthen enabling conditions for sustainable climate change adaptation.

▶ Engaging social actors and communities through participatory, trustworthy, and mobilizing strategies is key to foster social involvement and to hold policymakers accountable for their commitments. There is significant potential for collective social action to co-produce knowledge and tackle challenges related to sustainable climate change adaptation. Leveraging past experiences and local knowledge in handling extreme events and climate risks can inform public policies that align climate change adaptation with socio-economic development, as well as the promotion of health and well-being.

▶ Sustainable climate change adaptation requires substantial changes on different levels. Key aspects include improving knowledge about interdependencies between mitigation and adaptation scenarios, and increasing considerations of localities and socio-cultural dimensions in the processes of designing and implementing climate adaptation strategies. Sustainable climate change adaptation further requires considering trade-offs and potential synergies as well as reconsidering current path dependencies in coping strategies that reproduce unsustainable adaptation practices, and an increase in the societal support for and political action toward structural transformations.

► The assessment underlines how ambition and implementation gaps are reproduced. For example, the integration of empirical findings shows how these gaps are the outcome of (1) existing power dynamics and inequalities, (2) different ways of understanding, interpreting, and translating climate change-related norms and practices, (3) a lack of political coherence on different scales of climate governance, and (4) climate change mitigation and adaptation as multifaceted and wicked problems. In addition, uncertainty in social and physical dynamics as well as the interrelation of global and local dynamics affect the plausibility of sustainable climate change adaptation in different ways.

There is never just one agreed climate goal or one way to achieve that goal. To increase the future plausibility of climate change mitigation and adaptation, it is just as important to fight back constraining conditions as it is to strengthen enabling conditions in order to achieve qualitative shifts. The integration of diverse ways of knowing, for instance from local communities or Indigenous Peoples, is crucial for mitigation and adaptation practices, as it is to reduce social inequalities, foster just negotiation processes, and create synergies toward effective climate action.

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Döring, Martin; Beate Ratter; Eduardo Gonçalves Gresse (2024). *Toward Plausible Sustainable Climate Change Adaptation in Urban, Rural, and Coastal Areas*. In: Engels, Anita; Jochem Marotzke; Beate Ratter; Eduardo Gonçalves Gresse; Andrés López-Rivera; Anna Pagnone; Jan Wilkens (eds.); 2024. Hamburg Climate Futures Outlook 2024. Conditions for Sustainable Climate Change Adaptation. Cluster of Excellence "Climate, Climatic Change, and Society" (CLICCS), pp. 100-103. transcript Verlag, Bielefeld.

Section 5.3
Hanf, Franziska S.; Jörg Knieling; Malte von Szombathely; Martin Wickel; Jürgen Oßenbrügge; Sonja Schlipf; Jana Sillmann (2024). *Hamburg, Germany*. In: Engels, Anita; Jochem Marotzke; Beate Ratter; Eduardo Gonçalves Gresse; Andrés López-Rivera; Anna Pagnone; Jan Wilkens (eds.); 2024. Hamburg Climate Futures Outlook 2024. Conditions for Sustainable Climate Change Adaptation. Cluster of Excellence "Climate, Climatic Change, and Society" (CLICCS), pp. 104-108. transcript Verlag, Bielefeld.

Section 5.4
Gresse, Eduardo Gonçalves; Marcelo Soeira; Gabriela Di Giulio; Denise Duarte; Anita Engels (2024). *São Paulo, Brazil*. In: Engels, Anita; Jochem Marotzke; Beate Ratter; Eduardo Gonçalves Gresse; Andrés López-Rivera; Anna Pagnone; Jan Wilkens (eds.); 2024. Hamburg Climate Futures Outlook 2024. Conditions for Sustainable Climate Change Adaptation. Cluster of Excellence "Climate, Climatic Change, and Society" (CLICCS), pp. 109-113. transcript Verlag, Bielefeld.

Section 5.5
Waibel, Michael; Thuy Thi Thu Nguyen; Pham Tran Hai; Steven Petit; Le Hong Nhat (2024). *Ho Chi Minh City, Vietnam*. In: Engels, Anita; Jochem Marotzke; Beate Ratter; Eduardo Gonçalves Gresse; Andrés López-Rivera; Anna Pagnone; Jan Wilkens (eds.); 2024. Hamburg Climate Futures Outlook 2024. Conditions for Sustainable Climate Change Adaptation. Cluster of Excellence "Climate, Climatic Change, and Society" (CLICCS), pp. 114-117. transcript Verlag, Bielefeld.

Section 5.6
Schneider, Uwe; Kerstin Jantke; Michael Köhl; Annette Eschenbach; Martina Neuburger (2024). *Rural Areas of Northeast Lower Saxony, Germany*. In: Engels, Anita; Jochem Marotzke; Beate Ratter; Eduardo Gonçalves Gresse; Andrés López-Rivera;

Anna Pagnone; Jan Wilkens (eds.); 2024. Hamburg Climate Futures Outlook 2024. Conditions for Sustainable Climate Change Adaptation. Cluster of Excellence "Climate, Climatic Change, and Society" (CLICCS), pp. 117-120. transcript Verlag, Bielefeld.

Section 5.7
Neupane, Prem Raj; Kumar Bahadur Darjee; Jürgen Böhner; Michael Köhl (2024). Rural Communities in *Nepalese Highlands, Nepal*. In: Engels, Anita; Jochem Marotzke; Beate Ratter; Eduardo Gonçalves Gresse; Andrés López-Rivera; Anna Pagnone; Jan Wilkens (eds.); 2024. Hamburg Climate Futures Outlook 2024. Conditions for Sustainable Climate Change Adaptation. Cluster of Excellence "Climate, Climatic Change, and Society" (CLICCS), pp. 120-124. transcript Verlag, Bielefeld.

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Schnegg, Michael; Kerstin Jantke; Annette Eschenbach; Uwe Schneider (2024). *Pastoralists in Kunene, Namibia*. In: Engels, Anita; Jochem Marotzke; Beate Ratter; Eduardo Gonçalves Gresse; Andrés López-Rivera; Anna Pagnone; Jan Wilkens (eds.); 2024. Hamburg Climate Futures Outlook 2024. Conditions for Sustainable Climate Change Adaptation. Cluster of Excellence "Climate, Climatic Change, and Society" (CLICCS), pp. 124-127. transcript Verlag, Bielefeld.

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Döring, Martin; Philipp Jordan; Kirstin Dähnke; Johannes Pein; Beate Ratter; Peter Fröhle (2024). *Coastal Adaptation in North Frisia, Germany*. In: Engels, Anita; Jochem Marotzke; Beate Ratter; Eduardo Gonçalves Gresse; Andrés López-Rivera; Anna Pagnone; Jan Wilkens (eds.); 2024. Hamburg Climate Futures Outlook 2024. Conditions for Sustainable Climate Change Adaptation. Cluster of Excellence "Climate, Climatic Change, and Society" (CLICCS), pp. 127-130. transcript Verlag, Bielefeld.

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Ratter, Beate; Arne Hennig; Zahid (2024). *Small Islands Adaptation in the Maldives*. In: Engels, Anita; Jochem Marotzke; Beate Ratter; Eduardo Gonçalves Gresse; Andrés López-Rivera; Anna Pagnone; Jan Wilkens (eds.); 2024. Hamburg Climate Futures Outlook 2024. Conditions for Sustainable Climate Change Adaptation. Cluster of Excellence "Climate, Climatic Change, and Society" (CLICCS), pp. 131-134. transcript Verlag, Bielefeld.

Section 5.11
Wang, Hsiao-Wen; Peter Fröhle; Natasa Manojlovic; Dong-Jiing Doong (2024). *Coastal Adaptation in Taiwan*. In: Engels, Anita; Jochem Marotzke; Beate Ratter; Eduardo Gonçalves Gresse; Andrés López-Rivera; Anna Pagnone; Jan Wilkens (eds.); 2024. Hamburg Climate Futures Outlook 2024. Conditions for Sustainable Climate Change Adaptation. Cluster of Excellence "Climate, Climatic Change, and Society" (CLICCS), pp. 134-138. transcript Verlag, Bielefeld.

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Döring, Martin; Beate Ratter; Eduardo Gonçalves Gresse (2024). *Conclusion and Assessment*. In: Engels, Anita; Jochem Marotzke; Beate Ratter; Eduardo Gonçalves Gresse; Andrés López-Rivera; Anna Pagnone; Jan Wilkens (eds.); 2024. Hamburg Climate Futures Outlook 2024. Conditions for Sustainable Climate Change Adaptation. Cluster of Excellence "Climate, Climatic Change, and Society" (CLICCS), pp. 138-142. transcript Verlag, Bielefeld.

Chapter 6
López-Rivera, Andrés; Jan Wilkens; Eduardo Gonçalves Gresse; Anna Pagnone; Anita Engels; Jochem Marotzke; Beate Ratter; Antje Wiener; Achim Oberg; Martin Döring (2024). *Integration and Synthesis of Assessments*. In: Engels, Anita; Jochem Marotzke; Beate Ratter; Eduardo Gonçalves Gresse; Andrés López-Rivera; Anna Pagnone; Jan Wilkens (eds.); 2024. Hamburg Climate Futures Outlook 2024. Conditions for Sustainable Climate Change Adaptation. Cluster of Excellence "Climate, Climatic Change, and Society" (CLICCS), pp. 144-153. transcript Verlag, Bielefeld. DOI: 10.14361/9783839470817-009

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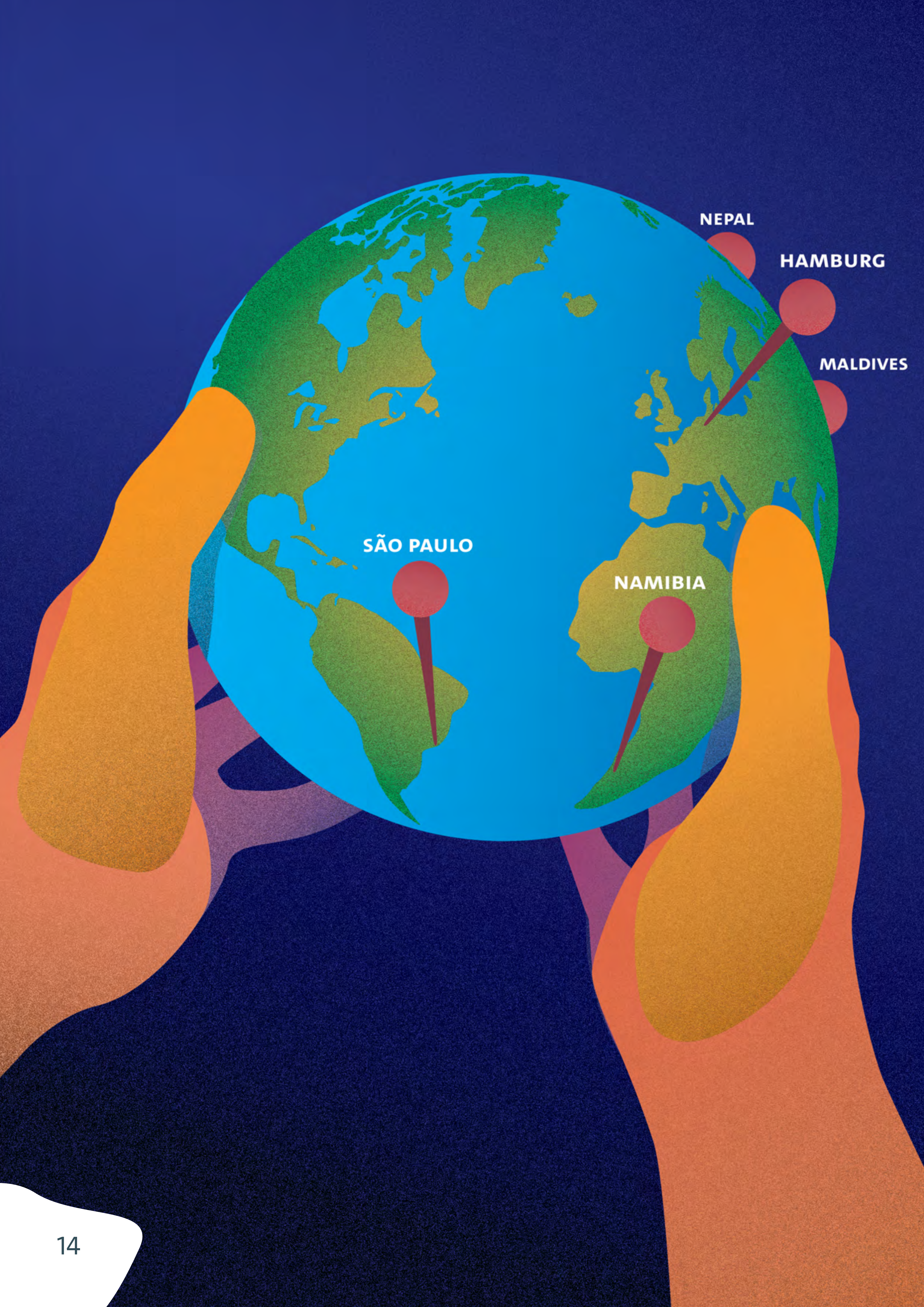
Engels, Anita; Jochem Marotzke; Beate Ratter; Eduardo Gonçalves Gresse; Andrés López-Rivera; Anna Pagnone; Jan Wilkens (2024). *Toward an Inclusive and Connected Repertoire of Climate Action*. In: Engels, Anita; Jochem Marotzke; Beate Ratter; Eduardo Gonçalves Gresse; Andrés López-Rivera; Anna Pagnone; Jan Wilkens (eds.); 2024. Hamburg Climate Futures Outlook 2024. Conditions for Sustainable Climate Change Adaptation. Cluster of Excellence "Climate, Climatic Change, and Society" (CLICCS), pp. 152-153. transcript Verlag, Bielefeld. DOI: 10.14361/9783839470817-010

Chapter 7
Engels, Anita; Jochem Marotzke; Beate Ratter; Eduardo Gonçalves Gresse; Andrés López-Rivera; Anna Pagnone; Jan Wilkens (2024). *Implications for Shaping Climate Futures*. In: Engels, Anita; Jochem Marotzke; Beate Ratter; Eduardo Gonçalves Gresse; Andrés López-Rivera; Anna Pagnone; Jan Wilkens (eds.); 2024. Hamburg Climate Futures Outlook 2024. Conditions for Sustainable Climate Change Adaptation. Cluster of Excellence "Climate, Climatic Change, and Society" (CLICCS), pp. 154-159. transcript Verlag, Bielefeld. DOI: 10.14361/9783839470817-011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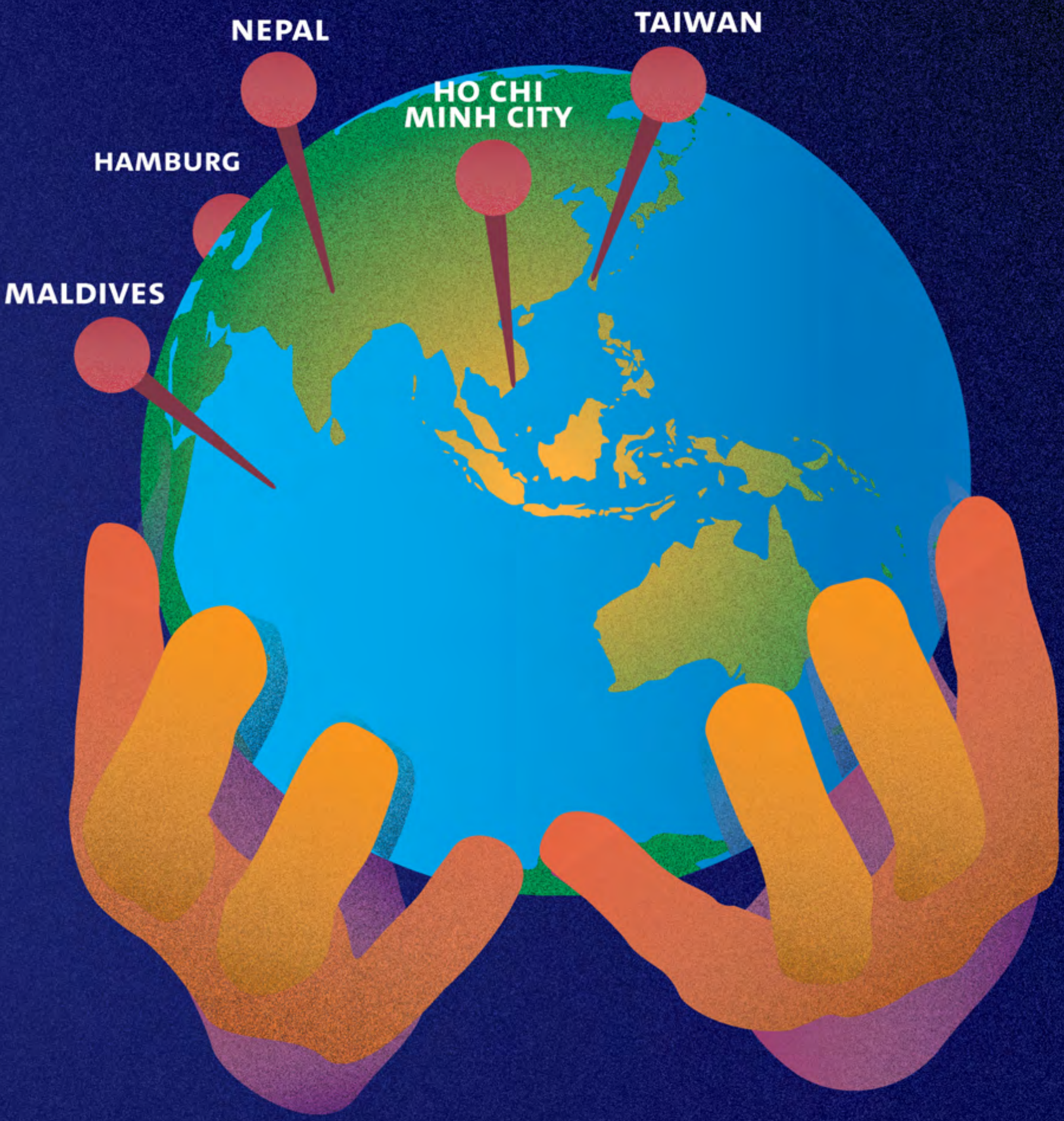

1

The Hamburg Climate Futures Outlook 2024: Goals and Structure

1

The Hamburg Climate Futures Outlook 2024: Goals and Structure

With global greenhouse gas emissions still on the rise and a new record global mean temperature reached in 2023, public and policy debates focus increasingly on the needs of adaptation to the impacts of climate change. However, adaptation does not happen simply out of necessity. Whether and how local communities succeed in creating greater resilience in a world where climate change leads to more extreme weather and climate events depends on complex social conditions, which in many places are not yet met. The Hamburg Climate Futures Outlook 2024 has the goal to assess under which physical and social conditions sustainable climate change adaptation is plausible. The assessment aims at audiences in different fields and with different degrees of expertise, with Chapter 7 in particular discussing the implications of our assessment for a wider, non-expert readership and for various types of practitioners.

If neither mitigation of climate change nor adaptation to its consequences can be taken for granted, which type of climate future is awaiting human society? We, the authors, try and answer this question by assessing the plausibility of specific scenarios of how the climate changes and society changes with it in times of multiple crises, and with a global temperature rise of 1.4°C already occurring in 2023 (Copernicus, 2023). We organize the assessment into three main parts: First, we investigate if and how the world is moving toward deep decarbonization by 2050 second, we assess physical conditions of regional variability and extreme events; and third, we assess social processes that render sustainable climate change adaptation plausible.

With deep decarbonization we mean a state in which society has come down to net-zero CO_2 emissions. Sustainable climate change adaptation is defined as a social, political, and technical process of adjusting to actual and expected climate change and its impacts. Such a process seeks to moderate or avoid harm, reduce vulnerability, and avoid maladaptation, that is, actions that result in negative effects and increased vulnerability, by enhancing synergies and minimizing trade-offs between climate action and other sustainable development goals (Gresse et al., 2023; Juhola and Käyhko, 2023).

In our assessment, the plausibility of deep decarbonization is linked to the dynamics of 10 social drivers from the fields of politics, law, economics, and culture. These drivers are assessed in their global effects: How do these drivers affect the prospects of moving toward or away from, deep decarbonization on a global scale? What changes do we observe in the drivers' dynamics, and how do these changes affect the plausibility of a net-zero climate future by 2050? The current Outlook provides an update of previous assessments (Stammer et al., 2021; Engels et al., 2023). We will explain in detail in Chapter 3 why, according to our assessment, the world has moved further away from achieving deep decarbonization by 2050, compared to our first assessment in 2021.

Whereas global emissions and the social drivers of decarbonization can be assessed through a global framework, adaptation to the impacts of climate change is always context-specific. Accordingly, the plausibility of sustainable climate change adaptation needs to be assessed specifically for each regional or local case. In Chapter 4, we delve into the interplay between regional variability and extreme events and thereby provide a physical rationale for the varying regional and local demands to adapt to ranges of climate futures and extreme events.

In Chapter 5, we empirically scrutinize the contextual conditions that affect the plausibility of sustainably adapting to climate change in various geographical localities and regions. We look at nine case studies in urban, rural, and coastal settings across different regional contexts. The case studies—Hamburg, São Paulo, Ho Chi Minh City, Lower Saxony (Germany), Kunene (Namibia), the Nepal Highlands, the German North Sea coast, Taiwan and the Maldives—examine barriers to sustainable climate change adaptation in order to find locally specific answers to the question:

"Under which conditions is sustainable climate change adaptation plausible?"

Chapter 6 synthesizes and integrates the findings from the three different assessments of Chapters 3 to 5, and Chapter 7 concludes with a reflection on the implications they may bear for different types of practitioners.

The assessment provided in this Outlook thus contains three different parts that are closely interrelated. Chapter 2 explains how we integrate the different elements into a coherent whole: the plausibility of deep decarbonization, the interplay between regional variability and extreme events, and the conditions under which sustainable climate change adaptation becomes plausible.

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2

The Plausibility of Climate Futures: Explaining the Methodology

2

The Plausibility of Climate Futures: Explaining the Methodology

This chapter contains a brief introduction to key concepts of the current Outlook. Our focus here is on how the different elements of the overall assessment relate to each other while the following chapters will provide deeper justifications of conceptual choices for the Social Plausibility Assessment Framework (Chapter 3), for the analysis of internal climate variability and extremes (Chapter 4), and for assessing plausibility conditions for sustainable adaptation to climate change (Chapter 5). All three parts of the overall assessment are based on a combination of literature review and our own empirical research.

Worldwide efforts toward deep decarbonization are on the rise, but structural challenges for the attainment of the Paris Agreement temperature goal persist and have, in some cases, even deepened. Our past assessments came to the conclusion that limiting global warming to 1.5°C—corresponding to the most ambitious part of the Paris Agreement temperature goal—is not plausible. This lack of plausibility also applies to the scenario that global warming will only temporarily exceed but thereafter again fall below 1.5°C. Such a scenario of limited overshoot requires deep decarbonization by around 2050, which we do not deem plausible. Furthermore, increased ambition and speed to achieve deep decarbonization is required for limiting global warming to below 2°C or to prevent even larger global temperature rises. Already under current climate conditions, engaging in climate change adaptation is increasingly important, and this need will aggravate if the Paris Agreement temperature goal is missed. Therefore, exploring sustainable ways of adapting to climate change is key to promote climate-resilient and sustainable development, in addition to efforts at decarbonization.

We have already shown in previous Outlooks that deep decarbonization depends on a complex interplay of social drivers and their enabling and constraining conditions. Agreeing on the necessity of deep decarbonization as a precondition for the attainment of the 1.5°C temperature goal of the Paris Agreement by no means guarantees that society will actually move in this direction. Along the same lines, agreeing on the necessity to prepare for negative impacts of climate change and to engage in adaptation measures does not guarantee that society will actually plan, finance, and implement climate change adaptation, least of all in a sustainable manner. Moreover, if the global mean temperature rises more than 2°C compared to pre-industrial times, the physical conditions for achieving sustainable climate adaptation will have become more challenging. Therefore, drawing on the interplay between deep decarbonization (mitigation) and adaptation, the current Outlook edition addresses the overarching question:

Under which conditions is sustainable climate change adaptation plausible?

This overarching question combines an updated assessment of the social plausibility of deep decarbonization by 2050 (Chapter 3), an assessment of the physical challenges that internal climate variability and extremes pose for adaptation (Chapter 4), and the plausibility of sustainable climate change adaptation in specific regions, organized around nine case studies (Chapter 5).

Key concepts

Climate Futures: CLICCS research is organized around the concept of climate futures, by which we mean potential future states of the co-evolution of the physical climate system and society. Physical boundary conditions influence but in no way determine the way in which society will evolve. Complex social dynamics, in turn, contribute in many ways to changes in the physical boundary conditions, for example by altering the chemical composition of the atmosphere or by changing the net functions of land and water masses as sinks or sources of greenhouse gases. How these changes affect both global temperature changes and local manifestations of climate and weather is to a certain degree dependent on internal variability of the climate system.

Plausibility: Climate futures cannot be determined in a probabilistic way due to the manyfold internal complexities and irreducible uncertainties of the co-evolution of climate and society. Acknowledging the limited feasibility of a robust probabilistic assessment, we have developed an alternative framework to assess the plausibility of climate futures (Stammer et al., 2021). “Our understanding of *plausibility assessment* is based on theoretical or mental models of social dynamics and physical processes. Once these models are established, we hold available empirical evidence against the main assumptions of these models and come to a conclusion whether the world is moving toward or away from a predefined climate future [scenario]. In light of this conclusion, we provide a conjecture on the plausibility of the climate future" (Engels et al., 2023, p. 14, emphasis by authors). What was developed with regard to social dynamics also makes sense for physical processes for which deep uncertainty exists and hence no agreed-upon quantitative measure of uncertainty can be formulated. For uncertainty that is not deep, probability distributions can be agreed upon, and plausibility is then defined such that an event may happen with appreciable probability. Whether an event will indeed occur depends not only on the future evolution of global warming but also on chance. Plausibility in any of these senses does not relate to the desirability of specific climate futures. We strive for a matter-of-factly approach to assessing climate futures, adopting a sense of sober realism because we think that it is important to know where society stands, globally speaking, compared to both overly hopeful and fatalistic expectations of the future.

Social Plausibility Assessment Framework: The Framework starts from a model of transformational change, further elaborated in Section 3.1, which acknowledges the importance of history, context, and agency (Aykut et al., 2021; Wiener et al., 2023). Plausibility refers to the level of confidence and to the strength of our knowledge judgments (Janasik, 2021), based on theoretical models of change and available empirical evidence. We understand this as a learning assessment, where repeated applications help improve the models and help them stand the test of time. We use the framework to look at the social plausibility of a specific climate future, in this case the scenario that global society will have achieved deep decarbonization by 2050. In the first Outlook, published in 2021, we identified 10 social drivers as key elements of potential change toward deep decarbonization (see Table 2.1), each influenced by specific enabling and constraining conditions and by specific relations to other drivers. In each new edition of the assessment, we screen newly available empirical evidence for changes in these conditions that might affect each driver's direction and how the drivers relate to each other. Of special interest is the generation and use of globally visible resources for climate-related societal engagement, such as new legal norms, discursive frames, or funding possibilities. Such resources form the basis of novel climate action "scripts", for example when activists develop new contentious practices, companies engage in new forms of climate reporting, or innovative climate litigation cases diffuse across national jurisdictions. New resources and scripts broaden existing repertoires of climate-related engagement and contribute to the "densification" of the global opportunity structure for climate action (see Section 3.1).

Interplay of internal climate variability and extreme events: Internal climate variability arises from the chaotic interactions within and between components of the climate system such as atmosphere, ocean, cryosphere, and land (see also Section 4.1). Since the existence of internal climate variability potentially obscures signals of anthropogenic climate change, it is important to quantify, understand, and project internal climate variability. Specific tools to address this challenge are required, such as single-model initial-condition large ensembles. Global warming exacerbates many extremes, but on the regional or local scale the distribution of internal climate variability is often wider than the anthropogenic effect. The interplay of regional variability and extremes poses particular challenges to the science supporting sustainable adaptation to climate change, for instance the capability of climate models to represent extremes, the attribution of extreme events to human influence, and the probability of compounding extreme events.

Adaptation: Conceptually, we classify adaptation responses into three analytical categories (Fedele et al., 2019): First, coping strategies: short-term reactive responses that aim at immediate reactions to climatic impacts in socio-ecological systems. Second, incremental adaptation: a stepwise approach along beaten paths, focusing on sectoral or context-specific adjustments with minor systemic stability disturbance. And third, transformative adaptation: fundamental changes that encompass broader and deeper actions directed at the root causes of vulnerabilities while at the same time envisioning long-term systemic shifts (for more details and concrete examples, see Chapter 5). Coping and incremental adaptation strategies are the most frequent types of adaptation and are characterized by lock-ins and unsustainable adaptation pathways. Transformative strategies, in turn, are a key enabling, but not necessarily sufficient, condition for sustainable climate change adaptation. Responses that aim at reducing risk but create adverse effects or increase vulnerabilities are called maladaptation (for further elaboration on these concepts, see Section 5.1).

Sustainable climate change adaptation: Adapting to climate change in a sustainable manner means accounting for the broader spectrum of societal goals and socio-ecological transformations involved when designing, planning, and implementing adaptation responses. Drawing on Gresse et al. (2023), we define sustainable climate change adaptation as the process of adapting to actual and expected climate change and its impacts by significantly reducing actual and potential conflicts and exploiting synergies between climate action and other sustainable development goals. Hence, a sustainable adaptation response necessarily has to extrapolate the various ranges of climate action while also fostering sustainability transformations, that is, multi-sectoral and system-wide shifts that foster human development while protecting and upholding the Earth's life-support systems' resilience (see also Section 5.1).

Context conditions for the plausibility of sustainable climate change adaptation: Organized around nine local and regional case studies, we focus on the interaction of societal systems with their various social, cultural, spatial, temporal, and natural environments. Based on an inductive rationale, the investigation builds on a commonly structured and joint assessment of empirical studies and conceptual reflections taken from these case studies. They examine, analyze, and assess the barriers to and the possibilities for sustainable climate change adaptation across different regional contexts. To account for locally specific and diverse ways of knowing (cf. Petzold et al., 2021; Wiener et al., 2023), the case studies were written by interdisciplinary groups of authors and in co-authorships with local experts situated in the respective case study context. This was implemented in accordance with calls to integrate various knowledge forms alongside current adaptation strategies, as for example acknowledged in the fifth and sixth Assessment Reports by the Intergovernmental Panel in Climate Change (IPCC). This integration is not merely seen to enhance the efficacy of adaptation efforts but also deemed essential for fostering ethical and sustainable adaptation practices (Nakashima et al., 2018; de Coninck et al., 2018, Petzold et al., 2020). In light of these assessments, we empirically reconstruct the conditions that make sustainable climate change adaptation plausible in each specific and place-based case.

Integrating the building blocks of the Outlook 2024

Assessing the plausibility of deep decarbonization by 2050 creates a first important building block for the overarching question of the plausibility conditions for sustainable climate change adaptation. If it is not plausible, or—as the assessment in Chapter 3 will show—even becoming less plausible that deep decarbonization will be achieved by 2050, this implies a global warming of more than 1.5°C that will persist until the end of the century; a warming level that, in turn, affects the physical boundary conditions for the future of human society. Understanding these physical boundary conditions helps define the challenges for adaptation to climate change impacts in different regional and local settings.

Global warming exacerbates many extremes, but on the regional or local scale the distribution of internal climate variability is often wider than the anthropogenic effect. Therefore, the interplay of internal climate variability and extreme events is the second important building block that affects the plausibility conditions for sustainable climate change adaptation. Each example discussed in Chapter 4 illustrates a particular fundamental point relevant for the plausibility of sustainable climate change adaptation: the capability of climate models to represent extremes (here: precipitation), the attribution of extreme events to human influence (here: marine heatwaves), and the probability of compounding extreme events (here: extreme heat in multiple breadbasket regions). In this fundamental sense, these examples foreshadow the relevance of the physical processes and results for the adaptation challenges that are assessed in Chapter 5.

The nine case studies and the combination of empirical analyses and theoretical reflection create the third important building block for assessing the plausibility conditions for sustainable climate change adaptation. The case studies analyze different types of adaptation responses (or lack thereof) and address the extent to which social systems are able to adapt to climate change, that is, the context-specific limits and limitations of adaptation. While the scenario for the plausibility assessment of the first building block—achieving deep decarbonization by 2050—has a clear time horizon, the scenario for sustainable climate change adaptation spreads into many different place-specific scenarios, each depending on the particular local manifestations of climate change, the expected climate extremes including their inherent uncertainties, and unclear time horizons. Which combination of sustainability goals, which level of adaptation, and which limits of adaptation make a good scenario for assessing the plausibility conditions in a specific local or regional setting is always subject to negotiation. Therefore, the nine case studies apply a common set of questions but are in themselves inductive in defining which type of climate change impact is most socially relevant, and what would actually constitute criteria for adapting to these impacts in a sustainable way.

Considering the challenges of such diverse geographical and temporal scales as well as the context-specific understandings of what it means to adapt to climate change in time, we come to a very differentiated answer to the overarching question of the plausibility conditions for sustainable climate change adaptation (Chapter 6).

Who are we? How do we work?

“We” are a group of 73 authors working together in the Cluster of Excellence Climate, Climatic Change, and Society (CLICCS) at the Universität Hamburg, its partner institutions, chiefly among them the Max Planck Institute for Meteorology and the Helmholtz-Zentrum Hereon, and from within the regions assessed in the nine case studies, contributing with practical knowledge and local perspective to climate change adaptation efforts in these different regions. While our goal is to provide a global assessment, we are aware of the risk of over-representing northern European views and understandings of the dynamics we are observing and of marginalizing views and voices from the Global South, or simply from places other than Northern Europe, as well as from epistemic perspectives other than the ones typically employed in mainstream climate science. In order to minimize this risk, we explicitly include assessments of dynamics in countries of the Global South. We made specific efforts to represent different epistemic perspectives in the literature reviews to also draw from scientific fields that are typically not represented in mainstream climate science, and to include diverse ways of knowing by including authors and perspectives from the Global South. We invited authors from outside of CLICCS to make sure that we write on specific regions together with authors from these regions (Brazil, Maldives, Nepal, Taiwan, and Vietnam). Finally, we invited authors from the Global South to review two previous versions of this Outlook. As we rely on different combinations of original data produced in CLICCS, existing data bases on many different topics, and deep literature reviews, we explain in every chapter the specific data foundation that the assessment contained therein is based on.

Learning assessment: Conceptual developments between Outlook versions

We have introduced a number of conceptual developments in this new Outlook version. Table 2.1 summarizes how key conceptual choices have been refined, added, and deepened. Each Outlook is organized around a new overarching question, which also guides us in the way we integrate the different assessment parts. While Outlook 2021 focused on deep decarbonization and temperature changes, Outlook 2023 added a new framework for Sustainable Climate Change Adaptation, which is now, in this Outlook, applied to 9 case studies. The number of authors has risen continuously from 43 to 73.

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TABLE 2.1

Learning Assessment: Conceptual developments between Outlook versions

	Outlook 2024	Outlook 2023	Outlook 2021
Overarching question	**Under which conditions is sustainable climate change adaptation plausible?**	**What affects the plausibility of attaining the Paris Agreement temperature goals?**	**Is it plausible that the world will reach deep decarbonization by 2050?**
Social Plausibility Assessment Framework	**Relationality** (push/pull dynamics) between social drivers	**Densification of climate action** (scripts and repertoires of Global Opportunity Structure)	**10 social drivers** Enabling and constraining conditions and resources of Global Opportunity Structure
Social drivers	**Stronger emphasis on drivers as processes:** ▶ Transnational Initiatives → Transnational Cooperation ▶ Climate Protests and Social Movements → Climate Activism and Social Mobilization ▶ Consumption Patterns → Consumption Trends	**Widening of one driver:** ▶ Journalism → Media	**10 social drivers** ▶ UN Climate governance ▶ Transnational initiatives ▶ Climate-related regulation ▶ Climate protests and social movements ▶ Climate litigation ▶ Corporate responses ▶ Fossil-fuel divestment ▶ Consumption patterns ▶ Journalism ▶ Knowledge production
Physical processes	**Three example interplays of regional variability and extremes:** ▶ Precipitation ▶ Marine heatwaves ▶ Extreme heat in multiple breadbasket regions	**Physical Plausibility Assessment Framework. Six example physical processes:** ▶ Permafrost thaw ▶ Arctic sea-ice decline ▶ Polar ice-sheet melt ▶ Atlantic Meridional Overturning Circulation instability ▶ Amazon Forest dieback ▶ Regional climate change and variability	**Temperature trends for the 21st century**
Sustainable Climate Change Adaptation	Inductive model of conditions of sustainable climate change adaptation via nine case-studies	Distinction between coping-incremental-transformative. Definition of sustainable climate change adaptation	Not discussed
Authors	73 from CLICCS and external partners from Brazil, Maldives, Nepal, Taiwan, Vietnam	63 from CLICCS only	43 from CLICCS only

The Plausibility of Achieving Deep Decarbonization by 2050

3

3

The Plausibility of Achieving Deep Decarbonization by 2050

3.1

The Social Plausibility Assessment Framework

The Social Plausibility Assessment Framework is a central contribution to scenario-driven research on climate futures. It was first developed in the Outlook 2021 (Aykut et al., 2021) and refined in the Outlook 2023 (Wiener et al., 2023) as a robust qualitative approach to assess if a particular climate future appears plausible or not, given what we know about relevant social dynamics. The assessment draws on in-depth analyses of processes that act as social drivers of the climate future in question, with a view to examining past, present, and emergent dynamics of these processes, as well as context conditions that might enable or constrain them in the future. In doing so, we do not adopt a normative approach that focuses on what *should* happen to make a desirable scenario plausible. Instead, we use an analytical approach that aims to systematically explore the social plausibility of a given climate future and understand what processes, institutions, and agencies shape this plausibility.

What do we mean when we say that we assess the *plausibility* of a particular climate future? Indeed, there is a vivid debate on how to conceptualize possible, feasible, probable, and plausible climate futures in the IPCC and elsewhere (Brutschin et al., 2021; Jewell and Cherp, 2023; Glette-Iversen et al., 2022; Pielke Jr. et al., 2022; Riahi et al., 2022; Schipper et al., 2021). There is also a strong call to quantify the probability of climate futures. However, looking at the probability of deep transformational change by 2050 would require prioritizing quantified trend extrapolations over the recognition of deep uncertainties inherent in social dynamics and of complex interrelations between them (Selin and Guimarães Pereira, 2013). While it may be possible to apply probability reasoning to much more narrow dynamics such as demographic change or energy demand, we do not think it is possible to establish a robust quantitative assessment of the probability of deep decarbonization by 2050. Instead, our assessment is based on a much more holistic, but also in many ways more modest, understanding of the complexities of transformational change over a long period of time, in which we acknowledge the importance of history, context, and agency (Aykut et al., 2021; Wiener et al., 2023; Engels and Marotzke, 2023). We define plausibility as a state in which an internally consistent future—or qualitative scenario—and a theory-based model of change are assessed vis-à-vis available empirical evidence on relevant social dynamics that can be held against this model of change. Plausibility in this sense is suitable for assessing processes of deep uncertainty, and it involves an inherently qualitative knowledge judgment (Glette-Iversen et al., 2022). We are therefore not far away from Jewell's and Cherp's (2023, p. 3) definition of plausible as "occurable in exploratory scenarios with internally-consistent assumptions", but go beyond their interest in *feasible* options that can be implemented by specific groups of actors. We also depart from Pielke Jr. et al.'s understanding of plausible emission scenarios, which use growth rates consistent with observations and near-term projections without employing an underlying theory or model of social change (Pielke Jr. et al., 2022).

Finally, our framework differs from research on social tipping points toward decarbonization (Otto et al., 2020; Fesenfeld et al., 2022). Studies in this tradition typically identify social fields or dynamics which can bring about radical transformational change once a critical threshold has occurred (Winkelmann et al., 2022; Lenton et al., 2023). The assumption is that from then on the unfolding dynamic becomes so strong and self-reinforcing that a new normality is firmly locked-in, leading to rapid decarbonization with limited reversibility of the process (Milkoreit, 2023). The typical S-curve of a technological innovation is the mental model here: It starts with only a few early adopters, but over time the number of adopters rises to a critical point at which the new technology very rapidly, and sometimes even disruptively, replaces an older technology (Kucharavy and Guio, 2011). We depart from this mental model for a number of reasons (Wilkens et al., 2023; Aykut et al., 2021). Mainly, our focus does not lie on identifying invariable social tipping points in social systems, but on understanding context-dependent social processes and the set of relevant context conditions of these processes that would actually have an effect on future shifts in social dynamics. This allows us to get a more realistic understanding of where current social dynamics and constellations of enabling and constraining conditions point to, given the available empirical evidence. Knowing that social dynamics very often follow the shape of recurrent waves or cycles rather than clear-cut S-curves, and knowing that it is often only possible to determine in hindsight whether some threshold has changed the direction of a dynamic permanently, we prefer a realistic assessment over providing optimistic narratives.

The past Outlook editions have applied the Social Plausibility Assessment Framework to assess the plausibility of deep decarbonization by 2050 and of limiting global warming to 1.5°C, relative to pre-industrial levels, based on the analysis of 10 selected social drivers (Stammer et al., 2021; Engels et al., 2023). As we understand it here, deep decarbonization describes a transition to net-zero carbon emissions, leading to a very low carbon intensity in all sectors of the economy, a reduced energy demand (Méjean et al., 2019), and very low demand for carbon-intensive consumer goods. Deep decarbonization can thus be thought of as reducing carbon emissions to as close to zero as possible, with residual emissions compensated by active carbon dioxide removal from the atmosphere (IPCC, 2018; Deep Decarbonization Pathways Project, 2015; Wimbadi and Djalante, 2020; UN Climate Action; IPCC 2021, Annex VII, Glossary). Such a transition also implies a profound social transformation, including changes in norms, regulations, institutions, individual behaviors, and personal values (Shove and Walker, 2010; O'Brien, 2018; Beckert, 2024). The scenario must be clearly distinguished from other, less constrained futures in which decarbonization is only partially achieved by 2050. However, it must also remain generic enough to allow for a broad range of emissions trajectories and technology pathways so as to place the analytical focus on the social transformations that enable deep decarbonization (Held et al., 2021, p. 25; see Figure 3.1).

The Social Plausibility Assessment Framework consists of a series of key concepts—social drivers, context conditions, resources, and the global opportunity structure—that allow us to capture and describe the continuous interplay of historical dynamics and path dependencies, structural and institutional conditions for social change, and the creative work of societal agency (Aykut et al., 2021; Wiener et al., 2023). Social drivers are defined as overarching social processes that generate change toward or away from a given scenario and its characteristics. As social processes, drivers mediate between agency and structure and span micro-, meso-, and macro-scales of global society (Jordan et al., 2018). They reflect societal multiplicity and the agency of a plurality of stakeholders (Wiener, 2022), but also economic and socio-technical dynamics (Geels et al., 2017). Social drivers capture a broad and multifaceted range of political and societal engagement with the climate problem, which facilitates or hinders decarbonization and generates "climatizing" effects by diffusing climate concerns in new policy fields, governance arenas, and societal spheres (Aykut et al., 2017). As in previous Outlooks, we analyze 10 social drivers, which represent relevant existing and emergent social processes that generate change away or toward a scenario of deep decarbonization by 2050. This list (see Table 2.1) represents an analytical choice based on the literature and our own expert elicitation. Given the intrinsic complexity of social systems and foreseeable changes in the dynamics of low-carbon transformations worldwide, this list may be subject to changes in the future (we address some newer developments below).

To assess the plausible contribution of these processes to a global low-carbon shift, we look at their historical trajectory and current dynamics, but also at the specific context conditions that are likely to shape future driver dynamics. This means that enabling and constraining conditions in our framework are not overarching structural features of a global social system, but need to be further specified with regard to specific drivers. They describe "those driver-specific institutional, structural, and material environments which favor or inhibit driver dynamics toward a specific climate future" (Aykut et al., 2021, 34f). Our research hence aims at a better understanding of the social dynamics of global climate politics by targeting social drivers, their historical and current dynamics, and evolutions in driver-specific enabling or constraining context conditions. Moreover, we complement this focus on processes and institutions by a focus on agency. To do so, we borrow the notion of opportunity structure from social movement research. This concept has been introduced in the context of cross-country comparisons to identify *political* resources and institutional arrangements for effective social movement mobilization (Kitschelt, 1986, p. 58). It enabled researchers to take account of nationally contingent relations between historical dynamics and path dependencies, institutional context, and agency. The Social Plausibility Assessment Framework uses the concept analogously but applies it to a global scale in order to reflect the planetary nature of climate change and the globalized politics of deep decarbonization. Against this backdrop, we assume that global opportunities for climate-related societal engagement are an emergent feature of global society, which forms and evolves through processes of transnational and inter-societal interaction. Accordingly, the global opportunity structure for climate action represents "the repertoire of resources and constraints for global societal agency to move toward a specific climate future" (Aykut et al., 2021, p. 35).

Finally, we use the term resources in a broad sense, which encompasses material, formal, and informal dimensions. Material resources include for example monetary support, financial assets, and built infrastructures; formal resources can refer to rules, procedures, and regulations; and informal resources consist of, among other, ideas, values, and knowledge. This broad understanding of the term builds on the above-mentioned tradition of comparative political science studies of new social movements (Wahlström and Peterson, 2006; McCammon, 2013). Resources that mattered in this context included economic funding, political support, appropriate societal institutions, and power structures. Importantly, resources were not merely conceived as structure-based (i.e., relative to a specific national context) but also as agency-generated (i.e., being generated through social movement politics) (Jenson, 1993). This approach also allowed for identifying a qualitative change of governance and an "increasing institutional density" as part of the evolution of EU institutions (Wiener, 1998, p. 296).

Through the inclusion of climate action resources, our analytical framework contributes to ongoing debates about agency vis-à-vis global climate change. Societal agents construct agency in the face of climate change by developing new discourses, communicative frames (Toivonen, 2022) and "climate imaginaries" (Davoudi and Machen, 2022), by enacting sustainable consumption practices (Yang et al., 2023), by amplifying local sustainability initiatives in the Global North and in the Global South (Lam et al., 2020), by building transnational networks and heterogeneous political coalitions (Heikkurinen et al., 2021), or by using judicial strategies that establish new legal norms and open new legal opportunities (Vanhala, 2020). In all of these cases, we can identify the emergence of patterned forms of social behavior that bridge social and political scales and circulate transnationally (Bhardwaj, 2022). We capture this evolution by using the terminology of climate action scripts and repertoires. Societal agents build agency by creating climate action resources and by using these to build new climate action scripts and repertoires.

The notions of social drivers, enabling and constraining conditions, resources, and the global opportunity structure constitute the conceptual backbone of the Social Plausibility Assessment Framework. As we observe an increasing variety and multiplicity of climate action within national political arenas and state-led governance processes, such as the UN climate change conferences, but also beyond in the form of transnational grassroots mobilizations, epistemic communities and expert networks or private climate initiatives (Wiener and Aykut, 2024), we place a supplementary focus in the current Outlook on understanding the dynamics of a *densification* of climate action and the *relationality* between social drivers. Densification has been introduced in the 2023 edition of the Outlook to capture quantitative increases and qualitative shifts in climate action resources, scripts, and repertoires. Through this notion, we attract attention to the emergence and global circulation of, for example, new discursive frames that constitute resources for political advocacy and social mobilizations, or new climate litigation scripts that enable novel forms of court actions across national jurisdictions. "As resources for decarbonization multiply, gain visibility, and materialize in new climate action repertoires, they provide novel opportunities for societal agency operating across national boundaries and social fields" (Aykut and Wiener, 2023). Analyzing densification therefore entails mapping changes over time in the global opportunity structure for climate action. The current Outlook adds the dimension of relationality to the analysis. This adds a novel conceptual layer that has been devised in order to systematically identify and study interrelations between social drivers and hence detect possible (positive or negative) feedbacks and clusters of change that might affect the plausibility assessment. Over this and the next assessments, we will progressively examine which resources within the global opportunity structure are used by other drivers than those from which they originated. This is the case, for example, when new formulations in international climate treaties or COP decisions are used in climate litigation cases to ground new legal rights or duties, or when scientific articles or expert reports are used by climate activists to build political narratives. Over time, this will allow us to understand which resources are produced regularly and used repeatedly in different social contexts until they become part of new climate action repertoires spanning several drivers. Answering these questions will allow us to further specify changes within the global opportunity structure, that is, the shift from visible climate action resources toward more stable (material) repertoires. We assume that this process of stabilization and materialization of climate action resources occurs through the use of these resources by a variety of climate agents. While so far we have operated on the assumption that this shift is possible and likely to occur, it is only with the help of the novel concepts of densification (mapping resources, agents, scripts, and repertoires within the global opportunity structure) and relationality (identifying relations between drivers, their push and pull dynamics, and the potential for more stable institutionalized links which generates additional climate action repertoires across drivers) that we will be able to identify driver relations and measure their dynamic effects on the plausibility of deep decarbonization with future Outlooks.

The approach and terminology introduced here is not limited to analyzing climate-aligned social dynamics. Over the past few years, similar tactics to those of pro-climate advocates, involving the creation of resources, scripts, and repertoires, have been used by counter-movements to undermine efforts to curb emissions or advance climate justice. This is the case, for example, in aggressive campaigns against sustainable transportation, which re-enact cultural norms of "petro-masculinity" and build mobilization scripts aimed at celebrating car culture and a patriarchal and fossil-fuel-dependent status quo (Daggett, 2018). It can also be observed in legal and judicial strategies to undermine corporate reporting on environmental, social, and governance indicators or intimidate potential climate activists and litigants (Sections 3.5 and 3.6). The question pertaining to the inclusion of these dynamics as separate social drivers or constraining conditions within the individual drivers will have to be addressed in each new Social Plausibility Assessment, to the extent to which the conservative backlash continues to grow and develop a dynamic of its own.

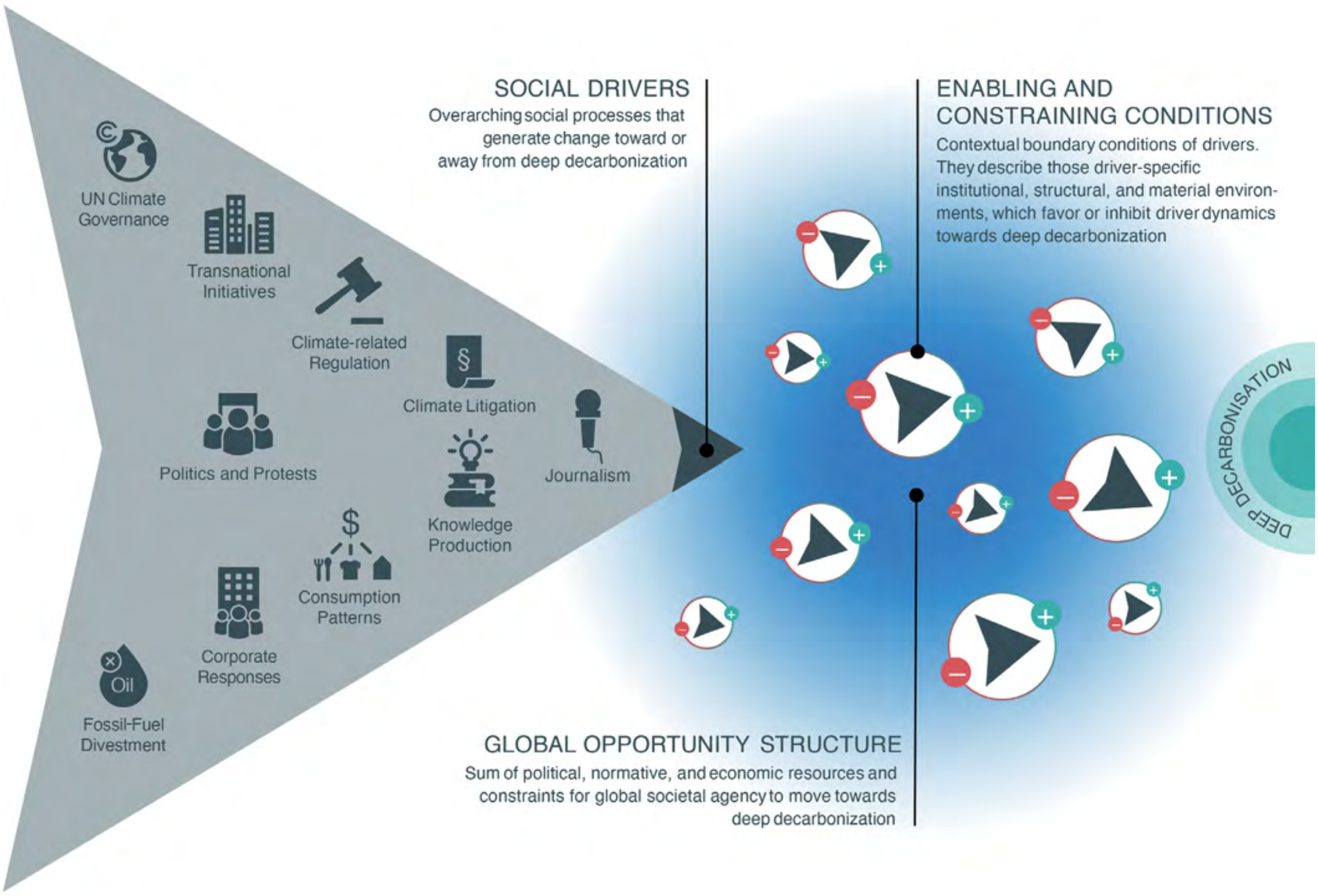

Figure 3.1: Social Plausibility Assessment Framework from the Outlook 2021. The figure shows the chosen climate future scenario, deep decarbonization (right), and the selected key social drivers of deep decarbonization (left). The assessment of the driver dynamics (center), their enabling and constraining conditions, and the global opportunity structure lead to a conjecture about the plausibility of the future scenario.

Guiding questions

To apply the assessment framework and include a stronger focus on relationality between drivers, we structured our work on updating the driver assessments through the following questions:

- Do you identify key events or dynamics since the publication of the Outlook 2023 that have shaped/changed the driver assessment?
- Do you see anything that is strongly enabling or constraining the driver dynamic toward deep decarbonization?
- If you look at the literature, have any new major studies been published on the driver?
- What resources generated by other drivers are being used by this driver?
- Does your driver assessment have any implications for the question of climate change adaptation?

The author teams for each driver started with group discussions to identify key events and publications relevant for their respective driver assessment. Discussions on relationality were conducted across the driver teams. In addition to relevant work produced within CLICCS, the author teams conducted a literature review focusing on new studies that had appeared since 2022 and that have received attention by the scientific community. The teams were specifically encouraged to include epistemic perspectives and studies as well as authors from the Global South. By sending two previous versions of the driver assessments to our team of international reviewers, the assessments underwent the same quality control as other chapters of the Outlook.

3.2

UN Climate Governance

UN climate governance comprises state-led cooperation under the umbrella of the UN Framework Convention on Climate Change (UNFCCC) and the Paris agreement, evolutions within the wider climate change regime complex, and climate-related activities of other international organizations. The wider climate change regime complex comprises other regulatory regimes that have an impact on climate governance and climate-related activities of UN organizations, other international agreements, and multi-lateral processes that have implications for climate change but do not fall under the Conference of the Parties (COP) process of the UNFCCC.

Key social driver dynamics since the previous Outlook

Since the last assessment (Aykut et al., 2023), a series of developments affected the dynamics of global cooperation within and outside the UN climate change regime. Overall, the evidence reviewed here suggests that the driver's contribution to deep decarbonization remains significant, but that it has slightly weakened as a result of these developments.

Despite geopolitical crises and conflicts that threatened to overshadow climate issues, COP27 in Sharm-el-Sheikh, Egypt, and COP28 in Dubai, United Arab Emirates, attracted record numbers of participants—39,000 and 85,000, respectively (Günel 2024)—and high levels of global media attention. The conferences implemented the final phase of the so-called Global Stocktake, a review cycle created by the Paris Agreement that prepares the submission of new country pledges (Nationally Determined Contributions or NDCs) by 2025. The Global Stocktake is important because global greenhouse gas emissions increased by 1.2% from 2021 to 2022 to reach a new record of 57.4 Gt of CO_2 equivalent ($GtCO_2e$), putting the world on track to crossing the Paris Agreement's temperature threshold of 1.5°C within this decade (UNEP, 2023a). Against this backdrop, negotiations made only limited progress on mitigation. At COP27, observers criticized the side-lining of discussions on mitigation ambition, the glacial pace of decarbonization (Masood et al., 2022), and a record number of unresolved agendas (Arora and Arora, 2023). The final decision merely reiterates the COP26 compromise of a "phasedown of unabated coal power and phase-out of inefficient fossil fuels subsidies" (UNFCCC FCCC/CP/2022/10/Add.1, §13). The conclusion of the Global Stocktake process at COP28 was more successful. The final decision contains for the first time a call to "transition away from fossil fuels in energy systems" and encourages parties to accelerate the shift toward renewable energies and energy efficiency (UNFCCC FCCC/PA/CMA/2023/L.17, §28a,d). This is undoubtedly a step forward, even though earlier drafts of the Global Stocktake conclusions contained even more direct language about phasing out fossil fuels. Moreover, the final text's references to carbon capture, utilization and storage, and low-carbon fuels (which can be read as an allusion to natural gas) could be used to justify further delays and bets on unproven technological solutions (Chandrasekhar et al., 2023). Negotiations did also progress in other areas. For example, the establishment of new funding arrangements for Loss and Damage at COP27 and the creation of a dedicated fund at the first day of COP28 constitute an important breakthrough after a decade of negotiations.

Outside of the negotiations, new climate policy initiatives were launched on a range of issues. Building on the Glasgow Forest and Land Use Declaration, a "forests and climate leaders' partnership" was announced at COP27, and the final declaration included a forest section and a reference to "nature-based solutions" (Arora and Arora, 2023). One week later at the G20 Bali summit, ministers from Indonesia, the Democratic Republic of the Congo, and Brazil announced a South-South rainforest leadership alliance. However, the Three Basin Summit held in October 2023 in Congo Brazzaville fell short of securing significant progress on reducing deforestation and forest degradation. New initiatives announced at COP28 include a pledge by over 130 countries to triple the world's renewable energy capacity by 2030 and double the annual rate of energy efficiency improvements (these objectives were later included in the Global Stoketake), a Joint Statement on the need to phase out fossil fuel subsidies, an Oil and Gas Decarbonisation Charter signed by major oil companies to reduce methane emissions, and a Declaration on Sustainable Agriculture, aimed at creating more resilient and climate-friendly food systems. However, there were also significant setbacks. The G20 meeting in India in July 2023, which brought together countries responsible for 80% of global greenhouse gas emissions—among which China accounts for 30%, the USA for 11%, and the European Union and India for 7% each (UNEP, 2023a)—did not yield any tangible outcome on renewable energies and fossil-fuel phase out. The absence of the Presidents of China, France, and the US at the Climate Ambition Summit convened by the UN Secretary-General in September 2023 and the failure of the US and China in pledging funding to the Green Climate Fund at the replenishment conference in October 2023 indicate an overall decline in climate commitments. Moreover, 12 new or updated country pledges have been submitted before, during or after COP28, bringing the total number of new NDCs since the Paris agreement to 149 as of 20 December 2023 (UNFCCC Nationally Determined Contributions Registry). According to the United Nations Environment Programme (UNEP) Emission Gap report, while more NDCs now contain economy-wide greenhouse gas reduction targets, and although implementation gaps have been reduced in some G20 countries, overall ambition remains insufficient, as current country pledges would lead to an estimated 2.5°C— 2.9°C warming this century (UNEP, 2023a).

More generally, recent studies cast doubts on the effectiveness of the Paris Agreement's ambition and orchestration mechanisms. Instead of rigorous peer monitoring aimed at naming and shaming laggards to raise ambition, existing assessment exercises have often "provided occasions for 'claiming and shining' through selective and punctual reporting" (Aykut et al., 2022b, p. 191). And even when failures are publicly addressed, this appears to be effective only in a limited number of countries with "high quality political institutions, strong internal concern about climate change, and ambitious and credible international climate commitments" (Dannenberg et al., 2023, p. 1). Catalytic impacts of orchestration on nonstate climate action have also not broadly materialized so far (Teunissen and Chan, 2024). The effectiveness of voluntary initiatives even appears to be trending downwards (New Climate Institute et al., 2022). As a result, a growing body of evidence suggests that the "global target-setting approach to solving climate change, driven by competitive national virtue signalling or shame avoidance, is reaching diminishing returns" (Dubash, 2023).

Developments within the wider climate change regime complex have been more encouraging, prefiguring a gradual, albeit still uncertain, reinforcement of international climate finance. First, Just Energy Transition Partnerships (JETPs) gained traction as a climate governance instrument, following a USD 8.5 billion deal with South Africa announced during COP26. The donor pool includes the International Partners Group and the Glasgow Financial Alliance for Net Zero (GFANZ) Working Group. Additional deals have been concluded with Indonesia, Vietnam, and Senegal. However, concerns have been raised that this mechanism may inadvertently finance the development of new fossil fuel infrastructure, including gas projects. Second, there has been a significant push toward mainstreaming climate concerns in global development finance by reforming lending strategies of multilateral banks and international organizations. The final document of COP27 for the first time backed a reform of the International Monetary Fund (IMF) and the World Bank (Masood et al., 2022). Calls for increasing and redirecting the banks' lending capacities toward climate-friendly projects receive increasing international support, including by newly appointed World Bank President Ajaypal Singh Banga. These debates were also at the center of the Summit for a New Global Financing Pact in Paris in June 2023. Initiated by Prime Minister Mia Mottley of Barbados and President Emmanuel Macron of France, its stated aims were to ramp up international climate finance, initiate broader reforms of the Bretton Woods System, and provide debt relief to poor countries.

With regards to other climate-relevant areas of UN governance, new treaties have been adopted concerning high seas and marine biodiversity protection, and discussions have started on the adoption of an international agreement to regulate plastic waste. The Kunming-Montreal Global Biodiversity

Framework adopted in 2022 establishes a common goal of conserving 30% of land, oceans, coastal areas, and inland waters by 2030. Developed countries also committed to investing USD 200 billion annually in biodiversity initiatives, which resulted in the launch of the Global Biodiversity Framework (GBF) Fund in August 2023. These parallel processes have important implications for the preservation of natural carbon sinks (IPCC, 2019a; IPCC, 2019b, p. 20). Furthermore, the Energy Charter Treaty, widely considered a major obstacle to a rapid decarbonization, has been significantly weakened. The European Court of Justice ruled that the treaty is not competent to handle legal disputes among EU member states, and several countries (France, Germany, Luxembourg, Netherlands, Poland, Slovenia, Spain) have decided to withdraw from the treaty. The European Parliament also adopted a resolution, urging the Commission to exit the treaty, in November 2022.

In sum, this driver's dynamics have been marked by growing resistance and even a risk of backsliding in the UN climate change regime as well as increasing doubts over the effectiveness of the Paris Agreements' ambition and orchestration mechanisms. These developments have been partly counterbalanced by the first ever mentioning of a transition away from fossil fuels in a COP decision, positive developments in the climate change regime complex, and wider UN governance on issues such as biodiversity, development finance, and energy investments. The concrete effects of the Global Stocktake and the outcome of debates over global financial reform will be crucial to watch in the upcoming year.

Enabling and constraining conditions affecting driver dynamics

Several of the context conditions for global cooperation have been affected by rising international tensions since the publication of past Outlook editions. Overall, our current assessment indicates little hope that the existing trend of the driver's limited contribution to deep decarbonization will be reversed in the near future.

In terms of world politics, the times for multilateralism are more difficult than ever since the signature of the Paris agreement in 2015. The ongoing war in Ukraine and rising global tensions after Hamas' attack on Israel on 7 October 2023 and Israel's ensuing bombing and invasion of Gaza pose major obstacles to global cooperation. US-China tensions remain important but seem contained for the moment. A meeting between US-President Joe Biden and Chinese General Secretary Xi Jinping took place in November 2023, in the aftermath of which the bilateral working group on climate issues that was paused last year resumed its work.

National policy environments are in constant flux, and a full assessment is outside the remits of this Outlook (see also Section 3.4). Developments that appear particularly significant for UN climate governance include record installations of low-carbon electricity generating capacity in China, particularly wind and solar. Together with a rebound in hydro output, this has observers projecting a drop in Chinese emissions in 2024 and possibly the start of a phase of structural decline of emissions thereafter (Myllyvirta, 2023). In Brazil, the election of President Lula da Silva has nourished hopes for a return of the country to climate ambition and yielded first results in terms of actions against deforestation. In the US, the Inflation Reduction Act (IRA) have produced some strong results while the victory of Republicans in the mid-term elections might well compromise future climate policy initiatives in Congress. The UK government under Prime Minister Rishi Sunak has significantly weakened climate policy ambitions by approving new oil and gas explorations and even a new coal mine in Cumbria. Climate action in a number of European countries (for example Germany, France, and Sweden) has been slowed down, partly due to a rising tide of right-wing and climate-skeptic populism (Boecher et al., 2022; Lockwood and Lockwood, 2022). The EU Green Deal also appears under pressure after the resignation of Vice President and Climate Commissioner Frans Timmermans, and in the wake of a high-risk European election in 2024.

Social movement pressure persists and at times intensifies in some countries, but overall stays very far from pre-pandemic levels of mobilization. In Europe, new and more confrontational tactics gained momentum over the past year with groups such as Just Stop Oil, Last Renovation, and Letzte Generation. However, opinion polls appear to indicate a potential risk of backlash related to these protest forms (see also Section 3.5).

In energy technologies and markets, the consequences of the energy crisis sparked by the Russian invasion of Ukraine are still not fully understood. On the one hand, high energy prices underscore the benefits of energy efficiency measures and prompted behavioral and technological changes to reduce energy use in some countries. International Energy Agency (IEA) data indicates that long-term investments since the Ukraine war might have reinforced renewable energy sources rather than fossil fuels (IEA, 2022). The agency also projects significant effects of the US Inflation Reduction Act on low-carbon investments, as global clean energy investments could see an increase of 50% by 2030, with annual solar and wind capacity additions in the US even growing. Overall, global energy investments in 2023 stand at an estimated USD 2.8 trillion, USD 1.7 trillion of which were directed to low-carbon sources (USD 382 billion to solar alone). On the other hand, a total of USD 1 trillion were still invested into unabated fossil fuels, USD 371 billion of which into oil, and USD 150 billion into coal (IEA, 2023d). While 2022 and 2023 were marked by record additions in renewable energy capacity, they were also record years for oil majors, complete with announcements of high-profile mergers in the sector, new oil and gas explorations, and major investments in fossil infrastructures. Moreover, short term effects of the global energy crisis include rising poverty and inequalities around the world. This has fueled contestations in the agriculture sector throughout Europe, following national measures aimed at reducing fossil fuel subsidies. The EU's diversification strategy in gas supply has also accentuated the vulnerability of gas importing countries from Asia and the Global South. This creates looming risks of recession, poverty traps, and new conflicts in many regions of the world.

All this has ushered a return of energy security scripts in public debates, which are increasingly used to legitimize the return to fossil fuel extraction and combustion. Despite these concerns, opinion polls around the world show that public support for climate action remains strong. This is particularly true for liberal democracies and countries that do not depend on fossil fuels for their electricity (Kenny, 2023). In many countries, media coverage of recent extreme events, as well as of the publication of the IPCC Synthesis Report of its Sixth Assessment Report in March 2023, have also constituted significant resources for climate-related agenda setting, reporting, and activism (IPCC 2023a).

Major studies published since the previous Outlook edition

Since the compilation of the previous Outlook, a range of studies and research papers have been published on UN governance. Among these, Masood and colleagues (2022) and Arora and Arora (2023) examine the outcomes of COP27. Aykut et al. (2022b), Dannenberg et al. (2023), and Teunissen and Chan (2024) analyze and assess practices of soft coordination and orchestration in the post-Paris regime.

In addition, there have been publications on the impact of the pandemic and some early assessments concerning the impact of the Russia-Ukraine war on global energy politics (IEA, 2022; 2023a). The IPCC Synthesis Report (IPCC, 2023a), the NDCs Synthesis Report (UNFCCC, 2022a), and the Emissions Gap reports (UNEP, 2023a), among others, provide important information of the current state of global climate science and global cooperation as well as crucial inputs for the Global Stocktake.

Generation of climate action resources and uptake from other drivers

NDCs are a product of climate-related regulation and a key ingredient of the Paris process. Positive examples of government action are also used as best practices in COP events. Reports (packaged knowledge) produced by the IPCC (for example the Synthesis Report of its Sixth Assessment Report published in March 2023), by international organizations (for example UNEP's emissions gap report), and global research projects (for example the Global Carbon Project) are used in the Global Stocktake of the Paris Agreement and other UNFCCC processes.

Climate protests, successful climate litigation cases, and media frames of extreme events are used as discursive resources by NGOs, UN and state representatives in negotiations, and plenary sessions at climate COPs (Aykut et al., 2022a). Transnational initiatives and net-zero pledges by companies and subnational actors are used to build momentum during climate COPs (Teunissen and Chan, 2024).

Due to its centrality in the coordination of global responses to climate change, UN Governance also produces a large number of resources for other drivers. Over the past years, the UN has contributed to forging Net Zero Standards for firms, investors, and civil society. An important step has been the establishment, by UN Secretary General António Guterres, of a High-Level Expert Group on the Net-Zero Emissions Commitments of Non-State Entities, which published its final report "Integrity Matters: Net Zero commitments by Businesses, Financial Institutions, Cities and Regions" at COP27.

Much like COP27, COP28 in Dubai provided a networking platform and media opportunities for transnational initiatives, states, cities, and companies. Civil society organizations and climate activists also used the COP to build networking capacities and circulate media frames, although conditions for access and mobilization for critical, activist social movements were more difficult in Dubai than in liberal democracies.

The First Global Stocktake concluded with an important, albeit not unequivocal, signal to transition away from fossil fuels. It also provided an unprecedented amount of data and analyses, from country reports, communications, and voluntary submissions via synthesis reports produced by the UNFCCC secretariat and the COP's subsidiary bodies to a wide range of submissions by non-partisan stakeholders. It also helped place a global media focus on gaps in policy ambition and implementation, both in terms of mitigation and provision of finance. The data and analyses compiled in the Global Stocktake can be used by other drivers, including in climate litigation cases.

Implications of driver dynamics for climate change adaptation

Negotiations are ongoing on the framework for the Global Goal on Adaptation. The Glasgow-Sharm el-Sheikh work program was agreed upon at COP26 in Glasgow in 2021 and includes a two-year work program as well as four workshops per year. Its objective is to provide input for the Global Stocktake. COP27 has also provided some progress on national adaptation plans (NAPs). As of November 2023, 49 countries have submitted such plans in which they articulate their adaptation priorities and needs. Importantly, discussions on Loss and Damage also address growing preoccupations on adaptation failure, or the impossibility to adapt to some global warming impacts. COP27 made progress on the governance structure of the Santiago Network on Loss and Damage and reached consensus to establishing a dedicated fund. COP28 selected the United Nations Office for Disaster Risk Reduction and the United Nations Office for Project Services as the hosts of the Santiago Network secretariat. Progress was made in discussions on a Global Goal on Adaptation, where a framework with objectives and a new work program to develop indicators was adopted. However, discussions on a new quantified goal for climate finance did not make significant advances. Moreover, new adaptation criteria were included in the Global Climate Action portal to encourage transnational initiatives, businesses, and cities to also report on adaptation.

3.3

Transnational Cooperation

Transnational cooperation encompasses diverse forms of coordination that cut across traditional state-based jurisdictions and operate across public and private divides (Bulkeley, 2014). Transnational cooperation happens, for example, within city networks, business self-regulation initiatives, transnational initiatives of NGOs, and public-private partnerships (Scheffran et al., 2021). It contributes to climate governance mostly through advocacy and policy monitoring to exert pressure on national governments, or through establishing voluntary arrangements, rules and standards for corporate, subnational or financial entities operating transnationally (Bäckstrand et al., 2017; Green, 2017).

Key social driver dynamics since the previous Outlook edition

Since the most recent assessment of this driver (D'Amico et al., 2023), the evolution of many of these initiatives and the ways in which they cooperate toward collective effects to mitigate climate change has been constant rather than defined by singular key events or sudden dynamics changing the strength or direction of the driver. Nevertheless, media attention around the annual UN Climate Change Conferences is used for expanding existing networks or presenting new initiatives. The sheer number and diversity of transnational cooperation complicates a global assessment, but six positive dynamics can be observed: (1) Many initiatives have seen a growth in the numbers of their members or an expansion of their activities (New Climate Institute et al., 2022; UNFCCC, 2023). (2) There is increasing transnational cooperation toward improving ambition, transparency, and accountability, particularly in terms of expanding and standardizing reporting and net-zero target setting (Net Zero Tracker, 2023; Science Based Targets initiative, 2024). For instance, the Say on Climate Initiative supported by the Children's Investment Fund Foundation incentivizes companies to establish robust net-zero transition plans with shareholder feedback in an annual advisory vote. Climate-related corporate and financial reporting rules have substantially strengthened in 2023, particularly in the European Union but also in other parts of the world, potentially driving a more sustainable economy (Task Force on Climate-related Financial Disclosures, 2022; Epstein, 2023). (3) Some initiatives are moving closer toward concrete planning, for example by providing sectoral decarbonization pathways or by promoting transition plans for specific industries or cities (Boehm et al., 2022; Sokolowski et al., 2023). (4) Indigenous activism has become increasingly visible. For example, the new operational work plan of the Local Communities and Indigenous Peoples Platform (LCIPP) adopted in Glasgow aims to facilitate the exchange of Indigenous knowledge and resources and their participation in the UNFCCC regime (UNFCCC, 2022c). (5) Adaptation is becoming a more important part of activities in the field of transnational cooperation pushed by UN climate governance institutions, for example by promoting large campaigns, such as the Race to Resilience campaign (UNFCCC 2022b, 2023). (6) Interrelations between climate change and other environmental topics, such as biodiversity, are receiving more attention (Widerberg et al., 2022). Major empirical developments in this regard are the 2022 UN Biodiversity Conference on biodiversity in Montréal, in which many non-state actors participated, or the updates and emergence of new reporting standards and frameworks, such as the Global Reporting Initiative's standards for biodiversity, the Task Force for Nature-related Financial Disclosure and the European Sustainability Reporting Standards on biodiversity and ecosystems. Despite these positive developments, initiatives for transnational cooperation are mostly framed as the panacea to sustain the dominant paradigm of liberal economies and global markets. Rising conflicts around the world, increasing tensions in world politics, and protectionist policies (see Section 3.2) are direct challenges to the governance model purported by transnational initiatives.

Enabling and constraining conditions affecting driver dynamics

Past assessments identified several enabling conditions for a movement toward deep decarbonization, including the existence of a business case for sustainability and a strong institutional design. The past years have seen continued attempts to create common rules and principles at organizational levels strengthening the institutional environment supporting decarbonization. This trend continues, as several international guidelines and (voluntary) standards are currently being developed or prepared for implementation. These include the ISO norm 14068, which provides clear definitions for climate neutrality pledges by organizations, companies, cities, and municipalities; the International Sustainability Standards Board's Disclosure Standards (ISSB); and the European Sustainability Reporting Standards (ESRS). Both address the consolidation of information on companies' and financial institutions' governance, strategy, risk management, targets, and metrics related to climate change. As a result, there have been some improvements in accountability and ambition levels in the sense that these new standards are becoming mandatory for operating in some jurisdictions and markets (Task Force on Climate-related Financial Disclosures, 2022). However, the standards differ in their level of stringency. While the European Sustainability Reporting Standards will adopt a so-called double materiality approach that includes the (financial) impact of climate change on companies as well as the companies' impact on climate change, the International Sustainability Standards Board's Disclosure Standards follow a single materiality approach and so are focusing on climate-related financial risks for companies only. Maintaining the double materiality approach can be regarded a success. However, the European Parliament has also considerably reduced the number of disclosure requirements suggested in the first drafts of the European Sustainability Reporting Standards in their final adoption and proposed to postpone some aspects, such as sector-specific disclosures, for two years until 2026 (European Commission, 2023; 2024). In addition, a group of critical watchdogs, such as the New Climate Institute, Camda, or Climate Action Tracker, highlights the poor quality of disclosure and the lack of robust targets, questioning the methodology and results of leading transparency and target setting NGOs such as CDP or the Science Based Targets initiative (Day et al., 2023; Net Zero Tracker, 2023).

Past assessments identified several constraining conditions, which remain relevant. Among them are a lack of resources, funding, and efficiency for non-state commitments. For instance, cities came out of the COVID-19 pandemic with strained financial resources, inflation issues, unemployment, and resource scarcity, which may negatively affect their transnational cooperation. At the same time, rising energy prices and the experience of extreme weather events highlight the need for exchanging practices for climate resilience, especially with a view on critical infrastructure (Global Covenant of Mayors for Climate & Energy, 2022). Furthermore, there is a persistent regional inequality with a strong over-representation of and large influence by organizations from developed countries of the Global North, such as the US and European countries (Kaiser, 2022; NewClimate Institute et al., 2022; Papin and Beauregard, 2023). This poses considerable justice issues, as climate responses continue to be framed by actors of the Global North, who are also the main perpetrators of environmental damages (Callahan and Mankin, 2022). Even though Indigenous voices may receive increasing recognition, for example through facilitating participation in the UNFCCC regime or in meetings around the Belém Declaration, transnational coalitions of Indigenous Peoples and local communities continue to face considerable constraints to influence climate politics. Among them are tokenism, lack of political will, and a lack of effective recognition of their role to maintain large stretches of preserved ecosystems (Belfer et al., 2019; Carmona et al., 2023; Dwyer et al., 2023). Finally, the geopolitical developments around Russia's invasion of Ukraine and the rising global tensions after Hamas' attack on Israel on 7 October 2023 and Israel's ensuing bombing and invasion of Gaza may further complicate transnational cooperation. In sum, the enabling conditions for transnational cooperation contributing to deep decarbonization are becoming slightly more favorable, while the main constraining conditions remain powerful and persistent. In this sense, we do not see any strong change in the overall driver assessment.

Major studies published since the previous Outlook edition

New publications highlight the following topics: Fankhauser et al. (2022) investigate transnational norm-making activities around net-zero and argue that seven attributes are important factors for making net-zero a successful framework for climate action. These attributes relate to the urgency of reducing emissions, the integrity of removals and offsets, and the consistency of climate action with other sustainable development goals (SDGs). Mai and Elsässer's (2022) critical view on the role of data shows that new data, data infrastructures, and actor constellations around the Global Climate Action Portal have changed because of a shift from using data to orchestrate and leverage non-state actor commitments toward tracking and animating implementation activity. Drawing on the analysis of Mexico City and Lima, Leal and Paterson (2023) argue that the C40 city network promotes particular forms of investment, pursuing the interests of transnational capital and assembling combinations of actors to generate this effect. This coerces cities to prioritize climate mitigation over adaptation, over-riding local preferences and ignoring local expertise. As a result, C40 potentially undermines the capacity for such cities to generate their own solutions. Papin and Beauregard (2023) provide a critical reflection on the influence of billionaire entrepreneurs on global climate governance. Taking the example of Michael Bloomberg, co-founder and former chair of the C40 network, they argue that this influence is centered on depoliticization, outgrouping, and technical solutionism. While these dynamics might generate short-term legitimacy, it risks undermining long-term goals of addressing climate change. A more positive role of city networks is highlighted by Picavet et al. (2023), who argue that these networks have a pivotal role in strengthening the capacity for collaborative governance by capacity building through providing structural arrangements, leadership, knowledge and learning, and resources. Another critique points to the still existing strong North-South imbalances in transnational climate change governance, present not only at the UN level but also among sub-state and non-state actors (Kaiser, 2022; NewClimate Institute et al., 2022). In the case of cities, Leffel et al. (2023) recently questioned the polycentric character of transnational municipal networks. They argue that a small fraction of economically strong cities is powerful in diffusing their agendas and innovations through participating in multiple initiatives.

Generation of climate action resources and uptake from other drivers

Transnational cooperation is interdependent with other drivers. On the one hand, many resources of the global opportunity structure underpin the growth in size of networks and initiatives, as well as the deepening of activities and strengthening of the connection between ideas, goals, and implementation activities. Firstly, whereas transnational cooperation has emerged as a direct response to the absence or the ineffectiveness of binding rules at the UN or national regulation levels, recent improvements in these drivers have provided enhanced resources to the stringency and reach of transnational cooperation. UN summits and orchestration from UN institutions have supported the development of new standards, for example with the Recognition and Accountability Framework for integrity in setting net-zero pledges and policies for accountability (Mai and Elsässer, 2022). In addition, it created more direct and binding opportunities for connecting with bottom-up initiatives (COP27 Presidency, 2022b) and promoted new multi-stakeholder coalitions for sectoral decarbonization pathways (Hermwille et al., 2022). Furthermore, improved access to presidencies and high-level state delegates provides better international and national agenda-setting opportunities to Indigenous Peoples and local communities (Belfer et al., 2019). However, while UNFCCC's focus on themes, mobilization of transnational initiatives, and emphasis on minimal requirements for institutional robustness can positively influence the effectiveness of transnational engagement, an assessment of the effectiveness of these developments is still difficult (Chan et al., 2022). Secondly, regulation provides essential resources for the uptake and development of transnational rules and standards (D'Amico et al., 2023). In the European Union, the recent revision of the Corporate Sustainability Reporting Directive (CSRD) has made sustainability reporting mandatory for large companies, thus considerably strengthening the role of standard transparency schemes as a basis for changes in companies' responses (Epstein, 2023). Thirdly, there is a constant uptake of frames, tools, and indicators from the outputs of the driver of knowledge production, as well as sourcing of best practices from corporate responses and city experimentation. Fourthly, external pressure such as transparency requests from financial investors for pursuing divestment strategies, or climate movements demanding enhanced accountability for emitters, are influencing corporations' and municipalities' adoption of transnational rules and standards (Epstein, 2023). However, these pressures might pursue divergent objectives or have limited reach and thus need further investigation.

Transnational cooperation also generates numerous resources for other drivers. It helps strengthening UN Climate Governance by sending signals of societal mobilization and joining sectoral coalitions to design decarbonization pathways, such as the Marrakesh Partnership or the recent Sustainable Urban Resilience for the Next Generation (SURGe) initiative (COP27 Presidency, 2022a). Even if only voluntary, corporate sustainability standards provide inputs for climate litigation cases, for example Shell Milieudefensie et al. vs. Royal Dutch Shell plc., and are sometimes one source, among others, for strengthening national regulation (Global Climate Change Litigation database, 2022). In addition, private sector initiatives and city networks contribute to disseminating norms (for example net-zero, reporting) which are supposed to be picked up by corporations or cities as a basis for rethinking their operations and services in response to climate change (Leffel, 2022; C40, 2022) or generate knowledge and best practice examples for industry-specific or regional challenges (Revi et al., 2022).

Implications of driver dynamics for climate change adaptation

In the wake of the Sharm-El-Sheikh Adaptation Agenda (COP27 Presidency, 2022b), activities in the field of transnational cooperation have also embraced adaptation-related issues. City networks have launched a number of initiatives to support local planning and the exchange of experiences on water management, heat stress, early warning system and emergency response plans for extreme climate events, renaturalization of city areas and protection against sea-level rise (i.e., C40 initiatives). Especially nature-based solutions are fostered as promising solutions to address both mitigation and adaptation challenges in urban areas and ensure more resilient and livable cities. The trend toward more disclosure includes vulnerability assessments to physical climate risks and adaptation matters, both for cities and corporations. In 2022, for example, 2021 cities reported their main hazards (Global Covenant of Mayors for Climate & Energy, 2022), while the increasing adoption of the Task Force on Climate-related Financial Disclosure (TCFD) framework promotes the assessment of physical risks and adoption of risk management strategies among companies (Task Force on Climate-Related Financial Disclosures, 2022). Overall, there are some signs that transnational cooperation increasingly understands mitigation and adaptation as complimentary and related actions. However, further integration of transdisciplinary approaches to adaptation that include traditional sustainable practices and Indigenous knowledge are paramount (Baker et al., 2023)

3.4

Climate-Related Regulation

Climate-related regulation refers to legislation and regulations issued by national and supranational government bodies with the intention of limiting or reducing the concentration of greenhouse gases in the atmosphere. It creates the bounds for legal operations and shape the incentive structure for companies, households, and other actors that are the immediate loci of greenhouse gas emissions. The extent to which climate-related regulation is able to induce technological and behavioral change toward low-carbon modes is a key component of the social plausibility of deep decarbonization scenarios (Engels et al., 2023).

Key social driver dynamics since the previous Outlook edition

The implementation gap, that is, the difference between a jurisdiction's emissions-reduction pledges and the actual projected reductions given the current set of regulatory instruments in operation (Perino et al., 2022), which was at the heart of the previous assessment of climate-related regulation, has been independently confirmed both conceptually (Fransen et al., 2023) and empirically (Rogelj et al., 2023; United Nations Environment Programme, 2023a). Marquardt et al. (2023) provide further conceptual insights on the origins of the implementation gap in the Global South. The most recent UNEP Emission Gap Report finds that the global implementation gap has halved from 3 $GtCO_2e$ to 1.5 $GtCO_2e$ since the previous report (UNEP, 2023a, p. XIX). Moreover, the gap does not move along usual default lines such as industrialized countries versus the Global South (Fransen et al., 2023, p. 755) and varies highly from country to country and among sectors (UNEP, 2023a, p. XIX; Climate Action Tracker 2023; Burck et al., 2024).

An important event at the international level is the crisis of the Energy Charter Treaty, which may make a difference for fostering more substantial climate-related regulation. The fear of investor-to-state disputes meant that European climate policy-makers abstained from more radical decarbonization agendas, yet the walk-out of Italy, France, Germany, the Netherlands, Poland, and Spain created momentum for an EU-wide exit (Ekardt et al., 2023). At the same time, the expansion of the treaty to West African countries and to the MENA region means that these countries are at risk to face investor-to-state-disputes and to liberalize their energy economies at a point where this may pose a threat to local small and medium energy enterprises.

In August 2022, the Inflation Reduction Act was adopted in the US, which constitutes a substantial investment in emission reductions. It reduces the implementation gap in the US substantially but is not expected to close it entirely (Bistline et al., 2023).

In early 2023, the EU passed key components of its Fit-for-55 package, implementing the European Green Deal's ambitions of climate neutrality until 2050 and an overall emissions reduction until 2030 of 55% compared to 1990. Specifically, it involved a redesign of the existing Emissions Trading System, with more ambitious reductions targets and a wider scope that now includes shipping. The Carbon Border Adjustment Mechanism was added to the system introducing a carbon price on the import of certain products. A second stand-alone emissions trading system has been legislated for the building and transport sectors, which will become operational in the second-half of the decade. The new emissions trading system is supplemented by the Social Climate Funds with a budget of EUR 86 billion to protect vulnerable households from adverse distributional effects (EU Commission, 2023). Taken together, the adoption of key components of the Fit-for-55 package constitute a major step toward closing the implementation gap in the EU compared to previous year's assessment.

In the Global South, Chile is an extraordinary case. It has recently adopted a comprehensive framework law on climate change, aiming at Carbon neutrality by 2050 (Government of Chile, 2022). India has updated its nationally determined contributions in 2022, including stronger ambitions on renewable energy production, but the contributions are still considered to be insufficient regarding the Paris Agreement (Climate Action Tracker, 2022). Costa Rica has climate policies in place that are 1.5°C-compatible. The progressive policies for the electrification of its national transport sector are pioneering (Climate Action Tracker, 2023). China is on the brink of reaching its renewable energy capacity objectives for 2030, possibly achieving them as early as five years in advance (Global Energy Monitor, 2023). Nevertheless, as nations discuss whether to gradually reduce or eliminate coal usage, around 2,100 GW of coal-powered plants are currently operational, and approximately 560 GW of new coal-powered plants are in development, primarily in developing nations such as China, India, Indonesia, and Bangladesh (Global Energy Monitor et al., 2023; Boehm et al., 2023, p. 3-12).

The US and the EU have made major steps toward reducing the implementation gap. The overall performance of the EU, however, is a combination of union-wide policies and climate-related regulation by member states. To illustrate, we report on relevant changes in Germany that have occurred since the previous Outlook. In Germany, the movement seems to be sidewards, with process in some areas and drawbacks in others.

The Federal Climate Protection Act sets climate targets and serves to coordinate various sectoral policies. The amendment currently debated in parliament aims at changing the monitoring mechanism. So far, monitoring is based on sector-specific annual emission targets. Exceeding them led to the obligation to draw up an immediate action program for the respective sectors. The proposed amendment introduces projection data as a new basis for monitoring. Only if the projections indicate that aggregate annual emission targets for the years 2021 to 2030 will be exceeded for two consecutive years, the government has to implement additional measures. The government promotes the reform as an increase in flexibility, foresightedness, and hence efficiency. However, the German Advisory Council on the Environment (SRU) criticizes the turn away from sector-specific targets as a dilution of responsibility and the replacement of past emissions by projections as being more susceptible to outcome-driven assumptions (SRU, 2023).

Positive effects are expected from amendments to the Renewable Energy Act that now assigns the status of a privileged status to construction and operation of renewable energy plants. Competing interests are to take precedence only in exceptional cases. In November 2023, a judgment by the Federal Constitutional Court sent shock waves through Germany climate policy by ruling that a law channeling EUR 60 billion into climate mitigation measures was unconstitutional (Bundesverfassungsgericht, 2023). It is too early to fully assess the repercussions of this decision, but it is highly likely to increase the implementation gap in Germany.

Overall, the implementation gap has been reduced but is still sizable.

Enabling and constraining conditions affecting driver dynamics

The prevailing concerns about the social impacts of climate policy continue to constrain implementation of stringent climate policy instruments (Vona, 2023). The debates ahead of passing the German Heating Law and the German intervention on the ban of combustion engines at the EU level serve as examples. There is mounting empirical evidence on the constraining role of right-wing parties (Huber et al., 2021; Kulin et al., 2021; Lockwood and Lockwood, 2022). Climate protests by the Fridays for Future movement have been shown to substantially increase voting shares for the Green Party in Germany between 2019 and 2021 (Waldinger et al., 2022) and the movements' decentralized approach to best accommodate behavioral patterns (Jarke-Neuert et al., 2023). More recently there has been an increasing trend of polarization over climate policy, with climate activists resorting to more disruptive actions such as blocking streets and attacking works of art on the one hand, and the rise of climate-skeptic parties on the other (Zilles and Marg, 2022). Internationally, the recent increase in interest rates has also been flagged as a constraining factor in renewable deployment (Pahle et al., 2022).

While social impacts, right wing populism, and a growing polarization are constraining conditions in some European countries, there are still other factors pointing to continued or even increased domestic extraction of fossil fuel reserves. In particular, the persistence of the production and use of coal despite health risks (Barbhaya et al., 2022) and high local pollution levels (Romana et al., 2022) deserves further scrutiny (Jakob and Steckel, 2022), as it foils decarbonization gains made by the growth of renewable energy production. China, while showing the fastest growth in wind and solar energy, is at the same time both the largest producer and consumer of coal, with India the second largest in terms of total quantities. More generally, there are strong coalitions between governments or political parties and the coal industry (Clark and Zucker, 2023) while local protests are oppressed (Fünfgeld, 2019). The legitimacy of continued coal exploration is often high in countries where large shares of the population still lack access to electricity and coal reserves are abundant, for example in India and Colombia. It is important to note that the enabling and constraining conditions for the continued production and use of coal in countries of the Global South are regionally diverse (Jakob and Steckel, 2022).

Major studies published since the previous Outlook edition

As stated above, the existence of the implementation gap and the conceptual framework explaining its existence that have been put forward in the previous Outlook and an associated paper (Perino et al., 2022) have been independently confirmed (Fransen et al., 2023; Rogelj et al., 2023). For the Global South, Marquardt et al. (2023) systematize the field of climate mitigation efforts based on an extensive literature review. They analyze how climate change mitigation is institutionalized and suggest a topology of (1) reform-orientation, such as market incentives, (2) transformative institutionalization aiming at fundamental change, and (3) institutional resistance.

For the EU, the introduction of the Carbon Border Adjustment Mechanism into the Emission Trading System has been criticized for replicating neo-colonial structures that will put developing and least-developed countries such as Mozambique at risk as they are not able to quickly decarbonize and will lose out on their aim of entering EU markets (Mbeva et al., 2023). Borghesi et al. (2023) point out shortcomings in the 2023 reform of the Emission Trading System that could undermine the carbon market's effectiveness, which is relevant because it is the cornerstone of EU climate policy in the electricity and industry sectors. Searchinger et al. (2022) draw attention to the conflict between the promotion of bio energy and carbon storage and biodiversity conservation in the EU.

Faccioli et al. (2022) show that a carbon tax on food would reduce emissions more effectively than informational interventions. Perino and Schwickert (2023) highlight that a majority of Germans support a moderate tax on meat, but support is higher if the same tax is introduced to protect animal welfare rather than reducing carbon emissions. Parlasca and Qaim (2022) point out that taxing meat could conflict with other sustainable development goals in the Global South.

China is likely to play an ever-increasing role in shaping climate related regulation. Qi and Dauvergne (2022) conclude that the country makes use of its central position within the Global South to promote a techno-centric strategy toward growth-oriented solutions in mitigation regulation. Research concerning climate governance in Africa, Southeast Asia, and the Andean region emphasizes the importance of coordination, long-term planning, and the institutionalization in local contexts to raise acceptance for climate action (Francis et al., 2022; Aleluia et al., 2022; Carrión et al., 2022).

Generally, net-zero targets have been identified to help highlighting the relevance of climate policies as commitment devices to guide expectations and investments rather than current emissions (Dolphin et al., 2023). However, new computations suggest that the point in time by which net zero has to be reached to meet the Paris Agreement climate goals has to be earlier than expected (Lamboll et al., 2023).

Uptake of climate action resources generated by other drivers

The Paris goals and the pledge-and-review process established as part of the UNFCCC provide an important resource for climate-related regulation as it sets a clear reference point with respect to ambition and creates an international audience scrutinizing efforts by individual countries. Climate protest and social movements ensure that the topic remains an important part of the public discourse and push policy makers toward more stringent policies (Waldinger et al., 2023).Some cases of climate litigation, such as the successful lawsuit against the German Climate Change Act (KSG), force policy-makers to implement more stringent policies. Shifting consumption patterns such as a rising share of vegetarians induced by a change in values reduce the opposition against some mitigation measures such as meat taxes in the Global North.

Implications of driver dynamics for climate change adaptation

Due to the way the driver has been defined, it does not cover regulation related to adaptation measures. Nevertheless, there are links: For one, the more effective climate-related regulation is, the less the need for adaptation measures in the medium to long term. Furthermore, there might be both trade-offs and synergies between specific mitigation and adaptation measures (Pasimeni et al., 2019, Lee et al., 2020).

3.5

Climate Activism and Social Mobilization

In the Outlook 2023, we assessed this driver under the title *climate protests and social movements*. We will move forward renaming the driver *climate activism and social mobilization* in order to capture broader dynamics within climate-related civic engagement (Fisher and Nasrin, 2021). This is necessary because climate activism has undergone significant developments since September 2022. The focus of this update will be on these developments in relation to the trajectory of deep decarbonization, in particular on the pluralization of strategies, the rising radicalization of climate protest activities and its surrounding debates on acceptability and legitimacy, and increasing state repressions. It also highlights the emerging prominence of the concepts of climate reparations and Loss and Damage in international debates following COP27, as well as the crucial role of Global South activist groups in this context.

To illustrate some of the recent dynamics, changes, and challenges, we are going to refer mostly to examples in the US, Germany, and the UK in more detail. This is mainly because these contexts have been at the forefront of the historic mobilizations of 2019. It shows in increased research on these groups, thus providing a rich set of data and literature. However, we are aware of the prevailing Eurocentrism in social science climate (justice) research. There is a substantial gap between the crucial role of Global South activism enabling climate action (Sultana, 2021; 2023; Crawford et al., 2023) and research on Global South activism (Kavya et al., 2023; Thiri et al., 2022).

Key social driver dynamics since the previous Outlook edition

The most recent assessment of climate movements and protests' driving capacity toward deep decarbonization in the Outlook 2023 concluded that it functions as a supporting factor for decarbonization but is not sufficient for deep decarbonization by 2050 (Pagnone et al., 2023). Yet, there were enabling conditions identified, such as the growing relevance of climate justice frames and shifting perceptions in the broader public allowing for more long-term and indirect effects. The interaction of climate movements and protests with other social drivers, such as media, climate governance, climate litigation, and knowledge production provided further supporting effects (Pavenstädt et al., 2023, 102f).

Climate movements in many countries are undergoing a transition phase. The initial surge of public concern has encountered obstacles in sustaining long-term mobilization and movement building, partly due to the COVID-19 pandemic's impact (Buzogany and Scherhaufer, 2023; Della Porta, 2022; Andrews et al., 2023). To adapt to changing circumstances, climate activists are diversifying their strategies. This includes symbolic and disruptive protests to escalate the public discourse and pressure policymakers, as seen in the advent of new groups such as Last Generation as well as a focus on alliance building, grassroots actions, and coalition building between other movements with groups like Fridays for Future and Extinction Rebellion.

In the US, the climate movement, including youth-led organizations like the Sunrise Movement and Fridays for Future, has experienced fluctuations in its momentum. The COVID-19 pandemic disrupted their activities, leading to a period of dis-grouping, reorganization, and strategic recalibration (Haßler et al., 2023; Pavenstädt et al., 2023). A growing radical flank of groups like Extinction Rebellion, Scientist Rebellion, and Declare Emergency! engages in direct action (Fisher and Renaghan, 2023). Groups like Sunrise Movement started to adopt a more decentralized approach with a focus on local initiatives (Bauck, 2022). The passage of the US Inflation Reduction Act has been influenced by many climate and environmental civil society actors, including environmental NGOs and climate movements (Aronoff, 2023). Some observers suggest that the Sunrise Movement played a crucial role in the process (Bordoff, 2022; Stokols, 2023). This landmark legislation represents a significant shift in climate policy, emphasizing stronger government investment and a linkage to job creation and justice. Although the Inflation Reduction Act is seen as an important first step, it has also been criticized as a forced compromise (Kleimann et al., 2023). In Germany, the Fridays for Future movement has encountered its own set of obstacles, and there are internal struggles and uncertainties about strategic direction as frustration over the inertia in current socio-economic systems rises (Marquardt, 2023). Some activists switched to direct-action, organized by Last Generation, and gained high public visibility. Last Generation's actions did not gather extensive mobilization in numbers, but they stood out due to their disruptive and unconventional tactics (Grimm et al., 2023). Last Generation engages in street blockades and blockages of critical infrastructures like highways, airports, and liquefied natural gas terminals (Rucht, 2023) as well as symbolic actions (Grimmbacher, 2023). Fridays for Future and the German trade union Verdi formed a coalition and engaged in issue-linkage between climate action and fair wages in the public transportation sector (Lucht and Liebig, 2023). In the United Kingdom, movements like Extinction Rebellion and Just Stop Oil also engaged heavily in direct action. They have been met with increasing state repression, primarily through stringent police laws and restrictions on the right to protest (Serhan, 2022). Recently, Extinction Rebellion UK has announced a strategic shift away from illegal actions (De La Garza, 2023), and mobilized 60.000 people for "The Big One" protest on Earth Day in alliance with other established environmental NGOs (Read, 2023).

Mobilization and contention, especially from Global South activists, have been further crucial in pushing for implementing effective steps with regard to adaptation, loss and damage, and climate finance. As a result, the topic of climate finance became more prominent within climate movements and affected the broader public discourse and relevant institutions (Jackson et al., 2023; Schalatek, 2022). The Global South-led and international Debt for Climate movement calls for debt cancellation owed by Global South countries to the Global North (Debt for Climate, 2023; Morgan and Charaby, 2023). The People's Forum on End Fossil Finance, held in June 2023, highlighted the urgency to promote a debt relief in order to enable a self-determined just transition in Global South countries (endfossil.finance, 2023). The International Monetary Fund claims to acknowledge the issue at hand, suggesting so-called debt-for-climate-swaps in August 2022, meaning partial debt cancellation in exchange for investments in climate action (Harvey, 2023). However, Debt for Climate criticized this as undemocratic and as evoking narratives of a charitable Global North (Adrogué and Plant, 2023). This campaign has recently been able to generate more attention, including protests in front of the International Monetary Fund and World Bank headquarters in Washington D.C., and during the G7 summit in Germany (Wilkins, 2022; Köpf and Wehner, 2022). Overall, and despite the recent Paris climate finance summit failing to deliver the urgently needed proposal to transform the global financial system, it is reasonable to say that the combined efforts of civil society and the persistent advocacy of Most Affected People and Areas (MAPA) states and organizations have created momentum for addressing these urgent finance-related issues. The months following COP27, coupled with years of civil society engagement, have contributed to a growing recognition of the need for reforming the global financial system (Morgan and Charaby, 2023). Nevertheless, Global South activists continue to struggle with the ongoing experience of disregard at various sites of climate governance, such as the COPs. In addition to the issue of vulnerabilities, some of the major points of contestation include how various structures of discrimination intersect with climate governance dynamics and how to forward diverse understandings of climate justice. Thus, Global South activists contest the discourse portraying the Global South as mere victims void of agency but highlight their formative role for climate action (Crawford et al., 2023).

Enabling and constraining conditions affecting driver dynamics

Increasing repression against climate activism has become a troubling global trend. First, the strategy of filing strategic lawsuits against public participation (SLAPP) is on the rise, through which large corporations aim to intimidate and ultimately silence activists and protestors (Monforte, 2023; Priyatno et al., 2023). Second, governments and authorities suppress environmental protests and activities with a variety of tactics, violating human rights and even harming the activists' physical integrity, sometimes with fatal consequences (Taylor, 2021; Temper et al., 2020; Weis, 2022). Although this is not unprecedented in the Global South, it is noteworthy that it is now being witnessed in liberal democracies in the Global North as well, which have historically been known for upholding strong principles of freedom of assembly. This may constitute a more general trend toward authoritarian measures (Fearn and Davoudi, 2021), including countries such as Germany, the Netherlands, France, the US, the UK, and Australia (Ataman and Paddison, 2023; Gulliver et al., 2023; Uyeda, 2022; Scheidel et al., 2020). In the US, repression against climate activism has been on the rise ever since Indigenous groups resisted environmentally destructive projects, most notably represented by the Standing Rock protests against the Dakota Access Pipeline (Correia and Wall, 2021; Gilio-Whitaker, 2019). Activists have had to face arrests, raids, and prosecution for decades already; but recently they have also been confronted with domestic terrorism charges. In early 2023, one climate activist has been killed by the police in Atlanta, marking the first police killing of an environmental activist in the US's recent history (Akbar, 2023; Mowatt, 2023). This growing repression is intertwined with framings as climate gluers or climate terrorists, portraying climate activists as obstructive and disruptive, seeking to delegitimize their cause and justify law enforcement actions (Akbarian, 2023; Kubiciel, 2023). While most court rulings imposed only moderate penalties, recent developments saw prison sentences of several months for gluing actions after activists announced that they would continue to commit to direct action (Rucht, 2023). Additionally, Last Generation activists were subject to wiretapping, surveillance, raids, and preventive detention, with investigations conducted to determine whether the grouping qualifies as a criminal organization (Zeit Online, 2023; Langmack and Brandau, 2023).

This was subject to legal debate, noting that these law enforcement practices are questionable and sometimes violate human rights (Rippert, 2022; von Bernstorff, 2023; Rucht, 2023).

Furthermore, the described driver dynamics themselves can have effects for enabling and constraining conditions, but there is still a lack of comprehensive empirical studies on these effects (Özden and Glover, 2023). Possible short-term effects of direct action are described in the literature on radical flanks (Haines, 1984). Possible enabling conditions are political concessions to climate advocates considered moderate by governments as a result of radical forms of protest by other climate movements (see e.g. 350.org's divestment campaign; Schifeling and Hofmann, 2019). Factors that would affect constraining conditions for further activism include the de-legitimization of the whole climate movement as well as increased public polarization. While polls do indeed signal public disapproval of the protest groups committed to direct action and even a general drop in support for climate activism and polarization (More in Common, 2023), there is neither evidence that disruptive protest methods will reduce general approval of stronger climate policies, nor that they yield significant gains (Özden and Glover, 2022; Kountouris and Williams, 2023).

The use of direct action as well as the subsequent criminalization of these practices can lead to so-called chilling effects, causing individuals or groups to self-censor or refrain from exercising in certain behaviors due to a fear of negative consequences (von Bernstorff, 2023). Scholars identified such effects, for instance, in recent waves of climate action in India (Goodman and Morton, 2023). This has significant implications for democratic participation, public discourse, and the mobilization climate (justice) movements. Some contend that transitioning from street protests to direct action could potentially shift the focus of public discourse from simply raising awareness to actively engaging in the cause by putting even stronger emphasis on the issue's immense urgency (Berglund, 2023; Capstick et al., 2022).

Long-term effects may entail deeper cultural and normative change in societies that will facilitate deep decarbonization. Initial studies indicate that parts of the climate movements in Germany, the US, and Belgium have increasingly incorporated critical narratives into their discourse (Crouzé et al., 2023; Pavenstädt and Rödder, 2024). Scholars note that direct action has the potential to contest hegemonic norms and discourses, which could eventually constitute an enabling condition for facilitating deeper cultural and normative change (Andrews et al., 2023, Christou et al., 2023). Yet, some scholars also argue that certain ongoing direct action campaigns focusing on radical tactics rather than making explicit demands, tend to undermine the promotion of critical discussions on existing socio-political and economic systems. (Rucht, 2023). Furthermore, there is growing concern that a focus on urgency and emergency in activism and politics would serve to lock-in current systems and inequalities (Goodman and Morton, 2023; de Moor, 2023). All of this, coupled with a surrounding public discourse that focusses on the legitimacy of direct action, might mean that potential for a deeper contestation of norms as well as current socio-political and economic systems may currently be missed (de Moor and Marquardt, 2023). Recent articles suggest that climate movements ought to address power imbalances and challenge dominant narratives more strongly in order to foster long-term mobilization (Hayes and MacGregor, 2023; Pavenstädt and Rödder, 2024; Buzogany and Scherhaufer, 2023).

Furthermore, there is an increasingly unfavorable discursive environment for climate (justice) activism: As actors in the economy, media, and politics promote discourses that focus on technology and market-centered policies along a green growth paradigm (Leipold, 2021). While discussions about the use and implementation of technologies and other measures are indeed necessary, climate activists will need to react to the frequent co-occurrence of climate delay discourses. These include, for instance, re-directing responsibility to individuals or other states, technological optimism, or framing fossil fuel use as the right to development (Lamb et al., 2020). Ongoing disapproval of protest tactics and repressive reactions by the state will likely have an effect on movements' future strategizing. Global conflicts such as the war in Ukraine and lately, rising global tensions after Hamas' attack on Israel on 7 October 2023 and Israel's ensuing invasion of Gaza, as well as insecurities about inflation and the development of the economy provide a further challenging discursive environment for this driver. Lastly, while some right-wing populist governments were voted out of office, right-wing populists elsewhere in Global North and Global South countries continue to mobilize with the goal of contesting stronger climate action, posing additional constraining conditions toward climate activism (Marquardt et al., 2022).

In sum, climate movements have reacted to increasing constraining conditions in the global opportunity structure, consisting of an increasingly unfavorable discursive environment, state repression, and public disapproval for direct action tactics. We identify a diversification of practices, from issue-enlargement and coalition building, to international demands. Moreover, new direct action protest groups gain relevance achieving comparatively high media attention, sparking internal disputes over tactics and advancing fragmentation within the broader climate movement. Striking a balance between moderate and radical approaches, between issue bridging to engage people long-term and reaching as many people as possible through broad messaging, between internal community strategies, public advocacy, and disruptive actions will be key to re-gaining momentum. Therefore, we conclude that the driver continues to contribute toward decarbonization, but not sufficiently for deep decarbonization by 2050.

Major studies published since the previous Outlook edition

New major studies include a collective volume on Fridays for Future in Germany, encompassing a range of different disciplinary and methodological perspectives (Pollex and Soßdorf, 2023). Buzogány and Scherhaufer summarize key findings about new climate movements in a chapter in the *Routledge Handbook of Environmental Policy* (Buzogány et al., 2023; Jörgens et al., 2023). In addition, there are studies on the global spread of Extinction Rebellion (Gardner et al., 2022) and the connections of Fridays for Future Germany to other societal stakeholder like NGOs and trade unions (Laux, 2023). Scheuch et al. (2024) analyze media reporting connected to different protest tactics in the UK. Survey-based studies look at the influence of climate protest on environmental attitudes (Kountouris and Williams, 2023; Fritz et al., 2023) and the reporting practices by the IPCC on protest behavior (Doran et al., 2023). A number of publications focus on the role of scientific knowledge in the climate movement (Rödder and Pavenstädt, 2023; Soßdorf and Burgi, 2022; Thierry, 2023), their digital discourse, mobilization, and organizing practices (Sorce, 2022; Suitner et al., 2023; Spaiser et al., 2022) as well as the use of post-apocalyptic narratives (de Moor and Marquardt, 2023). Criminalization of protest, however, is primarily discussed in academic and journalistic forums (e.g., in the Verfassungsblog, a popular German blog for national and international legal issues) and has not yet found its way into new major studies (with the exception of Gulliver et al., 2023).

Uptake of climate action resources generated by other drivers

- **Climate litigation:** Climate movements can build on legal frameworks and previous successful cases of climate litigation for subsequent legal (and moral) arguments in both Global South and Global North countries (Kotzé and Knappe, 2023; Donger, 2022; Moreira et al., 2023; Stuart-Smith et al., 2021).
- **Knowledge production:** Climate movements not only draw upon packaged knowledge provided by institutions like the IPCC but also use it as a source of legitimacy. In particular the movments focus on and call for the 1.5°C limit, is shaped by the scientific outputs, such as the IPCC's special report on "Global Warming of 1.5 °C". Notably, the IPCC's Sixth Assessment Report incorporated the concept of degrowth for the first time in 2022 in their technical summary of Working Group III. However, it was not discussed in the Summary for Policymakers. A more systematic exploration of degrowth pathways, for example through changes in modeling or assessment practices, may strengthen future consideration of alternative policy options (Braunreiter et al., 2021; Veland et al., 2018, Beck and Oomen, 2021). However, given concerns about the political feasibility (Keyßer and Lorenzen, 2021), such developments would likely depend on a re-evaluation of the meaning of policy-relevance. Additionally, there is increased interaction between these drivers, prompting a re-evaluation of academic practices at the science-policy interface, the role of social sciences (Glavovic et al., 2022; Cologna and Oreskes, 2022), and the responsibility of scientists to engage in advocacy and activism (Hartz, 2023).
- **Corporate responses:** Among the various effects this driver has on climate activism and social mobilization, the most prominent one surely still is the following: Corporate responses deemed inadequate become targets for negative campaigning against greenwashing, positioning corporations as adversaries within movement narratives (Yilmaz and Baybars, 2022; Alperstein, 2022).
- **UN Governance:** The annual climate summits act as peaks of global attention, serving as focal points for mobilization. This heightened focus attracts increased media and political interest, fostering international exchange and the formation of alliances among activists (Aykut et al., 2022a; de Moor, 2022; Uldam, 2013).
- **Physical drivers:** The attribution of extreme weather events or disasters to climate change plays a dual role for both climate movement narratives and public discourses. However, it also has the potential to divert attention from the socio-political factors underpinning vulnerability (Lahsen and Ribot, 2022). In the long term, the exposure-vulnerability trap (Sobhan, 2014) may hamper the means for mobilization in the most vulnerable regions.

Implications of driver dynamics for climate change adaptation

Since adaptation is a collective effort, successful adaptation also depends on how affected communities engage with climate risks. Social mobilization is therefore central to adaptation, particularly transformational adaptation (Kuhl and Shinn, 2022). This driver may have implications on adaptation through (1) activism and social mobilization for questions of adaptation, or (2) activism and social mobilization as adaptation, that is, through engaging in local community and prefigurative practices that foster adaptation on the ground.

1. On a more general level, the establishment of a climate fund in November 2022 at COP27 to address Loss and Damage, initially put forth by Vanuatu in 1991, marked a critical milestone for global climate justice and for climate movements worldwide (Raffety et al., 2022; Bakhtaoui and Shawoo, 2022; Gewirtzman et al., 2018). Civil society groups, especially from the Global South, played a pivotal role in advocating for the inclusion of climate financing in the official conference agenda. This highlights the urgent

need to address the disproportionate impacts of climate change on vulnerable regions, especially after the rejection of a climate fund proposal at COP26 (Adger, 2023; Niyitegeka and Mukayiranga, 2023; Schalatek, 2021). Despite immense restrictions and human rights violations, civil society engagement remained high throughout COP27 (Charaby, 2022; Raffety et al., 2022).

2. Overshadowed by large-scale social mobilizations demanding adaptive changes are long-standing traditions of grassroots organizing, capacity- and community-building, and prefiguration in and by communities heavily affected by climate crisis implications (Ziervogel et al., 2022). These kinds of local community practices facilitate survival, well-being, and care in times of multiple crises (Yates et al., 2023). They are able to create and maintain collectivities practicing alternative ways of living. Thus, life is constantly re-organized and adapted in light of changing needs and challenges (Dionisio et al., 2023; Fash et al., 2023). In that sense, adaptation does not refer to a conclusive and comprehensive strategy, but rather to the creation of a social network that is able to change and transform (Fash et al., 2023). Furthermore, the concept of climate change adaptation is in itself contested, criticizing that adaptation governance focuses on "tangible, biophysical impacts of climate change in a given geographic area" (Fünfgeld and Schmidt, 2020, p. 437), thereby sidelining social complexities of both the climate crisis and adaptation planning and governance, including issues of racism, colonialism, and extractivism (Parsons, 2023; Yates et al., 2023).

3.6 Climate Litigation

Climate litigation refers to individual and strategic cases aimed at achieving decarbonization and climate justice. It comprises lawsuits against governments, administrations, or companies to strengthen national emissions reduction commitments, prevent carbon-intensive infrastructure projects, or hold firms accountable for global warming impacts. There is no clear distinction between individual and strategic cases. However, strategic litigation is brought with the intention of going beyond the individual enforcement of rights in a single case and achieving or working towards a regulatory change relevant to a wider group of actors (see also Setzer and Higham, 2023).

Key social driver dynamics since the previous Outlook edition

In the 2023 assessment of climate litigation, we found it plausible that it would continue to increase in number and spread geographically and thus have the potential to support social dynamics toward deep decarbonization. However, this trajectory is highly dependent on the dynamics of closely related drivers such as climate-related regulation, climate activism and social mobilization, and knowledge production.

Overall, dynamics in the climate litigation driver have remained relatively stable since the previous assessment. We observe further geographical spreading, a continuing rise in cases at a lower growth rate, an increase in cases against private companies, further diversification in scripts (i.e., legal bases and lines of argument), and enhanced knowledge production in attribution science that can be used in various types of cases to establish responsibilities for the reduction of greenhouse gas emissions or compensation of global warming impacts. According to the Sabin Centre's database on climate cases in 2022, 144 new cases had been filed in the US and 79 cases globally outside the US. With regard to 2023, the database accounts for 61 new climate cases in the US and 22 new cases in other jurisdictions until the middle of July (five of those in the UK and four in France). Compared to the number of cases filed per year in 2019 and 2020 (152 and 164, respectively) the number of new cases submitted in the US slightly declined in 2021 and 2022 (142 and 144, respectively). Globally (excluding the US), the number of annually submitted cases steadily rose each year since 2014, from 27 cases in 2014 to a peak of 111 cases in 2021. 79 new cases have been filed globally in 2022, which was still more than in 2020. From the 61 newly submitted cases in the US in 2023, around 47 were pro-climate cases and about 14 non-climate-aligned. Notably, all new cases submitted outside the US in 2023 were pro-climate cases, and all but one of them were filed by NGOs. Germany saw a stark rise in climate-aligned cases after the landmark Neubauer ruling of the Constitutional Court (from seven in 2020 to 11 in 2021 and 22 in 2022). However, it has to be noted that 13 of the 22 cases filed in 2021 were direct follow-up and parallel cases against 13 German states that were not accepted for decision by the Constitutional Court.

We continue to observe a geographical spreading of cases. Drawing on the Sabin Centre's database, Setzer and Higham (2023) identified first climate cases in Finland, Romania, Russia, and Thailand between 2022 and May 2023. Overall, the vast majority of climate cases is still documented for the US (over 1,500), followed by Australia (130), the UK (102), the EU (67), Germany (59), Brazil (40), and Canada (35) (Setzer and Higham, 2023). A total of 135 climate cases are accounted for in countries of the Global South with around 20 cases filed each year in 2020, 2021, and 2022.

In terms of outcomes, around 55% of the decided climate cases documented in the Sabin Centre's database had direct judicial outcomes that support decarbonization (Setzer and Higham, 2023, p. 28). However, it is important to bear in mind that an assessment of actual effects is highly complex.

With regard to the plaintiffs, we observe that the vast majority of non-US cases submitted in 2022 and 2023 have been brought to court by NGOs and individuals or both (Setzer and Higham, 2023, p. 3). On the defendant side there is a decline in cases brought against governments and a rise in strategic cases initiated against corporate actors of a growing range of sectors (Setzer and Higham 2023, pp. 3, 21). However, still more than half of the cases submitted in 2022 and 2023 were brought against governments.

Setzer and Higham (2023) identified a set of common strategies in climate-aligned strategic litigation across non-US jurisdictions filed between 2015 and May 2023 that can be understood as new scripts in the analytical framework of the Global Opportunity Structure (Section 3.1). According to this categorization, the most applied script was "integrating climate considerations", identified in 206 cases that aim to include climate-related standards and principles into decision-making, often challenging new fossil fuel projects. The next most applied script consisted of so-called "government framework" cases (81), challenging (lacking) state climate policies. A rather new and increasingly used script is the so-called "climate-washing" litigation (57 cases, 52 of which brought against companies). Also increasing are "turning off the taps" cases (28), which aim to prevent funding of carbon intense projects. Not large in numbers but in scope are five new "global guidance" cases (requests for advisory opinions) filed with the International Tribunal for the Law of the Sea, the Inter-American Court of Human Rights, and the International Court of Justice (Setzer and Higham, 2023, pp. 3, 22, 23).

Enabling and constraining conditions affecting driver dynamics

The key structural and institutional enabling conditions remain access to justice and—for human rights-based cases—fundamental substantive rights, such as the right to a healthy environment or extensions thereof, for example a right to a stable climate or to a life-sustaining climate system. With regard to legal enabling conditions, we observe a rise in climate-related legislation such as the US Inflation Reduction Act, the EU taxonomy, and more and more climate change framework laws that offer statutory bases for new cases, including at sectoral level. However, it has to be stressed that the relationship between legislation and litigation is complex (see also Setzer and Higham, 2023, p. 13). In the US, the discussion about the scope of regulatory competence of the Environmental Protection Agency after Supreme Court rulings is still ongoing. Another recent development is a rise in regulatory and soft law initiatives that work toward more detailed and transparent climate taxonomies. There are plenty of salient examples: the UN Secretary General's High Level Expert Group on Non-State Actor Net Zero Commitments; the OECD Guidelines for Multinational Enterprises on Responsible Business Conduct; the EU Commission adopted a proposal for a Directive on Green Claims, and the European Parliament approved a Corporate Sustainability Due Diligence Directive that imposes responsibility for climate transition planning on company management; the UK Competition and Markets Authority published new code; the US Securities and Exchange Commission launched a Climate and Environmental, Social and Governance (ESG) Task Force to develop initiative to proactively identify ESG-related misconduct and streamline ESG-related disclosure rules for investors; the Glasgow Financial Alliance for Net Zero. Last but not least, the UN Global Stocktake under the Paris regime produces new data (see Section 3.3). All this enables new climate-aligned litigation such as climate washing cases, but also provokes cases by affected companies challenging the new standards.

A key scientific enabling condition that strengthens the plaintiffs' arguments regarding responsibilities and causation in climate litigation are advances in climate science, especially those assembled in the latest IPCC assessment reports, as well as newer developments in attribution science. Attribution science is climate science that analyses and evaluates the relative contributions of various causal factors to a changing climate or to a specific event (Otto et al., 2020; Wentz et al., 2023). Furthermore, a new, not yet peer-reviewed study by Grasso and Heede (2023) argues that 21 leading fossil fuel companies are liable for annual climate reparations amounting to at least USD 209 billion, which is likely to support future damage claims.

With regard to socio-political enabling and constraining conditions, we observe a new wave of activism using civil disobedience tactics as well as courtrooms as a supplementary public arena to voice their claims (Just Stop Oil, Letzte Generation, Dernière rénovation). Related climate activist cases are increasingly heard in court. In very few instances, courts in the US and one German court accepted "climate emergency" as a justification for acts of trespassing and similar civil disobedience actions.

As noted above, for the purposes of this assessment we define climate litigation solely as climate-aligned litigation because we consider the social processes leading to pro-climate cases inherently different from such that fuel anti-climate litigation. This implies that we capture anti-climate litigation as one of the constraining conditions of pro-climate litigation if it is either directly tackling the plaintiffs of pro-climate cases or if it is filed in reaction to certain scripts and repertoires used by climate-aligned litigation. While there has only been one anti-climate case recorded outside the US since 2022, we observe further cases of Strategic Litigation Against Public Participation (SLAPP), aimed at exerting a chilling effect on activists and potential litigants, and anti-ESG litigation to weaken the growing climate taxonomy alliance in the US. Anti-ESG lawsuits emerged in the US in the context of an observable densification of climate action opportunities in the field of climate taxonomies. This densification consists in the confluence of three developments: First, a growing number of global firms participate in climate disclosure alliances and self-report data. Second, a more thorough engagement on part of regulators such as the EU Commission and the US Securities and Exchange Commission with processes to define stricter reporting standards. Third, an increase in climate lawsuits targeting corporations and greenwashing practices that use self-reported data and could, in the future, invoke new regulatory standards. The Anti-ESG lawsuits therefore constitute at least in parts a reaction to pro-climate litigation and aim at minimizing future litigation risks for companies.

Major studies published since the previous Outlook edition

The following larger synthesis and review studies have been published within the past year:

Setzer and Higham (2023) published an update of their yearly observation of global trends in climate litigation based on the two largest databases of climate cases. Among their key findings are the continuous growth of climate cases at a slowing growth rate and a continuing expansion of geographical scope and typologies (i.e., strategies) of cases.

The Global Climate Litigation Report 2023, which is jointly published every three years by UNEP and the Sabin Center for Climate Change Law, underpins these key findings and complements them by looking at the role of women in climate litigation. They do not only see women as victims who suffer disproportionately from the effects of climate change, but more importantly as agents of change who can contribute significantly to climate justice.

Iyengar (2023) examines the social embedding of human rights-based climate litigation using qualitative socio-legal research methods with a special focus on how lawyers and activists bring and think about the cases.

Peel et al (2022) reviewed 280 publications of grey and academic literature addressing the impacts of climate change litigation in the time period of 2000 to 2021. They found that only a few contributions conduct a systematic review of impact and assume that this is due to the complexity of impact assessment and the lack of analytical frameworks (approaches, definitions, and methods).

Uptake of climate action resources generated by other drivers

New climate laws and standards developed by climate-related regulation are arguably the most relevant resources for climate litigation, followed by scientific knowledge on climate risks and causalities developed in attribution science and strategic litigation networks expanding in cooperation with social movements.

Implications of driver dynamics for climate change adaptation

Climate change adaptation litigation has been on the rise recently. Of the more than 1800 ongoing or concluded climate change cases worldwide, Setzer and Higham (2023) find 180 that touch on the issue of adaptation—100 in the US and 61 before Australian courts. The most common form of adaptation litigation and scholarship in this area has focused on land use and urban planning at the city or local government level. Plaintiffs have used environmental and administrative law to challenge individual developments, from the Keystone XL Pipeline Project in the US to residential development projects in Australia. Tort law compensation claims for past failures to adapt are less common so far.

3.7

Corporate Responses

Corporate responses to climate change can be defined as communicated strategies and corresponding actions by organizations to mitigate as well as adapt to a changing climate, which ideally could serve as a social driver for progress toward deep decarbonization by 2050. Carbon management activities such as science-based target setting and increased investments in renewable energy support these deep decarbonization strategies.

Key social driver dynamics since the previous Outlook edition

While most companies have not adequately responded to climate change, recent evidence (e.g., Net Zero Tracker, 2023; Science Based Targets, 2023) demonstrates an increase in corporate actions such as target setting, net-zero targets, and communicated investment plans. Despite the fact that these signals of commitment toward deep decarbonization are reaching more elevated levels of ambition with regard to their emissions reduction (MSCI, 2023), implementation is still weak. Recent assessments have brought forth that although targets are set, proper actions plans and transparency concerning reduction and offsetting practices remain scarce (Hale et al., 2021). Furthermore, a gap between the Global North and the Global South persists: The majority of emissions have been and are being caused by companies that amass wealth in the Global North, while people in the Global South will bear the brunt of climate change (Hickel and Slamersak, 2022).

While public corporate commitments to deep decarbonization are becoming more prevalent, overall corporate responses still restrain deep decarbonization by 2050, as communicated targets and other promises are not translated into effective actions and greenhouse gas emissions continue to rise. This update thus confirms the previous assessments, which concluded that corporate responses are currently insufficient for deep decarbonization and are unlikely to change in the next decade.

Enabling and constraining conditions affecting driver dynamics

Two significant conditions have impacted the corporate landscape concerning climate change mitigation, both of which can be considered both enabling and constraining. Firstly, Russia's invasion of Ukraine led to an immediate rise of global energy prices, particularly in Europe, thereby primarily affecting nations and industries dependent on fossil fuels such as electricity and power generation, heavy industry (e.g., cement, iron and steel, chemicals, etc.), food and beverage processing, and transportation. Overall, the impact of this is rather ambivalent: On the one hand, it appears more constraining in the short term, as nations and corporations are now more concerned with energy security no matter the energy source (e.g., US companies are more and more reliant on state-provided natural gas). On the other hand, it could become more enabling in the long term as nations and large companies in the Global North seek to adopt renewable energy as a means for energy security (Zuk and Zuk, 2022). Since the outbreak of the war, the EU has been pursuing a new strategy, called REPowerEU, to lessen its reliance on Russian fossil fuels and expedite the green transition by way of energy savings, investments in renewable energy sources, and diversification of energy supply (European Council, 2023a,b). Building on this new strategy, the EU adopted the revised Renewable Energy Directive in 2023, an earlier version of which had already been proposed under the Fit-for-55 package in 2021 (European Council, 2023a). The revision includes the introduction of a new binding target concerning the share of renewable energies, increasing to at least 42.5% by 2030 and ultimately aiming for 45% (European Commission, 2023). Furthermore, it includes indicative targets for the following sectors: construction, industry, transport, and district heating and cooling (European Council, 2023a; IEA, 2024). However, if and how these targets will be translated into action is still unclear, as member states are expected to submit their draft action plans only by June 2024 (IEA, 2023a).

Secondly, although there has been an increase in sustainable financing to give companies the necessary capital to invest in low-carbon transformations, global investments imply rather constraining tendencies. Some financial institutions and investors are increasingly incorporating environmental, social, and governance considerations into their investment decisions, allowing more funds to be allocated to climate-friendly projects and organizations. However, a simultaneous increase in spending on new fossil fuel exploration and extraction activities undermines much of the progress accomplished (IEA, 2023d). This is part of extensive cross-sectoral nature-negative funding activities, which exceed current private investments in nature-positive solutions (UNEP, 2023b). Moreover, the inadequacy of voluntary initiatives in addressing climate finance challenges, exemplified by the failure of the

Glasgow Financial Alliance for Net-Zero, where key members left after realizing that others in the alliance continued to fund fossil-fuel industries, has become apparent. In sum, the insufficient compliance with policies restricting financing for new fossil projects underscores the prevailing constraints in this context (see Section 3.8 for details).

These events have highlighted the need for urgent action, more sufficient corporate commitments and their subsequent implementation, and enabling conditions for greater collaboration among governments, businesses, and other stakeholders to address the climate crisis as well as the tolerated unsustainable investment and production practices around the globe. However, as long as global events such as the increased risk of war and expansion of fossil fuel investments persist, major corporations will take advantage of the situation to keep business running as usual.

Major studies published since the previous Outlook edition

Recent studies concentrate on proposing methods for assessments of corporate climate action and applied strategies. Vieira et al. (2023) focus on the European oil majors' strategies in transitioning from carbon dependence to renewable energy sources in the face of climate change. The study reveals four main strategies adopted by these firms: sustained carbon dependence, carbon emissions compensation, carbon emissions mitigation, and carbon independence. The findings highlight varying levels of action among the companies, with only one out of ten surveyed actively transitioning away from fossil fuels.

This is also confirmed in an assessment by Reclaim Finance (2023), which highlights the lack of transparency of and seriousness in the decarbonization efforts exhibited by certain industries, such as the oil and gas industry, where certain key players are attempting to expand production of fossil fuels, thereby withdrawing from earlier decarbonization statements.

Furthermore, Cherepovitsyna et al. (2023) propose a method for assessing progress based on a carbon intensity reduction goal. Their assessment shows similar results as Vieira et al. (2023), according to whom companies are mostly falling below their goals, demonstrating either no movement or a negative trend.

Expanding the scope of analyzed companies, Coen et al. (2022) study companies on the Dow Jones Sustainability Index and the Financial Times Stock Exchange 100, the latter containing 100 companies mostly from the United Kingdom and Europe. The authors provide a more specific focus on operational improvements as a significant predictor of climate performance improvement, highlighting the significance of strategies beyond emissions reductions. Promisingly, we can see an increase in ambition and commitment, particularly in corporate climate target setting (Bendig et al., 2022; Berger-Schmitz et al., 2023); however, it is either too early to detect significant reductions in absolute greenhouse gas emissions or unrealistic to expect massive reductions.

Practice-oriented publications such as the Corporate Climate Responsibility Monitor by the New Climate Institute (2023) and the Net Zero Tracker (2023) by the US finance company MSCI, track the progress of mostly Global North companies in fulfilling greenhouse gas reduction commitments. They confirm our previous assessment on corporate responses, that is, that there is an increase in commitments but that the majority of the assessed pledges lack robustness and are of low integrity. An Allianz Research Report (2023) focuses on investment strategies to decarbonize the industrial sector in Europe, emphasizing the urgency of action. Overall, these practice-oriented publications highlight the importance of genuine commitments and the need for urgent action to address climate change effectively.

Generation of climate action resources and uptake from other drivers

Social drivers such as climate-related regulations, transnational cooperation, climate litigation, consumption patterns, and fossil-fuel divestment play a crucial role in creating tangible and intangible resources for corporate responses to climate change. Climate-related regulations such as the EU Taxonomy influence corporate responses via strict guidelines and mandatory practices. The EU Taxonomy provides a framework for classifying environmentally sustainable economic activities, which guides companies in aligning their operations with sustainable practices. This creates a common understanding and common criteria for investors, facilitating sustainable financing and investor feedback.

Transnational cooperation provides crucial resources to companies that positively affect sustainability practices and climate action, including knowledge and best practices that address industry-specific challenges. Initiatives like the Science Based Target initiative (SBTi) offer guidance, capacity building, knowledge generation, and legitimacy for the companies. Yet, although gaining high traction, such initiatives should not be misconstrued as neutral, apolitical bodies looking out for the greater public interest. While they are definitely an important step toward the mainstreaming of more ambitious and robust targets, the choice of underlying emission scenarios, the neglect of principles of distributive climate justice, and the promotion of a win-win paradigm are important points of criticism of the SBTi (Tilsted et al., 2023). Given these recognized issues, the UN Race to Zero campaign encourages companies to commit to achieving net-zero emissions, fostering collective efforts in addressing climate change. Beyond its direct impact, transnational cooperation provides valuable resources to other drivers that can also affect corporate responses, such as climate litigation. Climate litigation has the potential to hold companies accountable for their environmental impact and can lead to financial and reputational consequences, pushing companies to adopt more low-carbon practices. One example, which is considered unprecedented, is the Milieu-defensie et al. vs. Royal Dutch Shell plc. case (Tosun, 2022). While this case will surely go through an appeal process, the Court's initial decision that Shell is obliged to reduce its emissions is provisionally enforceable, meaning Shell will be required to meet the reduction obligation even if the settlement was appealed (Climate Change Litigation Database, 2019). Consumption patterns and fossil-fuel divestment are two further social drivers that influence business behavior. On the one hand, consumption patterns provide social legitimacy and demand for low-carbon products; whilst also tolerating the continuation of products with high carbon footprints, if only for the sake of cost savings. On the other hand, sustainable finance, particularly investments in clean technologies and fossil-fuel divestments, are on the rise. However, we continually observe large investments in fossil-fuel exploration and extraction, which acts as a backlash for the fossil-fuel divestment movement (Reclaim Finance, 2023). These three drivers (corporate responses, consumption patterns, and fossil fuel divestments) are inextricably linked and demonstrate how the willingness or reluctance of key players to engage with these drivers will most likely determine the fate of deep decarbonization.

Moreover, corporate responses generate resources such as innovations, economies of scale, lobbying, legitimacy, and risk mitigation strategies that contribute to the overall progress in addressing climate challenges and can be utilized by other social drivers. Companies that bring low-carbon and climate-neutral innovations to the market contribute to market readiness, making clean technologies more accessible and affordable for other companies and encouraging sustainable consumption patterns. Additionally, the economies of scale achieved through corporate responses make clean technologies more cost-effective, benefiting not only the companies implementing them but also the wider business community and society. Finally, companies often lobby and advocate for climate policies that can align with the Paris Agreement, especially when it is in their own interest to do so (Ketu et al., 2022). However, corporate lobbying activities against more stringent climate policies continue to persist. It is therefore necessary to scrutinize these companies' lobbying and advocacy practices, as these can act against progressive climate laws and regulations (Brulle, 2022; Pulver, 2023).

Implications of driver dynamics for climate change adaptation

In both academic and business settings, corporate responses to climate change are mostly split into mitigation and adaptation strategies, with few overlaps at the moment. Nevertheless, several concepts exist at the intersection of these two concepts: organizational risks, organizational resilience, and nature-based solutions.

Organizational risks deal with how companies respond to climate-related loss and damage, which could encourage both mitigation and adaptation efforts simultaneously (Sun et al., 2022). However, companies still do not pay the real costs of environmental damage, especially in the Global South (Lee et al., 2022). Organizational resilience has emerged as a concept to consider the extent to which companies can absorb loss and damage from severe weather impacts related to worsening climate change, and how they can recover while maintaining their current or future operational functions (Linnenluecke and Griffiths, 2012; Buzzao and Rizzi, 2023). One recent study (Seddon, 2022) examines how both corporate mitigation and adaptation can be addressed through nature-based solutions, such as management of natural and seminatural ecosystems within river catchments or along coastlines to protect against flooding and erosion. Having said that, even the study's author admits that nature-based solutions will not suffice on their own.

As a final observation of this specific research field, it is important to offer insights into the limitations of research on corporate adaption strategies. In light of the known vulnerability of Global South countries to the effects of climate change, corporations operating in these regions will become more equipped with comprehensive adaption strategies. Nevertheless, as mentioned before, the most prominent academic perspectives on corporate responses lack global inclusivity, since most studies and solutions originate from the Global North. Further research with corporate responses in susceptible regions may enable us to elaborate further on the role this driver plays in the context of climate adaption.

3.8

Fossil-Fuel Divestment

We use the term divestment in a broad sense, referring to any form of reduction or cessation of financial flows, from private or public sources, to existing or new upstream or downstream fossil fuel engagements. In this sense, we can observe both the expansion of acts of divestment by large institutional investors and the continued financing of the fossil fuel industries, and even of massive new extractive activities.

Key social driver dynamics since the previous Outlook edition

On the one hand, according to the divestment database (Global Divestment Commitments Database, 2023), more than USD 40 trillion have been divested by 1591 institutions by 2023, which is slightly more than in the previous year (1550 institutions). On the other hand, the upstream investments into oil in 2023 have reached their highest levels since 2015, and oil producers maintain their plans on expanding production capacity (IEA, 2023d). In 2022, the major oil companies achieved record profits (Sharma, 2023). Major banks have increased fossil fuel financing (Rainforest Action Network et al., 2023), and overall banks' financing for low-carbon energy supply is lower than that for fossil fuels (White et al., 2023). In response to the energy crises that followed Russia's invasion of Ukraine, some countries, such as Germany, have invested in new oil and gas agreements, thus prolonging or deepening fossil dependencies. Plans for extraction are still vast: A recent study identified 425 fossil fuel projects with more than 1 $GtCO_2$ of potential emissions globally, which would exceed a 1.5 °C carbon budget by a factor of two (Kühne et al., 2022). The same study, however, emphasizes that 40% of these fossil fuel projects had not started extraction by 2020.

Compared to this driver's assessment in the previous Outlook, in which it pointed toward decarbonization, we see a partially reversed dynamic, as even under divestment pressure oil majors commit more openly to continued and even expanded extraction investments. To the extent that divestment is actually leading finance away from continued or new fossil fuel engagements, it is always pointing toward decarbonization. However, we see half-hearted divestment or even a renewed wave of financing towards extraction. There might be strong enabling conditions for more and more effective divestment in the future, but the current signs point to a change in direction, as companies are almost always able to acquire capital to finance their activities elsewhere, even if hit by divestment activities.

Enabling and constraining conditions affecting driver dynamics

Some constraining conditions became obvious recently. The new and ongoing wars around the world contribute to increased geopolitical tensions and increase the demand for fossil fuels for military operations (see Box 2). Moreover, in some countries the national income from fossil fuel extractivism creates the foundation for social policy programs and is therefore important to maintain democratic structures; or this income serves to maintain the power of corrupt elites and is therefore under their protection (Jakob and Steckel, 2022). Other constraining conditions are failed divestment promises or renewed interests in fossil fuel investments: A recent review article on climate action in the US concludes that colleges and universities have not committed to real divestment (away from fossil fuels), but have instead only increased their investments in renewables (Basseches et al., 2022). The Glasgow Financial Alliance for Net-Zero founded in 2021 in collaboration with the UN Race to Zero campaign (Glasgow Financial Alliance for Net-Zero, 2022), turned quickly into a failure. Only a few members of the Alliance have policies in place that restrict the financing of companies developing new fossil projects, and various members continue to finance the expansion of fossil-fuel based companies and industries (McCully, 2023). For various reasons, many members already left the Alliance (Marsh, 2023; McNally, 2023; Hodgson, 2022; Schwartzkopff and Marsh, 2022). The weakening of the Glasgow Financial Alliance for Net-Zero requirements (Segal, 2022) and the numerous dropouts from the Alliance indicate that voluntary initiatives are not sufficient. In addition, the recent backlash against Environmental Social Governance by the Republicans in the US (Wilkes et al., 2023) and announcements of major oil and gas companies to continue fossil fuel production (Reclaim Finance, 2023) rather point into the opposite direction. Currently, fossil fuel majors display a renewed sense of profitability, and investors show strong interest in the six largest publicly listed fossil fuel extractors Saudi Aramco, Shell, BP, ExxonMobil, Chevron, and Total Energies.

Some recent developments could turn into enabling conditions for divestment: First, researchers on divestment activism in higher education have pointed to the need of combining divestment and reinvestment practices more tightly (Dizon et al., 2022). Second, international treaties can become more supportive, or their hindering effects can be corrected. The Energy Charter Treaty, for example, started as a systemic hindrance, effectively preventing substantial climate policy-making due to the fear of investor-to-state disputes. But the treaty's ongoing expansion to West Africa and the MENA region will put decarbonization strategies at risk and strengthen discourses of climate delay. The exit of major players, most probably including the entire European Union, might limit this systemic hindrance (Eckes et al., 2023). Third, partnerships and networks can provide support. there is also a growing awareness of the potential distortions that both rapid and stalled decarbonization mean for many countries in the Global South. A related broadening of the Just Energy Transition Partnership and new outcomes of innovative finance tools from the Paris Climate Finance Summit might lead to the improved facilitation of divestment moves in the Global South, especially targeting economies that face a high risk of stranded assets and seem unable to manage a green transition without external support. The Just Energy Transition Partnership model, encompassing the respective domestic government, a Climate Financial Task Team situated at the Partnership's presidency, the International Partner Group, and the Partnership's secretariat may be an innovative model for transition governance, as long as democratic legitimacy and transparency is guaranteed (Hege et al., 2022). Expectations connected to South Africa's Just Energy Transition Partnership include a green economic stimulus package, enhanced energy security, accelerated decarbonization of the heavy industry, and job security for workers (Fakir, 2023; Xaba, 2023). The expansion of the Partnership approach to Senegal, Vietnam, and Indonesia underscores the attractiveness of the model. The macro-economic effects and the contribution to divestment cannot be quantified. Still, as proponents of the Partnership's extension to Vietnam point out, the Partnership may bear the ability to speed up Vietnam's coal exit, streamline the domestic energy transition, and engage in the reskilling of workers. A general hindrance may be a lack of political will on the domestic side, as well as vested interests both by domestic and by transnational actors (Behrens, 2023).

Major studies published since the previous Outlook edition

There have been several new studies of interest since the previous Outlook. The most pertinent ones refer to stranded assets, the quantitative determination of divested funds, the motives and determinants of divestment, and potentially negative effects of divestment, respectively.

Stranded Assets: A systematic review by Firdaus and Mori (2023) provides an overview on how stranded asset risks influence energy companies' decisions and their impact on the sustainable energy transition. Most commonly, the stranding of assets is understood as a devaluation or conversion to liabilities caused by market changes, regulation, or financing conditions in the course of climate change. The authors find that high perceived risk with regards to stranded assets may impede investors to move toward renewable energy sources. Instead, energy incumbents will only adopt clean technologies if the costs of divestment are offset by the investments into renewables (Firdaus and Mori, 2023). This is contested by other studies (e.g., Guo et al., 2022). Semieniuk et al. (2022) calculate the distributive effects of market risk of stranded assets and find that the majority of market risk falls on private investors in the OECD countries. They hence conclude that OECD countries have a major influence in how the transition away from fossil fuels is managed.

Quantitative determination of divested funds: Giuliani et al. (2022) analyze equity portfolios of the 10 largest institutional investors in the US. While these investors build a narrative around their commitment to climate action, they have only marginally divested from fossil fuels. The analysis of the 1000 European largest pension funds revealed that only 13% of the funds have committed to divestment (Egli et al., 2022).

Motives for divestment: Latest research has provided insights on various motives of investors to divest (Nyiwul and Iqbal, 2022). Van Benthem et al. (2022) show that one major motivation for divestment is to reduce one's exposure to climate risks, both physical and regulatory. A study by Egli et al. (2022) shows that large publicly owned funds and private funds competing for clients are more likely to divest.

Potentially negative effects of divestment practices: Hartzmark and Shue (2023) find that increasing cost of capital for firms with continued fossil fuel engagements leads to large negative changes in firm impact. Thus, investors that direct capital away from such "brown" firms and toward "green" firms may even be counterproductive in that this makes brown firms more brown without making green firms more green.

Uptake of climate action resources generated by other drivers

Social movement impact on divestment: Divestment movements employ discursive strategies of stigmatizing the fossil fuel industry, relying either on emotions and affects or on cause-and-effect explanations (Ferns et al., 2022). Becht et al. (2023) observe that stigmatization campaigns directed at the fossil industry on social media influences share prices and hence can lead to stranded assets. This finding is somewhat contested by other studies showing less strong effects or fewer effects (van Benthem et al., 2022; Schwartz et al., 2023).

Climate related regulation: National regulation has a huge potential for creating or reducing financial risks of fossil fuel engagements and for the transition to renewable energy systems (Nyambuu and Semmler, 2023). Regulation on effective climate policy impacts transition risks, which shape investors' expectations on divestment (van Benthem et al., 2022). Finally, many states directly invest in continued fossil fuel engagements, especially in countries of the Global South, due to structural dependence, internal power relations, and lack of alternative source of finance (Jakob and Steckel, 2022).

Climate litigation: In some cases, climate litigation has increased the costs of continued fossil fuel engagements, as in the successful case against Shell, in which the company was sued to pay EUR 15 million in compensation for petrol-pollution in Nigeria (Müller, 2023). The possibility of future climate litigation might serve as a resource for divestment actors (Sato et al., 2023). Publication like the Greenpeace report "Fossil Fuel Crime File" collect cases of corruption, human rights violations and complicity in war crimes (Greenpeace Nederland, 2023). Some US signatories of the Glasgow Financial Alliance for Net-Zero are increasingly concerned about legal risks, such as the potential breach of antitrust law (Wilkes et al., 2023), but also about consequences in case they fail to reach the proclaimed net zero goals (Schwartzkopff and Marsh, 2022).

Implications of driver dynamics for climate change adaptation

The continued investment in fossil fuel extraction is a key driver of global warming, therefore increasing the risks of adverse climate impacts and the demand for adaptation. From a climate justice perspective (Sardo, 2023), this raises serious concerns about the global distributions of climate change's benefits and burdens: So far, the growing profits gained in continued fossil fuel engagements are not systematically linked to the expected damage that are the consequences of these profitable investments.

3.9

Consumption Trends

Consumption patterns refer to actions aimed at fulfilling needs or wants that lead to expenditure patterns within and across categories of products and services. These patterns are influenced by economic, political, cultural, and other factors and context conditions, and they can be bundled into typical lifestyles, ranging from high- to low-carbon lifestyles (Gresse et al., 2023). Consumption can be a major lever of sustainability transformations (Creutzig et al., 2022; Fuchs et al., 2021). However, our past plausibility assessments of global consumption patterns revealed that the observed dynamics of this social driver significantly hinder the prospects of achieving deep decarbonization by 2050 (Gresse et al., 2021; Gresse et al., 2023). These assessments focused on consumption patterns as a social driver of decarbonization, that is, on particular ways in which consumption—as a social act—is done, is organized, or happens, and thereby influence global decarbonization. This time, the starting point of the analysis is global consumer trends, which relate not only to the conditions but also to the prevailing tendency of consumption around the world. In this vein, this chapter provides an update on the dynamics of global consumption trends that affect the plausibility of reaching deep decarbonization by 2050, including the growing inequality in consumption and its effects on low- and high-carbon lifestyles.

Key social driver dynamics since the previous Outlook edition

Global greenhouse gas emissions continue to increase, driven by worldwide unsustainable patterns of consumption and production (IPCC, 2023b). There are still no observable structural changes in global consumption trends, indicating that the dynamics of this social driver continue to inhibit the pathways toward deep decarbonization. While low-carbon consumption patterns such as electric mobility and renewable energy use increase at insufficient levels to achieve decarbonization (IEA, 2023e; 2023f; IPCC, 2023b), very-high-carbon consumption trends (e.g., fossil fuel-powered Sports Utility Vehicles/SUVs, yachts, space tourism) continue to gain momentum (Markard et al., 2023; Hirth et al., 2023). In general, current consumption trends are strongly associated with increasing emissions and high social inequalities and represent key barriers to sustainability transformations (Gresse et al., 2023; UNEP and International Resource Panel, 2024). Global patterns of consumption and investment drive unequal contributions to climate change (Chancel et al., 2023; Khalfan et al., 2023). The wealthiest 10% of households are responsible for almost half of global consumption-based emissions and are therefore the highest global emitters, while the bottom 50% contribute only 13-15% (IPCC, 2023b, p. 5). The 2023 Climate Inequality Report shows how wealth inequality relates to climate injustice (Chancel et al., 2023). Figure 3.2 highlights the shares of global population by income and reveal that high emitters (10% of the world population) face only 3% of relative income losses due to climate change, while those contributing the least to global greenhouse gas emissions (the bottom 50%) are exposed to 75% of climate-related income losses (Chancel et al., 2023, p. 85-86). In addition, the figure shows that the wealthy minority of the global population is not only who contributes the most to climate change, but also those who hold much greater finance capacity, indicating that achieving the same emissions reductions would require a significantly lower effort for this group than for low-emitting ones (Chancel et al., 2023; see also Büchs et al., 2023).

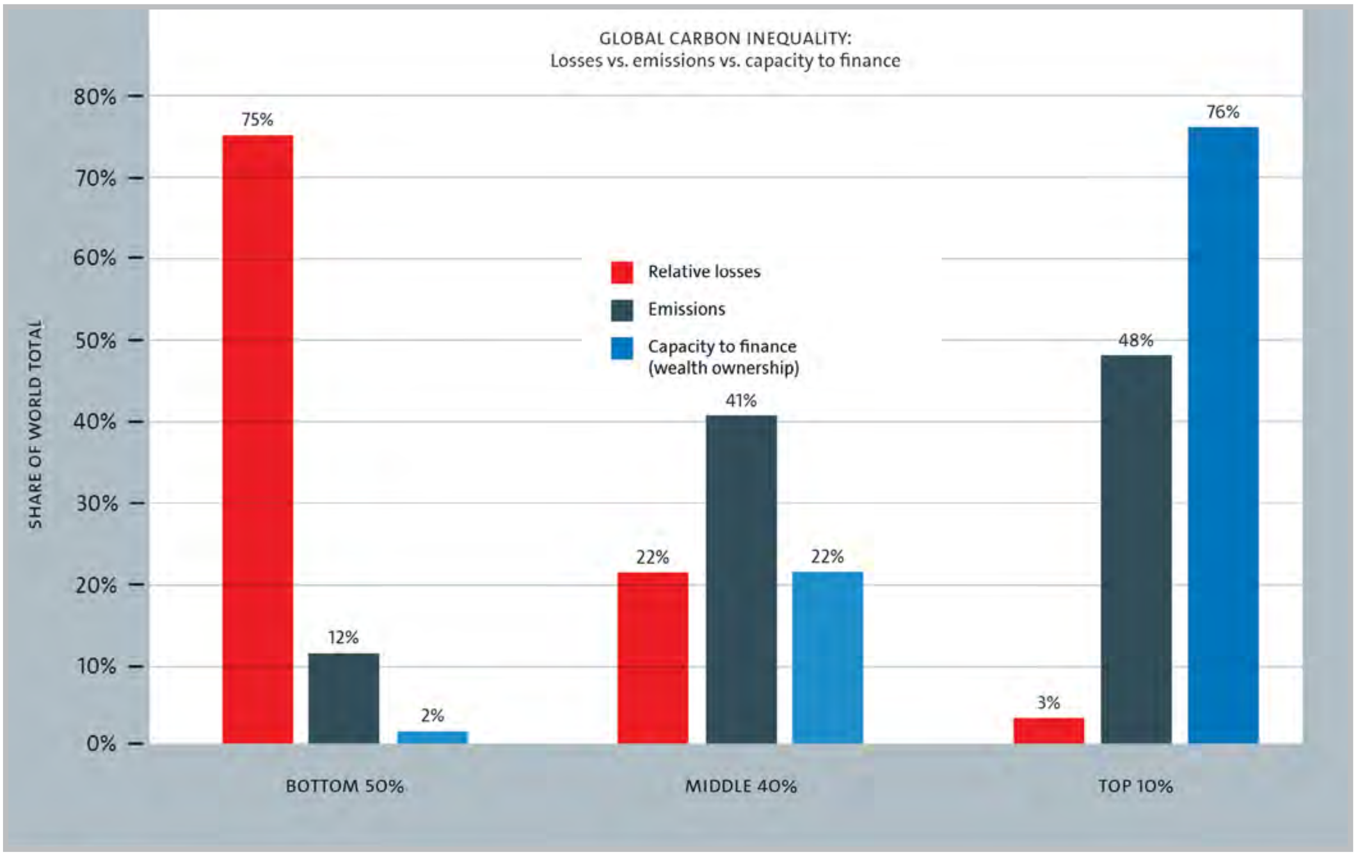

Figure 3.2: Global carbon inequality: relative losses, emissions, and capacity to finance, see next comment. The chart illustrates that the bottom 50% of the global population is responsible for 12% of worldwide emissions but faces 75% of relative income losses attributable to climate change. The emission inequality data is derived from the World Inequality Database for 2019. The total global relative income loss burden, weighted by population, is obtained by summing these loss scores and is distributed across emitter groups. It is crucial to interpret these estimates of global inequality in income losses cautiously, given the simplified approach used to construct them. Nevertheless, they offer a valuable representation of the substantial global inequality in climate change impacts identified in the literature. Source: Chancel et al., 2023.

Furthermore, as Figure 3.3 shows, the disparities in carbon emissions within countries have recently become more significant than the disparities between countries: Carbon emissions inequality within countries currently represents the bulk of global emissions inequality (about two thirds of the total), indicating a complete reversal compared to the year 1990 (Chancel et al., 2023, pp. 9-10). In other words, the gap between emissions from affluent consumers and non- affluent consumers within countries is larger than that between countries, suggesting that the wealthy are the most responsible for high consumption-related emissions, no matter from which country they are. As Khalfan et al. (2023) show, the climate crisis is mostly driven by wealthy individuals (i.e., the richest 1%) through their emissions, investment patterns, and political influence. Governments around the world do not regulate upper limits for the personal carbon footprints of consumption, and so no automatic emissions reduction can be expected from the side of affluent consumers. Unless policies to substantially reduce both poverty and social inequalities are implemented around the world, just low-carbon transitions in consumption trends will remain not plausible (Khalfan et al., 2023).

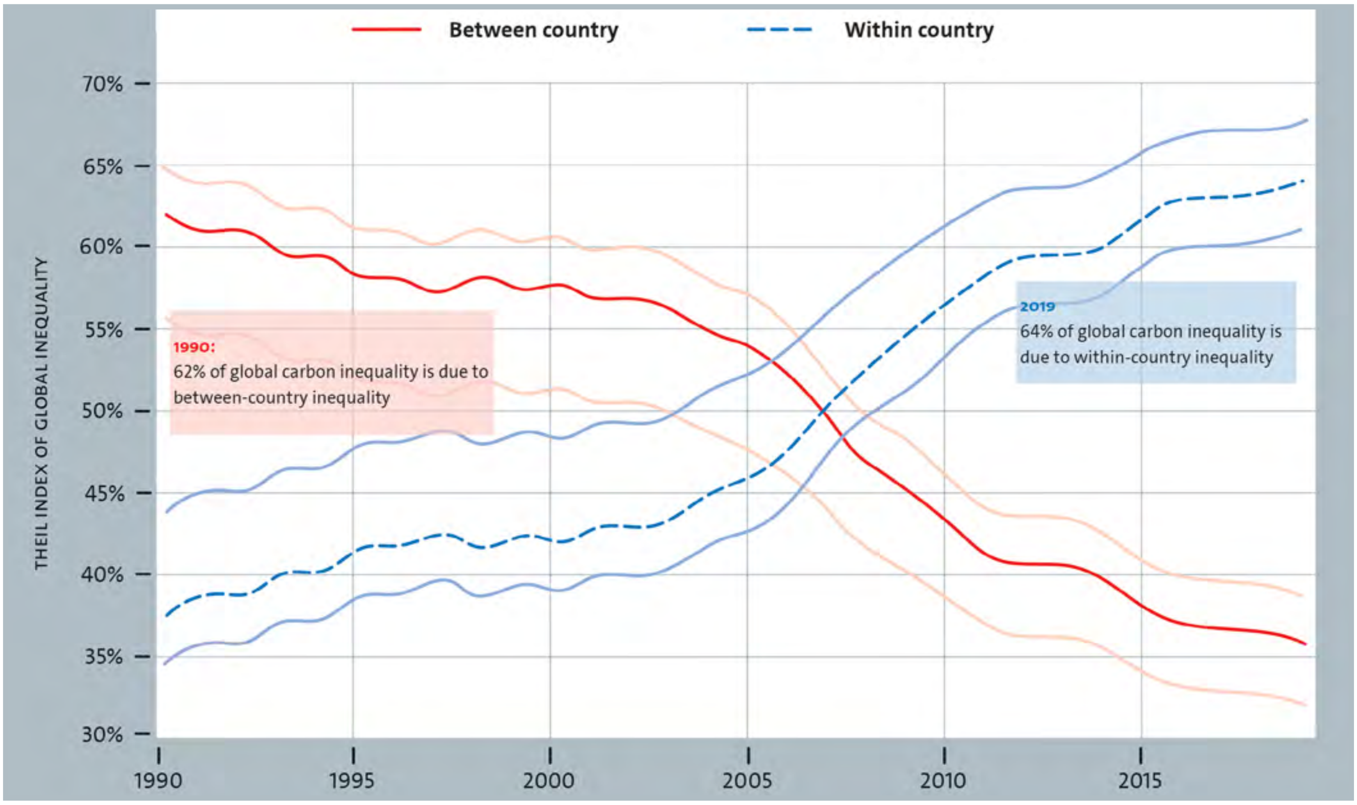

Figure 3.3: Global inequality of individual emissions: between vs. within country inequality, 1990-2019. This figure shows that in 1990, the predominant factor contributing to 62% of worldwide disparities in individual carbon emissions was the variation in average emissions between countries. However, by 2019, this scenario had undergone a significant shift, with 64% of the global inequality in emissions attributed to differences within countries. These findings present a breakdown of global inequality using the Theil index, utilizing modeled estimates derived from the systematic integration of household surveys, tax data, and environmental input-output tables. The emissions considered encompass footprints associated with both consumption and investments, and the values account for the carbon embedded in international trade. Source: Chancel et al., 2023.

Disruptive events such as the COVID-19 pandemic and Russia's invasion of Ukraine provoke sudden changes in consumption trends. For example, during the COVID-19 pandemic, the average consumer in the 28 countries of the Organisation for Economic Co-operation and Development (OECD) reduced consumption in transport and restaurants, but spent more on food and housing (OECD, 2021). Another example is the considerable reduction in gas consumption in Europe in the aftermath of Russia's invasion of Ukraine (IEA, 2023a; Ruhnau et al., 2023). Nevertheless, consumption reductions in response to these crises were facilitated by seasonal factors, and proved temporary or incremental at best (Gresse et al., 2023; Renn et al., 2022; Pang et al. 2022). In terms of overall consumption trends and emissions reductions, these events are associated with increased social inequalities and rebound-effects (Gresse et al., 2023). Noteworthy is also the fact that although global clean energy investment has received a significant surge due to the efforts made in recovering from the COVID-19 pandemic and the energy crisis (IEA, 2023b), subsidies for fossil fuel consumption reached an unprecedented amount of over USD 1 trillion in 2022, marking a substantial increase and setting a new record for the highest annual value observed (IEA, 2023c; see also Section 3.8).

Enabling and constraining conditions affecting driver dynamics

The implementation of policies, technologies, and infrastructure that combine social protection with climate change mitigation and adaptation is key to support important shifts in consumption trends, such as the adoption of low-carbon diets, low-carbon modes of transport, and renewable energy consumption (Chancel et al., 2023; Hirth et al., 2023; IPCC, 2023a). As important as shifts in consumption trends is addressing social inequalities and reducing overall consumption, especially among affluent groups (Wiedmann et al., 2020; Khalfan et al., 2023). In this regard, the IPCC has recognized the need to promote energy and material consumption reduction and sufficiency, which is regarded as a "set of measures and daily practices that avoid demand for energy, materials, land, and water while delivering human well-being for all within planetary boundaries" (IPCCa, 2023, p. 72). According to the Global Resources Outlook 2024, the effects of material extraction and consumption on climate and biodiversity greatly surpass the goals set by the Paris Agreement, and for this trend to be reversed integrated policies and action on resource efficiency, climate and energy, food, and land are needed (UNEP and International Resource Panel, 2024). These transformations are crucial enabling conditions for this social driver to support deep decarbonization by 2050. However, there are no signs that these enabling conditions are strongly at play.

Currently, there are constraining conditions that strongly inhibit the pathways toward decarbonization, let alone deep decarbonization. The fundamental constraining conditions of this social driver are the growth-based political economy of mass and affluent consumption and the persisting investments in fossil fuels and subsidies for fossil fuel-based consumption (see also Section 3.8; IEA, 2023c). That is, the unchallenged pursuit of continued economic growth and accumulation as a key societal goal, which enables and is pushed by the institutionalization of mass consumption (Blühdorn, 2019; Boström, 2020) and the power structures shaping worldwide consumers' conduct toward high-carbon and highly resource-intensive consumption (Cohen et al., 2022; Dubuisson-Quellier, 2022; Hirth et al., 2023). These constraining conditions inhibit structural transformations in worldwide consumption and production processes, especially as production is still mostly based on fossil fuels (Hirth et al., 2023; see also Section 3.7). Increasing social inequalities also represent key constraining conditions for deep decarbonization, inasmuch as they negatively influence social cohesion and cooperation toward environmental protection and decarbonization efforts (Creutzig et al., 2022). The insistence of powerful social actors on technological progress and the role of markets and individuals' action as solutions to the global ecological crisis also hinder decarbonization and sustainability transformations at large (Fuchs et al., 2021; see also Gresse, 2022). Experts show that innovations in technology and behavior do not necessarily lead to lower levels of total emissions but have the potential to both create new inequalities and reinforce existing ones (Sovacool et al., 2022).

Social inequalities are also reinforced and reproduced by corporate responses to inflation, which elevates the general price level of goods and services and affects the purchase power of most economically vulnerable consumers (Weber and Wasner, 2023). Consumption is thus reduced among those who contribute the least to global emissions, while overall consumption and emissions continue to rise. For instance, the substantial rise in Europe's inflation over the past two years can be largely attributed to the increase in corporate profits, as companies have raised prices to a greater extent than the surge in costs associated with imported energy (Hansen et al., 2023). Finally, disruptive events and military conflicts around the world lead to deep uncertainties, multiple crises, and instability, which considerably hinder global efforts toward decarbonization (see Box 2). For example, the COVID-19 pandemic, the Russian invasion of Ukraine as well as the military conflicts and instability in the Middle East region have an important impact on energy market and prices (IEA, 2023a;f), making it difficult for societies to prioritize transformations toward deep decarbonization over short-term crisis management.

Major studies published since the previous Outlook edition

The latest World Energy Outlook published by the International Energy Agency (IEA) shows that the global transition to clean energy is moving at unprecedented speed, but remains too slow and incompatible to the 1.5°C global warming scenario (IEA, 2023f). In addition, the report reveals that demand for fossil fuels might peak before 2030 since the deployment of low-emission alternatives is accompanied by a slowdown in the incorporation of new assets reliant on fossil fuels into the energy system (IEA, 2023f, p. 18).

A recent study on affluence consumption highlights how innovations may even make societies less sustainable (Markard et al., 2023). By focusing on Sports Utility Vehicles (SUVs) and space tourism, the study shows how the former reproduce unsustainable consumption trends while the latter creates new ones. In other words, it reveals that innovations in socio-technical systems eventually create new barriers or constraining conditions for sustainability transformations such as deep decarbonization. New reports focused on climate justice highlight the enormous disparities in emissions, vulnerabilities and adaptive capacity around the world and advocate for radical reductions in social inequalities, power shifts, and structural transformations toward climate neutrality (Chancel et al., 2023; Khalfan et al., 2023). The latest Global Resources Outlook also shows how unsustainable consumption patterns are linked to unequal impacts on climate and biodiversity. It also highlights that predominant emphasis on supply-side (production) measures must be balanced by a stronger emphasis on demand-side (consumption) measures toward climate neutrality (UNEP and International Resource Panel, 2024).

A systematic review of empirical observations on lifestyles and consumption patterns sheds light on a series of enabling and constraining conditions for sustainable consumption (Hirth et al., 2023). Among them, so-called deep barriers for lifestyles compatible with the 1.5°C global warming scenario are economic business models relying on the fossil fuel industry, which are backed by powerful political actors; the strong institutionalization of the economic growth paradigm in social relations; the belief in neoliberal governance; as well as political priorities and valuations related to satisfying high and rising energy demand at the expense of sufficiency strategies for energy use (Hirth et al., 2023, p. 5). Conversely, key enabling conditions for sustainable consumption patterns are strong regulation and litigation of supply and demand, climate-friendly infrastructure, corporate responses and subsidies, public access to minimum levels of essential goods and services, sufficiency strategies in combination with climate justice narratives as a basis for increasing societal acceptance of climate mitigation measures, and shifts in societal values toward collective well-being and alternative paradigms focused on sustainable consumption for a "good life" (Hirth et al., 2023, p. 6).

Uptake of climate action resources generated by other drivers

Changing the dynamics of this social driver is extremely difficult and depends on the utilization of resources produced by other social drivers, such as knowledge production and climate-related regulation. Knowledge production generates resources that inform social practices and processes toward decarbonization and can be used by societal agents to promote shifts in consumption trends. Nevertheless, knowledge production with regard to mitigating climate change remains highly contested (see Section 3.11). The resources produced by climate-related regulation to steer consumption toward low-carbon patterns or toward sufficiency are still limited or non-existent (see Section 3.4). Political systems worldwide do not refrain from but actually rely on and often stimulate carbon-intensive consumption behavior. For example, encouraging consumption through fiscal and monetary policy is a very common strategy used in times of economic crisis and also as a tool for overcoming poverty (Arestis et al., 2021; Abdulrahman and Oniyide, 2023). Sustainability standards or ecological labels produced by transnational initiatives, for instance on food, textile, or household appliances, still provide very limited incentives for less carbon-intensive consumption patterns (Plakantonaki, 2023; Yokessa and Marette, 2019; Hameed and Waris, 2018; see also Section 3.3)

Implications of driver dynamics for climate change adaptation

The interplay between social inequalities and consumption trends is also evident in the context of climate change adaptation. Climate-related risks and vulnerabilities (for example water insecurity, poor sanitation, migration in response to climate-related disasters) disproportionately affect those who contribute the least to consumption-based emissions, especially women and girls in developing countries (Chancel et al., 2023; Schipper et al., 2021; Khalfan et al., 2023). Promoting climate justice thus requires the combination of significant reductions in carbon-intensive consumption with social protection programs that promote sustainable development and improve resilience (IPCC, 2023b).

3.10

Media Debates

Media debates as drivers of public debates on climate change can be split into news media (professional journalism), alternative fringe media outlets, and social media networks. Since the most recent publication of the Outlook, structural changes in the digital media environment and political dynamics have impacted the media debates on climate change, with different effects.

Key social driver dynamics since the previous Outlook edition

In the previous Outlook we concluded that this driver is currently at a critical juncture, with media attention toward climate change in constant flux, making its impact difficult to assess. Though there are trends toward transformative journalism and newly established formats and websites which could support social dynamics toward deep decarbonization, the impact of this driver will depend on individual patterns of information use, the overall role journalism will play in society, to what degree social media and alternative media will be regulated, and the general state of world affairs providing distractions from the issue of climate change.

Within the past year, this driver has been strongly shaped by structural changes in the digital media environment such as, first, the broadened accessibility of generative artificial intelligence for the production of texts (e.g., ChatGPT), images, as well as audio and video content; second, changes in ownership (e.g. Twitter/X) and regulation of social media platforms; but also by, third, a rise in novel transformative practices among journalists; and, fourth, the success of climate-related entertaining media content.

The newly available generative artificial intelligence tools can help journalists work more efficiently and make their products more accessible and attractive for a more diverse range of audiences (Caswell, 2023). This could improve journalistic coverage of climate change, for example by providing more personalized and interactive information (Newman, 2023) about the impacts of climate change, climate change mitigation, or adaptation measures to citizens. However, generative artificial intelligence also threatens to destabilize professional journalism itself. It can be used (and is already being used) to replace journalistic staff in some areas—it remains to be seen whether this will also concern the highly qualified and specialized climate (policy) journalism. At the same time, the digital media sphere threatens to be flooded by unverified and potentially false information produced by generative artificial intelligence (which has been shown to "hallucinate" and provide nonexistent facts and sources, see Ji et al., 2023). This increases the already high pressure on professional journalism to verify and counteract climate misinformation (Lelo, 2023; Porter and Wood, 2021; Hassan et al., 2023).

There is also a positive trend of a journalism that is more engaged in covering climate change and motivating a debate about ecological transformations: transformative journalism (Brüggemann et al., 2022). However, climate change is still rather neglected by many media, such as Germany's main TV news broadcast, the Tagesschau (Tschötschel et al., 2022). Having said that, climate journalists have also benefited from the success of popular entertainment media content (for example the movie "Don't Look Up") which succeeded in raising awareness for climate change within the general public (similarly to "An Inconvenient Truth", see Nolan, 2010) and thus creating a greater interest in and demand for journalistic coverage of these topics.

Looking at fringe alternative media or hyper-partisan right-wing media opposing climate policy—and in case of Fox News (US) and GB News (UK) mainstream right-wing media—, the direction is somewhat clearer: For them generative artificial intelligence will greatly facilitate the production and distribution of mis- and disinformation, aiming to push societies away from deep decarbonization.

The final sale of Twitter/X to Elon Musk and the resulting changes to the platform have also re-shaped this driver: While Twitter/X has so far retained its role in connecting scientists, journalists, politicians, and—to a lesser degree—the public, it has become significantly more unpredictable, and the share of unreliable information has increased. But by effectively closing down academic data access, it has deprived the research community of an important tool to monitor public debates about climate change. Reacting to the increasing political polarization in the US, other social media platforms have rolled back some of their measures against the spread of misinformation (Myers and Grant, 2023). Hence, it will be important to see whether the recently adopted EU Digital Services Act regulating digital platforms (Helberger et al., 2021) will succeed in stabilizing the media sector and the quality of available information, including information on climate change.

Enabling and constraining conditions affecting driver dynamics

Political dynamics have both enabled and constrained media debates as drivers toward deep decarbonization. Some countries have seen increased disruptive climate protests such as those organized by the Last Generation in Germany, Austria, and Italy or Just Stop Oil in the UK. New protest forms targeting rush-hour traffic have triggered much public debate, which has been used by conservative actors to de-legitimize or even criminalize the climate movement. So far, however, there is no empirical evidence that disruptive climate protests have lessened support for climate policy or decreased climate engagement (Kenward and Brick, 2023; Özden and Ostarek, 2022).

As climate debates move closer to the implementation of climate policies, they also become more controversial. Climate contrarian think tanks (Almiron et al., 2023) and industry campaigns (Sassan et al., 2023; Holder et al., 2023) continue to push narratives of delay and denial (Meyer et al., 2023c), which are increasingly taken up by more mainstream actors to mobilize political support against governments trying to implement climate policies. At the same time, recent electoral successes of authoritarian right-wing actors and the general trend of democratic backsliding have restricted the freedom of the press in a number of countries, with particular pressure on investigative journalism of environmental or climate-endangering crimes (Medeiros and Badr, 2022). Since many right-wing populist actors also propagate climate denialism (Forchtner, 2019), this is likely to decrease the plausibility of deep decarbonization.

Finally, media debates continue to be affected by Russiás invasion of Ukraine and the rising global tensions after Hamas' attack on Israel on 7th October 2023 and Israel's ensuing bombing and invasion of Gaza, which take away media attention from climate change related issues. At the same time, the overlap of policy measures aiming to reduce Russian influence and curb greenhouse gas emissions has charged the public debate surrounding climate mitigation in rather unforeseeable ways. The policy measures responding to and the general economic impact of the war have triggered substantial protests, likely contributing to a notable increase in support of parties denying the need for these measures. Concurrently, the sanctions against Russia are limiting the activities of some alternative media responsible for climate change misinformation (such as RT, formerly Russia Today)—or at least pushing them into clandestineness.

Major studies published since the previous Outlook edition

New studies in the field of climate communication focus on a whole range of issues, three of which should be mentioned here due to their relevance for the plausibility of climate futures: first, media constructions of climate futures; second, the move from denial to narratives of delay of climate action; and third, the polarizing debates around climate protests.

The first strand of research identifies dominant visions of the future as represented in news media discourse: Overall, climate futures are imagined similarly in leading news outlets in countries from both the Global North and South, as comparative content analyses of media in Germany, India, South Africa, and the US shows. This is due not only to the global nature of climate change risks but also to the strong voice of science institutionalized in one global body (the IPCC). We find that, across countries, climate change is being depicted as far away geographically, far in the future, and not concerning audiences directly. This is captured in the journal article title: "Not here, not now, not me" (Guenther et al., 2023). This finding is relevant, as psychological distance is commonly viewed as an important reason why people do not engage with climate change, even though the evidence for this mechanism is actually weaker than generally assumed, as a recent systematic review shows (van Valkengoed and Brüggemann, 2023). In terms of concrete frames, four can be distinguished. The most important is a distant risks-to-ecosystems frame, followed by risks-to-humanity, a technical solutions frame, and an economic opportunity frame (Guenther et al., 2023; Guenther et al., 2024). What is rather rare is an apocalyptic climate catastrophe framing, and what is almost totally absent is a great transformation frame, which would envision substantial system changes in society. While the need for broad and deep socio-ecological transformations of society have been widely debated in academia for years (e.g. Schneidewind et al., 2016), journalists do not seem to engage with these debates. But there is also evidence that, at least in countries of the Global South, journalists are focusing more on the effects of climate change on humans, thereby encouraging societal change (Hase et al., 2021).

Second, while climate denial still exists on Twitter/X, it has become a minority claim (Meyer et al., 2023c). Even in a context that features elite-sponsored climate denialism like in Australia, denial has become a minority position (Bednarek et al., 2022). Apparently, after years of increasing droughts, wildfires, floods, and record-breaking temperatures, anthropogenic climate change is no longer deniable. Instead, strategies of obstructionism against climate policies have moved on to a variety of "discourses of climate delay" (Lamb et al., 2020, p. 1), which effectively all argue against immediate far-reaching action. Fossil-fuel companies use Facebook to frame their argument for the importance of fossil fuels around catchwords like pragmatism, innovation, patriotism (Holder et al., 2023). A broadly used strategy is greenwashing, that is, pretending to be climate-friendly while effectively sticking to a business-as-usual approach, as a study shows that compares communication with the actual investments of large oil companies (Li et al., 2022).

Third, a hotly debated topic in Europe in 2022 and 2023 were disruptive forms of climate protests. Some studies have explored the media coverage of the more conventional climate movements (such as Fridays for Future) and found a high salience of youth protests in the news, but from an apolitical perspective, not providing a voice to the protesters as actors with political demands (von Zabern and Tulloch, 2021; Poot et al., 2023). Two studies under review compare coverage of the more disruptive climate movements with the more conventional ones and find evidence of polarization around disruptive climate protests in Germany on both Twitter/X and in news outlets: Toxic interactions are fueled by frames that originate among political and media actors from the far right of the political spectrum, in which the frames are set by political actors from the extreme right and their respective media outlets in Germany (Meyer et al., 2023 a, b).

Uptake of climate action resources generated by other drivers

Climate protests and social movements trigger media attention and provide reporting opportunities for climate action, even though, effectively, coverage of protests might focus on the protesters rather than their demands (von Zabern and Tulloch, 2021; Poot and Bauwens, 2023; Meyer et al., 2023b)

Similarly, UN climate governance offers reporting opportunities providing voice to calls for climate action. Particularly the climate conferences have done so (Brüggemann et al., 2017) and continue to be a main driver for media attention to climate change (Hase et al., 2021).

Implications of driver dynamics for climate change adaptation

Our own manual quantitative content analysis of news media from India, South Africa, the US, and Germany (Guenther et al., 2023a) shows that adaptation measures are not often mentioned or advocated for in media coverage related to climate futures. Generally, media coverage is still focused on describing the risks associated with climate change. Political demands raised in media coverage are not highly frequent, but if they occur, the call for mitigation rather than adaptation measures, as shown below in Figure 3.4. Country differences are not displayed as the countries showed fairly similar general pattens of news reporting.

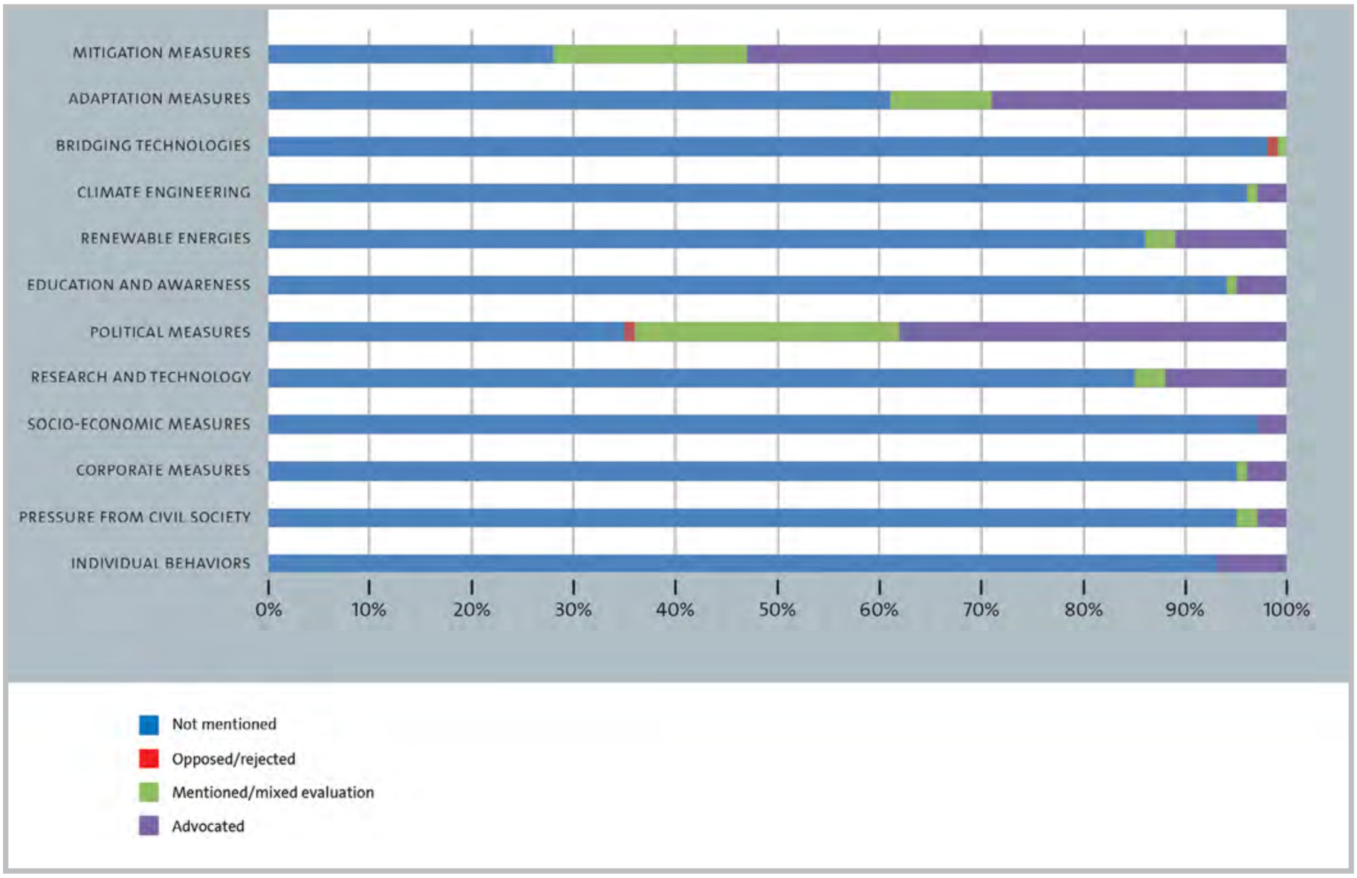

Figure 3.4: Climate actions: mentioned or demanded in media reporting on climate futures across German, Indian, South African, and US media (n=734); data is retrieved from quality print media, regional print media, tabloid media, digital news media, and weekly news magazines.

3.11

Knowledge Production

Knowledge production refers to practices of knowledge generation and validation that provide facilitative capacities for envisioning and enacting transformations toward deep decarbonization.

Key social driver dynamics since the previous Outlook edition

The previous Outlook found that the knowledge production driver continues to support decarbonization as there is a continuous increase in global knowledge resources, including earth observation capacities, that are packaged and tailored to specific governance problems and policy processes. The dynamics of the driver were found to be insufficient for deep decarbonization, however, among other reasons due to the weak integration of diverse ways of knowing to produce socially robust knowledge (Wilkens et al., 2023, p. 138). In the current Outlook, we continue to see an increase in knowledge resources that feed into the global opportunity structure and affect the dynamics of other drivers toward decarbonization by 2050. These include the release of landmark publications such as the Synthesis Report of the IPCC Sixth Assessment Report and the UNEP Emissions Gap Report 2023. At the same time, there is an opposing development that has recently gained momentum: the increasing contestation of consensual and authorized climate knowledge as well as the targeted spreading of disinformation and false news about climate change and its consequences (see Fischer, 2019; Oreskes and Conway, 2022; Shue, 2022). The problem of disinformation and organized climate change denial is not a new phenomenon. However, it has taken on a new significance during the past year. The reasons are multiple and complex and include the rise of right-wing parties in many Western countries, the amplification of disinformation through social media networks and underlying algorithms (Section 3.10), and global political events such as ongoing implications of the COVID-19 pandemic as well as the war in Ukraine and resulting economic turbulence (Oreskes and Conway, 2022).

Enabling and constraining conditions affecting driver dynamics

On the one hand, the production of packaged climate knowledge continues to serve as enabling condition in the global opportunity structure, most prominently through the production of IPCC and other global assessment reports (see next section for an overview). On the other hand, this development is constrained by three interlocking forms of contestation: rejection of knowledge, unpacking authorized knowledge, and counter-packaging. First, the packaged knowledge resources tailored to the needs of climate governance are often complex and condensed, abstracting from local experience (Wilkens et al., 2023). As Sundqvist et al. (2018) point out, the near certain, consensual nature of authorized climate science, makes it an easy target for denialism and disinformation. In their words: "Political discussions about trust or distrust in science occur when knowledge comes in one single package without alternatives, creating dichotomies between believers and nonbelievers" (2018, p. 460). In the current context of the war in Ukraine and resulting economic instabilities, this dualistic representation has enabled conservative and far-right actors to contest and reject consensual scientific knowledge.

Second, the emergence of particular climate denial discourses could be understood as a form of unpacking authorized climate knowledge. Unpacking can be understood as a distinct epistemic practice directed against authorized scientific organizations like the IPCC and their key publications. Many conservative, right-wing actors in fossil-fuel producing states (such as Saudi Arabia, Russia, or the US) do not outrightly deny the existence of climate change anymore, but question the seriousness of its impacts, the feasibility of mitigation measures, or incite concerns about societal transformation toward decarbonization (Fischer, 2019, p. 147). They have moved from denial to delay (Shue, 2022; see also Section 3.11). In other words, such actors unpack authorized knowledge resources such as the IPCC assessment reports by affirming some of its findings while discrediting and denying others.

Third, the literature on non-knowledge and ignorance shows that climate skeptics and deniers are themselves involved in the packaging of knowledge resources (Stehr, 2012; Wehling, 2022). In this literature, authors have stressed that uncertainty and ignorance should not just be understood as the absence of knowledge, resulting for example from lack of data or methodological limits, but as something that is actively produced and manufactured (Aradau, 2017, p. 330). Non-knowledge, in this sense, becomes a strategic resource that can be mobilized by political actors in public controversies. Large think tanks, such as the Heartland Institute in the US, actively produce resources of ignorance through a range of packaging practices that imitate those of climate science. For example, these organizations host yearly international conferences and produce major reports, maps, and other resources. The main aim of these packaged forms of non-knowledge is to cast doubt and challenge the consensual knowledge of the IPCC. They thus enter the global opportunity structure as counter-resources, in which they act as obstacles to the goal of decarbonization by 2050. The dynamics of the knowledge production driver, therefore, remain insufficient for deep decarbonization.

Considering these forms of contestation, which happen in parallel to the increasing production of packaged climate knowledge, it is crucial to assess the direction of the driver and its impact on the global opportunity structure for deep decarbonization by 2050.

Major studies published since the previous Outlook edition

A key publication during the past year was the Synthesis Report of the IPCC Sixth Assessment Report, which was finalized in March 2023. The Summary for Policymakers of the Synthesis report in particular underlines the growing tension between knowing fundamental problems, such as the ongoing growth of greenhouse gas emissions and the declining carbon budget, and a lack of substantial climate action (IPCC, 2023a; see also Forster et al., 2023). The Emission Gap Report 2023 has synthesized knowledge on emission trends, highlighting not only insufficient mitigation efforts but also underlining the need for knowledge sharing for a successful energy transition on a global scale (UNEP, 2023a). A number of new studies and reports have been published adding empirical details to key challenges, such as climate change and inequality (Chancel et al., 2023) and transboundary climate risks (Anisimov et al., 2023). A good example of how expert knowledge can exert a more direct influence on global climate governance, and hence the plausibility of deep decarbonization by 2050, is the open letter calling for an International Non-Use Agreement on Solar Geoengineering. Initially published in 2022 in WIREs climate change (Biermann et al., 2022), the letter has been signed by more than 490 academics from 61 countries since then. In the letter, the scholars express concern that research into solar geoengineering approaches could diminish the international community's ambitions for decarbonization. This criticism is particularly resonating with vulnerable developing countries, which rejected a proposal by several industrialized countries to establish a geoengineering expert group at the sixth session of the United Nations Environment Assembly (UNEA-6) in Nairobi in February 2024 (CIEL, 2024).

Other recent publications highlight how non-knowledge has been actively produced and used by the fossil fuel industry and other economic actors to hinder deep decarbonization. In a recent study that confirms the role of the fossil fuel industry, Supran et al. (2023) reveal how ExxonMobil accurately predicted global warming using their own internal models and nevertheless pursued a strategy of climate denial. In a similar way, the report "The Emperor's New Climate Scenarios" (Trust et al., 2023) shows that the climate-scenario models used by financial services underestimate climate risk by minimizing or ignoring large-scale impacts such as potential tipping points, sea-level rise, or climate-related migration.

Generation of climate action resources and uptake from other drivers

Expert (and other) knowledge generated by climate science offers resources for virtually all other social drivers by providing the knowledge base of social practices and processes toward decarbonization and adaptation. Knowledge production, at the same time, uses resources generated by other drivers as it integrates these in packaging practices which assemble different forms of knowledge for a variety of audiences. UN climate governance, for example, works as a global platform for the production and validation of consensual climate knowledge. The IPCC and the UNFCCC work largely as boundary organizations that mediate between science and policy. The IPCC's Summary for Policymakers (2023c) is a clear illustration of the interplay between political and scientific consensus. The UNFCCC, in a similar vein, works as a boundary organization not only for scientific communities but also for a wider diversity of actors, most prominently Indigenous and local knowledge holders, especially via the Local Communities and Indigenous Peoples Platform (López-Rivera, 2023).

As the evolution of the IPCC communication strategy illustrates, the media debates driver is another important one to generate resources for knowledge transfer and science communications. The introduction of communication innovations by the IPCC has led to an increasing outreach and stronger media coverage. This includes live-streamed press conferences, the formulation of headline statements, and a greater use of social media and digital technologies (Lynn and Peeva, 2021). The resources derived from the media driver thus enhance outreach and potentially the diversity of audiences for climate science.

Further resources are being generated by social movements, which constitute sites for the generation, reformulation, and diffusion of knowledge (Casas-Cortéz, 2008; Choudry, 2020). The diverse knowledges of social movements become tangible in experiential and embodied practices of resistance and mobilization for social and climate justice. A number of concepts that originated in social movements have thus been taken up by certain strands of critical climate and environmental research in the social sciences. These concepts include climate justice, the rights of nature, food sovereignty, land grabbing, ecological or climate debt, and extractivism, among others (Martinez-Alier et al., 2014). The repertoires of action of climate movements, at the same time, are being taken up by scientists who engage in climate activism. Prominent examples include Scientists for Future and Scientist Rebellion.

Implications of driver dynamics for climate change adaptation

The driver dynamics of knowledge production not only produce resources for decarbonization but also for adaptation. In the IPCC, in particular, adaptation has become an increasingly important topic, especially since the third assessment report. The knowledge packaging practices of the IPCC have been crucial in framing the concept of adaptation within a specific understanding of science-policy interactions. The IPCC's global and regional perspectives on adaptation, however, require down-scaling to the local contexts where adaptation takes place. IPCC assessment reports increasingly acknowledge the importance of bottom-up approaches through the recognition of the role of community-based adaptation, as well as Indigenous and local knowledge (IPCC, 2022b).

There is extensive evidence regarding the importance of Indigenous and local knowledge in adaptation actions. Local observations have been shown to improve or supplement the absence of weather and climate forecasting (Petzold et al., 2020; Leal Filho et al., 2022). There is case-specific evidence that the use of Indigenous and local knowledge positively correlates with higher levels of implementation of adaptation actions (Zvobgo et al., 2023). The case study assessments in this volume provide additional evidence in this respect. Nepalese rural communities utilize Indigenous and local knowledge in adaptation practices, thus supplementing limited observational data and providing guidance for locally appropriate adaptive responses (see Section 5.7). The case study on Namibian pastoralists highlights the importance of considering the specificities of local understandings of weather and climate (see Section 5.8). The German North Frisian case, for its part, provides a counter-point insofar as local knowledge and place-based identities reflect a historical preference for a technical intervention, namely dikes, to the detriment of alternative approaches (see Section 5.9).

Research in the field of global climate governance has shown how inequalities in knowledge production shape current processes and complicate knowledge co-production especially in light of diverse ways of knowing climate change (Wilkens and Datchoua-Tirvaudey, 2022). While knowledge co-production in climate change mitigation and adaptation is increasingly seen as a prerequisite for just and successful practices, its implementation remains contested and risks to reproduce inequalities if it degrades into a mere technical point of conducting research (Muhl et al., 2023). The plausibility of adapting to climate change in a sustainable manner is therefore highly dependent on the way in which situated knowledges inform social and cultural responses to climate-related impacts.

3.12

Summary of Social Driver Assessments

Following the Social Plausibility Assessment Framework (see Section 3.1) to assess the climate future scenario of achieving deep decarbonization by 2050, we have updated the social driver assessments based on the analyses of changes in driver dynamics and context conditions, as well as reviews of newly published studies relevant to each driver. We analyzed whether key events have led to significant shifts in driver trajectories and if notable developments occurred in their enabling and constraining environments since the publication of the previous Outlook edition. The social dynamics of a global low-carbon shift continue to highly depend on interactions between drivers and climate action by individuals, groups, and organizations that cut across societal spheres and social processes. We therefore tracked how resources for societal transformation produced by social drivers acquire global visibility, become part of climate action scripts, and materialize into broad repertoires of climate action. The assessments highlight that these resources encompass a broad range beyond material means, such as economic capacity, but also includes discursive, epistemic, normative, and political resources. To evaluate the unfolding of these dynamics over time, we have introduced the concepts of densification and relationality (see Section 3.1). Densification refers to both quantitative increase and qualitative change of resources for climate action (i.e., documented by institution-building, societal interaction, routinised practices, repertoires, and scripts), whereas relationality refers to the dynamics generated through interrelations among social drivers (i.e., interlinkages). It captures observable linkages of increasingly institutionalized relations. As such it offers invaluable data in order to map and evaluate dynamics that support or undermine the plausibility of deep decarbonization. This section synthesizes the main findings of the social driver assessments with regard to the current status of driver dynamics. It is based on the information provided in the respective driver assessments in the Sections 3.2 to 3.11.

Signs of change in social drivers' dynamics

In Stammer et al. (2021) and Engels et al. (2023), we found that deep decarbonization by 2050 is not plausible although most analyzed social drivers support at least a partial transition toward deep decarbonization. The previous assessment concluded that the "current trajectory of seven social drivers (i.e., UN climate governance, transnational initiatives, climate-related regulation, climate protests and social movements, climate litigation, fossil-fuel divestment, and knowledge production) supports decarbonization but not deep decarbonization", while "[t]he dynamics of two other social drivers (i.e., corporate responses and consumption patterns) continue to substantially undermine the pathways to decarbonization […]" (Pagnone et al., 2023, p. 34). In the current Outlook, we observe that reaching deep decarbonization by 2050 remains not plausible under current circumstances. This emerges from the updated assessments of social drivers, most of which show continuation, while some display considerable changes in their dynamics compared to previous editions. One social driver in specific, fossil-fuel divestment, changed its direction, as it now points away from the deep decarbonization scenario, contrary to previous assessments. As in the 2021 and 2023 Outlook editions, none of the 10 social drivers supports deep decarbonization by 2050, meaning a reduction of carbon dioxide emissions that is fast and strong enough to achieve net-zero carbon emissions by that date is not plausible.

Drivers supporting decarbonization

Six social drivers—one fewer than in the previous Outlooks— are currently supporting decarbonization, but not deep decarbonization. These supporting drivers are UN climate governance, transnational cooperation, climate-related regulation, climate activism and social mobilization, climate litigation, and knowledge production. While none of these exhibits a shift in direction, there are noticeable changes in the dynamics of each driver. The assessment of UN climate governance (Section 3.2) describes how a series of events affected developments within the United Nations Framework Convention on Climate Change (UNFCCC) as well as in the wider global climate governance space. Although driver dynamics have weakened, there is no decisive change in the driver's direction. Likewise, no shift is observed in the updated assessment on transnational cooperation (Section 3.3) despite a constant increase in initiatives forging cooperation among various actors to mitigate climate change. The assessment of climate-related regulation (Section 3.4) points out three major positive developments: the decision to introduce a Loss and Damage fund at COP27, the adoption of key components of the Fit-for-55 package in the EU, and further steps to reduce the implementation gap in the US and the EU. Overall, however, the ambition gap remains unchanged, and the implementation gap is still sizable despite notable reductions. In the assessment of climate activism and social mobilization (Section 3.5), significant dynamics with ambivalent effects can be observed, though they do not lead to a change in the overall assessment. While in the long term it may support deep decarbonization through deeper cultural and normative change in social contexts, in the short and medium term profound dynamics since the last assessment point to both positive effects, such as maintaining the pressure to keep climate change on the political agenda in light of multiple crisis, and negative effects, such as the polarization with regard to protest repertoires and the increasing criminalization of movements. The climate litigation driver (Section 3.6) shows a continued geographical spreading of cases, the use of new litigation scripts and legal standards, an expansion of hybrid transnational litigation networks, a growing variety of global climate agents, and the broadening of the scientific evidence base for court cases. Despite signs of a growing political and judicial backlash against climate litigation, especially in the US, the driver continues to support decarbonization. Finally, the assessment of the driver knowledge production (Section 3.11) highlights new empirical evidence that both supports and undermines the driver's dynamics toward deep decarbonization. For example, IPCC assessment reports and other packaged forms of knowledge, which are tailored to climate action, strongly support the scenario by addressing governance problems and policies; but at the same time different actors spread mis- and disinformation, new forms of climate denialism, and delayism, all of which undermine the plausibility of the deep decarbonization scenario.

Driver with unclear direction

Unchanged from the most recent Outlook edition, the assessment of the media debates driver (Section 3.10) points to an ambivalent outcome vis-à-vis deep decarbonization. A key development points to structural changes in the digital media environment that entail both positive impacts, such as broadened accessibility to new technologies, and negative ones, such as an expected increase in the production and distribution of mis- and disinformation.

Drivers inhibiting deep decarbonization

While fossil-fuel divestment (Section 3.8) has so far been assessed as pointing toward decarbonization, this is no longer the case. To the contrary, shifts away from decarbonization have been observed since the most recent assessment. The empirical evidence now indicates that divestment announcements are rarely implemented, and even if they are this does not necessarily lead to lower emissions. Moreover, the pressure on investors to divest from fossil-fuel engagement is lessening, while investments in new fossil-fuel engagements are soaring. Therefore, the assessment of this driver now points away from decarbonization. Corporate responses and consumption trends (Sections 3.7 and 3.9) continue to strongly inhibit dynamics toward deep decarbonization. While corporate responses witness some positive dynamics with regard to ambition, for example through an increase of companies subscribing to specific climate goals and target-setting, implementation continues to be weak. This materializes in the corporations' ongoing and substantial contributions to ever-increasing greenhouse gas emissions. In a similar way, current dynamics such as global inflation and increasing social inequality shape the driver consumption trends, but without generating structural changes. Therefore, this social driver also continues to considerably inhibit the pathways toward deep decarbonization.

Social drivers' resources: densification and relationality

The assessment of social drivers' dynamics toward or away from deep decarbonization is supported by information on key changes in social dynamics as well as by the analysis of densification and relationality. One guiding question in the Social Plausibility Assessment Framework for the updated driver assessments points to the generation and use of climate action resources, which lead to patterns of densification in the global opportunity structure for climate action and to increases in the relationality of drivers by institutionalizing exchanges and strengthening interactions among them. All social driver assessments find a proliferation of resources for climate action, which are generated by the driver and used in other contexts, or used by the driver and generated elsewhere. These resources include net-zero standards, networking platforms, legal precedents from successful climate litigation cases, a multiplicity of forms of protest, new tools for media communication, and innovative knowledge-policy platforms, among others. The global resources generated by UN climate governance or transnational cooperation, for example, when incorporated into stable repertoires of climate action, can contribute to align expectations and build trust among state and non-state actors or enhance climate-related standard-setting and certification processes. This continuous densification of climate action and increase in relationality among drivers is an important development since the previous assessment. It indicates new opportunities and potentials for a global low-carbon shift as well as new avenues for research on societal climate futures.

The findings of the updated social driver assessments regarding resources, relationality, and signs of change lead to two general observations, especially notable in those social drivers which show a continuation compared to previous Outlook editions. First, all drivers provide empirical evidence for an increase in dynamics and activities within the driver, which often creates new resources for other drivers. Second, despite the plethora of resources and an increase in dynamics, no *qualitative transformative shift* toward deep decarbonization can be observed. These seemingly contradictory observations indicate that beyond the quantitative increase in resources and interlinkages, there is ostensibly less change affecting key structural and institutional context conditions of the drivers. Furthermore, patterns of densification rarely entail decisive qualitative shifts, such as a shift from soft law to hard law in UN climate governance. There is only little case-specific evidence about positive trends in this regard, especially in transnational cooperation, where voluntary corporate sustainability standards feed into specific climate litigation cases or become a source for national climate-related regulation (Section 3.3). In climate litigation, we see the use of specifically produced attribution knowledge strengthening litigation cases, as well as a new type of cases using private standards and state regulations to denounce corporate climate-washing (Section 3.6). At the same time, climate mobilization highlights the crucial role of climate movements in translating claim-making into implementing steps with regard to adaptation and loss and damage. Nevertheless, in other contexts, such as social movement campaigns addressing corporate responses, resources appear to have a less direct impact, yet shape the discursive context in which corporations operate (Section 3.5). An additional issue that is observable in the dynamics of some drivers is a form of spurious use of resources, which counteracts or undermines climate action. The knowledge production driver, for instance, mentions the use of misleading climate scenarios by financial actors to make the risk of climate change appear smaller than it is (Section 3.11). The media driver assessment, for its part, observes that the use of new technologies such as Generative Artificial Intelligence in the climate field will facilitate the spread of mis- and disinformation by fringe alternative media (Section 3.10).

In summary, the updated social plausibility assessments highlight a seemingly contradictory trend: Despite an observable densification of resources and increasing relationality among social drivers, little development toward the scenario of deep decarbonization by 2050 is observed; rather, individual drivers are showing changes pointing away from deep decarbonization. This indicates that a mere increase in resources and interlinkages is not sufficient to usher in significant changes in driver dynamics toward deep decarbonization. For example, the emissions gap remains high despite new net-zero standards and updated national pledges in the framework of UN climate governance; the wide mobilization by climate activists, including disruptive actions, are ensuring continuous media attention, but at the same time there is an ongoing social and political backlash in the form of repression or even criminalization of protests. Resources are not being sufficiently used to support deep decarbonization, or are even being used to undermine the goal as in the case of climate denialism in technology debates. The existing enabling conditions for climate action, therefore, are not leading to system-wide societal transformations. A concrete manifestation of this is the widening implementation gap in climate action. These uneven and contradictory developments indicate that, without any major shift in global decarbonization dynamics, a low-carbon shift will not follow a linear upward pattern but will rather continue to be shaped by a non-linear trajectory with uncertain unfoldings over time. The unsettling issue that highlights the urgency of in-time climate action is that even if the current momentum of social drivers remains the same in the near future, the plausibility space for deep decarbonization will continue to shrink as the time horizon for societal transformations draws nearer. This, in turn, has several implications for the plausibility of sustainable climate change adaptation: the less mitigation there is, the more climate-related risks and impacts are expected, and thus more challenges for adaptation, let alone sustainable climate change adaptation, are posed.

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BOX I The Implications of Degrowth Scenarios for the Plausibility of Climate Futures

Our assessment of deep decarbonization by 2050 shows that the plausibility of this scenario is substantially constrained by the persistent, or in some contexts even increasing, dependence on and profitability of fossil fuels. The climate protection plans and the climate-related regulations of most countries are still based on economic growth scenarios (Section 3.5), revealing that economic growth remains a key societal goal around the world. Despite the unprecedented deployment of renewable energy production and demand, global consumption trends and corporate responses pose fundamental barriers to the plausibility of decarbonization (not to mention deep decarbonization) because they remain very much based on fossil-fuels and are thus responsible for rising greenhouse gas emissions (Sections 3.8 and 3.10). Unlike previously assessed (Engels et al., 2023), the dynamics of fossil-fuel divestment now even point away from deep decarbonization. Recent geopolitical events, such as new military conflicts, and the lack of restrictions for subsidies or investments in fossil fuels have significantly hindered fossil-fuel divestment while increasing the sector's profitability and therefore the financial engagements with it (Section 3.9).

These driver assessments all indicate that growth is still a very strong organizing principle of social dynamics and that there is no observable empirical evidence for a path departure that would effectively lead away from a universal growth pattern. Therefore, a growing number of studies critically analyze political programs that are legitimized as green growth or green capitalism (Fox, 2023), which promise a decoupling of economic growth from emission intensities or even volumes, as well as from other environmental and resource-oriented indicators. Degrowth scholars and advocates contest these assumptions central to conceptualizations of green growth (Vogel and Hickel, 2023), or they point out how pathways to decarbonization, for example via sweeping electrification, may paradoxically lead to new dependencies on raw materials and lock-in investments in fossil fuel infrastructure if there is no departure from the growth model (Vezzoni, 2023).

Parallel to the increasing recognition of limits to green growth, there is ever more research (Kallis et al., 2018), recognition, and political relevance of degrowth as a concept and as a new development approach (Kallis et al., 2024). Degrowth is both a normative and an analytical concept that refers to "a planned reduction of energy and resource use designed to bring the economy back into balance with the living world in a way that reduces inequality and improves human well-being" (Hickel, 2020, p. 1). Degrowth scholars therefore not only contest the prevalent focus on GDP growth as a measure of human and economic development, but also advocate for a planned, equitable reduction in production and consumption. They do so by referring to concepts such as conviviality and sufficiency as proposals to shifts in consumption and production patterns that couple human development with environmental sustainability while promoting climate justice (see also Abi Deivanayagam et al., 2023; Sandberg, 2021; Wiedmann et al., 2020). The concept of degrowth rejects the assumption that economic growth is a universal precondition for societal development and advocates for alternative ways of organizing the economy based on a preferred path where societies consume fewer natural resources and prioritize norms and practices such as sharing, simplicity, conviviality, and care (Kothari et al., 2014). Sufficiency, in turn, regards a "set of measures and daily practices that avoid demand for energy, materials, land, and water while delivering human well-being for all within planetary boundaries" (IPCC, 2023, p. 31). For the first time since the IPCC was established, degrowth was recently included both in its key climate adaptation and mitigation assessments as a perspective on development and as an alternative to growth-based models as well as carbon-intensive consumption and production patterns (IPCC, 2022a; 2022b). This indicates an incipient broadening of perspectives on pathways of transformation and climate futures within the key context of knowledge production shaping climate governance dynamics (see Section 3.11). The IPCC has been criticized for limiting assumptions about possible mitigation pathways (Beck and Oomen, 2021; Pielke and Ritchie, 2021) and for not accounting for the multiplicity of visions about desirable pathways (Braunreiter et al., 2021). The example of excluding degrowth from previous mitigation scenarios, as Cointe and Pottier (2023) show for the IPCC's Fifth Assessment Report (AR5), highlights the responsibility of involved researchers to reflect not only on their own underlying assumptions, but also to account for diverse visions of climate futures. This does not mean to take other visions, such as degrowth, as a new default. It rather highlights the necessity to not assume the growth model as naturally given or as a universal truth, but to acknowledge that it is a socially constructed paradigm (Schmelzer, 2016).

Degrowth scenarios involve climate mitigation options that question the feasibility of green capitalism, green growth, and circular economy (Hickel, 2020; Hickel et al., 2021). Some are also based on the principle of "private sufficiency, public luxury," which refers to promoting social equity, sustainable consumption, and increased access to high-quality public services, such as education, health and mobility (Wilson, 2023). Amongst the concrete proposals of degrowth advocates are the implementation and diffusion of sufficiency strategies as well as the transformation of modes of production and consumption through regulation (e.g., the end of planned obsolescence) and modes of governance (toward more participatory arrangements and inclusive international organizations) (e.g., Hartl et al., 2023; Bodirsky et al., 2022; Hickel, 2020). Coined in the Global North and influenced by Global South perspectives (Demaria et al., 2013; Hickel, 2020; see also Eastwood and Heron, 2024, Part V), degrowth, its diffusion, and increasing political influence are also relevant to and have implications for the Global South. While degrowth is comparable to Global South principles such as Buen Vivir (from Latin America), Swaraj (from India), and Ubuntu (from South Africa), its approach and concrete measures have been mostly developed for Global North countries (Kothari et al., 2014; Hickel et al., 2021). Global South activists and scholars advocate for more participation in the international debates and establishment of concepts alike (Rodríguez-Labajos et al., 2019) while also recognizing opportunities for positive impacts on socio-environmental issues and challenges in terms of societal legitimation and for policy-making processes (Oboro, 2023; Joseph et al., 2023; Salman et al., 2023).

In light of our plausibility assessments and drawing on the observed densification of resources for climate action, it is imaginable that degrowth scenarios can become resources for climate action, for instance if they are used by social movements or other social actors as parts of packaged knowledge (see Section 3.12). If and to the degree that this happens, degrowth scenarios can enlarge the plausibility range of deep decarbonization. So far, however, degrowth as a concept and new development approach has not gained enough traction to affect the direction of any driver. Currently, our plausibility assessment of the social drivers inhibiting the pathways toward deep decarbonization (such as corporate responses, fossil-fuel divestment, consumption trends) rather underlines how the prevailing belief in economic growth shapes all social driver dynamics. The Outlook assessment updates will remain inclusive as to how diverse ways of envisioning climate futures affect decarbonization dynamics. This encompasses exploring degrowth scenarios, particularly if empirical evidence indicates their influence on social dynamics.

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BOX II The Costs of Military Spending, Wars, and the Plausibility of Climate Futures

The Russian attack on Ukraine is both an expression of and a driver for increased geopolitical tension, further worsening the prospects for international cooperation in many policy fields (Scheffran, 2023). Beyond its great human toll and destruction, the war has hastened major increases in spending on military forces and increased the danger of more armed conflict elsewhere. Both effects are likely to hamper efforts to mitigate and adapt to climate change.

Rising military expenditures

Already before the recent war in Ukraine, global military expenditures had risen since 2014, attaining a record high of USD 2.24 trillion, corresponding to about 2.2% of global GDP and 5.9% of global government expenditure in 2022 (Lopes Da Silva, 2023). Based on announcements of future miliary spending, additional substantial increases are to be expected in the coming years (Lopes Da Silva, 2023). Growing military spending signals an increase in the perception that threats need to and can be met by military force. This reinforces a view that pervades documents from defense ministries and armed forces worldwide, namely that some likely consequences of climate change—such as increased violent conflict—require to be met with military means (Vogler, 2023).

Military emissions

Military activity and its financing are directly relevant for climate change policies primarily because of two effects. One is the carbon footprint of the military; the other is the opportunity cost of military spending.

Data on emissions from military activity is neither comprehensive nor reliable (Rajaeifar et al., 2022). Official national data for the US, Germany as well as the few other countries which publish such data covers both direct emissions and emissions from purchases of energy as well as transport of goods and people from civilian contractors but exclude those emissions for the production of goods, infrastructure and other services purchased by armed forces. The US military's carbon footprint for the fiscal year of 2021 is given as 51 $mtCO_2e$, corresponding to about 1% of total national emissions (US Department of Defense, 2023). Outside estimates including secondary emissions are substantially higher (Parkinson and Cotrell 2022; Rajaeifar et al., 2022). In the case of Germany, the total is reported as 1.71 $mtCO_2e$ (Bundesministerium der Verteidigung, 2022).

Official data for most of those countries whose governments publish data show a downward trend in emissions over the past decade or longer. Main drivers have been the increased use of renewable energy, particularly for electricity, and improvements in energy efficiency in miliary buildings (Crawford, 2022). However, despite considerable investment there has so far been little success in substituting traditional fossils fuels in use by military vehicles, warships, and aircraft (Barry et al., 2022).

Furthermore, increased military spending counters this trend of decreases in emissions by the military. Much of the increased military spending is used for new weapon systems, such as aircraft and their operation, whose contributions to the militaries' carbon budgets are particularly difficult to reduce. Germany is a case in point: While there has been an overall reduction in emissions of 35.7% between 2005 and 2021, emissions increased by 16 percent between 2020 and 2022 (Bundesministerium der Verteidigung, 2022).

The difficulty in reducing emissions of major weapon systems has stimulated discussions about changing force structures, substituting fuel-intensive systems with others that are more energy efficient, such as small drones and missiles (Barry et al., 2022). Judged by current investment plans of major military powers, however, it seems likely that manned aircraft, warships and tanks will continue to dominate military arsenals for decades to come (Depledge, 2023; de Klerck et al., 2023).

Opportunity costs of military spending

Beyond direct emissions from materials they pay for, military expenditures affect carbon budgets through their demands on public budgets by increasingly squeezing out funding for other purposes. One of the policy fields which has already suffered is development assistance, resulting in a growing likelihood that a number of the Sustainable Development Goals will not be met (Sachs et al, 2023). Promises of financial assistance for climate mitigation and adaptation are also becoming more difficult to fulfill. The UN Secretary General has therefore called upon member states to reduce "the human costs" resulting from military spending (UN Secretary General, 2023).

Armed conflict emissions

The number of armed conflicts in the world has grown alongside global military spending. The early 2020s have seen record highs since the end of the Cold War, with more than 50 conflicts reported by the Uppsala Department for Conflict Research (Davies et al., 2023).

Armed conflicts have many costs, human, material, and immaterial. The aggregate global GDP loss directly attributable to war has been substantial (de Groot et al., 2022). With growing involvement of armed forces from high-income countries in recent years, the carbon "bootprint" of wars in some poor countries, such as in Iraq and Afghanistan, has been large. Even so, other aspects of armed conflict, such as large-scale fires, as well as post-conflict reconstruction had more effects on emissions than military activities themselves in most armed conflicts (Depledge, 2023).

Estimates of the scale of emissions from wars are rare and differ widely, depending on the way they were conducted and what types of climate costs are considered. One case that has been studied in some detail with a focus on environmental damage is the war following the Iraqi invasion of Kuwait in 1991. Large-scale irregular oil burning led to the release of about 130-140 $mtCO_2e$, corresponding to about 2-3% of global emissions in 1991 (Lindén et al., 2004). Focusing on one aspect of direct military emissions, a study reports additional fuel use corresponding to 140 $mtCO_2e$ emissions between the fiscal years of 2001 and 2018 through the participation of the US military in the wars in Iraq and Afghanistan (Crawford, 2019).

The impact of the war in Ukraine and emissions

A more comprehensive estimate has been made for the war in Ukraine. A group of experts supported by the Ukrainian Ministry of Environmental Protection and Natural Resources arrived at a total of 119 $mtCO_2e$ of greenhouse gas emissions for the first year of the war (de Klerck et al., 2023). They added up estimates of the carbon footprint of war-related military activities (fuel and ammunition, build-up of fortifications) of 21.9 $mtCO_2e$, of fires resulting from military operations (17.7 $mtCO_2e$), of additional fuel consumption in global civil aviation due to rerouting of flights (12.0 $mtCO_2e$), refugee movements (2.7 $mtCO_2e$), the reconstruction of destroyed buildings, infrastructure, industry and utilities (50.2 $mtCO_2e$), and the destruction of the Nord Stream 1 and 2 pipelines (14.6 $mtCO_2e$). Some of the assumptions used for these estimates can be questioned—for instance, the release of methane and other greenhouse gases from the destruction of the Nord Stream 1 and 2 pipelines is generally estimated at about half the amount considered in the study (Jia et al., 2022). At the same time, the study leaves out some emissions attributable to the war for lack of data, such as the increase in wartime production of arms and ammunition in Russia as well as in those countries supplying Ukraine with weapons. It also does not attempt to estimate the indirect effect of reductions in economic activities in Ukraine and other countries due to the war.

Post-war reconstruction can be a major driver of the emissions resulting from wars. In the case of Ukraine, both the government and international donors aim for critical steps toward low-carbon reconstruction (World Bank et al., 2023, p. 1). Such reconstruction will also be a major challenge after the end of the war in Gaza, which began after the terrorist attack of Hamas on Israel on 7 October 2023. More than 60% of all buildings in Gaza had been destroyed or damaged by January 2024, with the war still ongoing (World Bank, 2024).

Effects of military conflicts on Climate Futures

The war in Ukraine demonstrates anew that wars can have substantial effects on emissions, as does, probably to a smaller extent, the war in Gaza. Both wars already led to more military spending and increased geopolitical tension. They also raise the danger of more warfare in the future.

The plausibility of specific climate futures will likely be increasingly affected by the declining willingness of states to cooperate over geopolitical divides, including on issues related to climate change, as well as growing emissions from increased military activity and the corollaries of wars. Focusing on the immediate impact of wars on the climate, more comprehensive analytical work on emissions from military activity and warfare is warranted. As of now, the database is small, and methods for estimations are not well developed. In view of the carbon footprint of reconstruction, it will be instructive to learn about the extent of the implementation of emission objectives in times of dire need for quick provision of infrastructure and housing.

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4

Regional Climate Variability and Extremes: Challenges for Adaptation

4

Regional Climate Variability and Extremes: Challenges for Adaptation

4.1

Introduction

Climate change mitigation goals, such as deep decarbonization by 2050, play a central role in the development of climate futures. However, a crucial yet under-researched reason for climate change impacts and adaptation challenges lies in the effect of internal climate variability, which arises spontaneously in the coupled climate system (Section 4.2), and in particular in how extreme weather events „ride" on the tails of statistical distributions. The issue is perhaps best illustrated by an example. It is well known that storm surges tend to become more severe when they occur on top of rising mean sea level (e.g., Fox-Kemper et al., 2021, WGI AR6 Chapter 9). Similarly, the entire statistical distribution of summer temperatures shifts toward higher values with mean climate warming, implying warmer extremes (e.g., Suárez-Gutiérrez et al., 2018). By contrast, it appears to be less appreciated that the occurrence of the extremes themselves not only follows the long-term climate change but shows internal climate variability on interannual to decadal timescales, meaning that the frequency of extreme events might go up one decade but decrease during the next, against the backdrop of an overall increase with global warming. As an example of this lack of appreciation, the IPCC Special Report on Global Warming of 1.5°C (IPCC SR1.5, 2018) mentioned internal climate variability quite a few times but did not offer a single quantitative analysis.

However, we showed in the 2021 Outlook edition (Marotzke et al., 2021; based on Suarez-Gutierrez et al., 2018) that worlds differing by 0.5°C in decadal global surface temperature show hotter extremes in the warmer world but also substantial overlap in possible extreme European summer temperatures. This overlap is a manifestation of internal climate variability, defined loosely as those variations in climate that "simply occur" with no apparent cause (Section 4.2). Suárez-Gutiérrez et al. (2023) show another important effect of decadal internal climate variability: Events currently considered extreme and expected to be normal by 2100 in a warming climate will become plausible already in the coming two decades. By "plausible" we mean here that the events will happen with appreciable probability; whether an event will indeed occur depends not only on the future evolution of global warming but also on chance. This role of chance (technically described as aleatoric uncertainty) contrasts with the dominant expectation that a decadal change in extremes is solely due to anthropogenic effects (e.g., Christidis et al., 2015), whereas what is observed actually shows a combination of anthropogenic effects and natural variability.

Knowledge of regional variability and extreme events is a crucial ingredient when trying to deal with climate change adaptation, which must prepare for extremes no matter what their cause. Global warming exacerbates many extremes, but on the regional or local scale the distribution of internal climate variability is often wider than the anthropogenic effect (e.g., Lee et al., 2021, WGI AR6 Chapter 4). "Regional climate change and variability" was one of the six physical processes analyzed in the previous Outlook (Sillmann, 2023). We addressed physical processes that determine regional climate variability and the role of climate variability in amplifying or attenuating changes in climate extremes on a regional scale. We further explained how global warming plays out differently on the regional scale due to climate variability and regional processes. Here we follow up on that assessment and establish regional climate variability and extremes as physical boundary conditions to the overarching question of the current Outlook: Under which conditions is sustainable climate change adaptation plausible? The physical boundary conditions set the room to maneuver both for mitigation and adaptation.

The interplay of regional variability and extremes poses a particular challenge to sustainable adaptation to climate change as assessed in Chapter 5. The sequence of examples discussed in the subsequent sections of this chapter represents an eclectic ensemble of opportunities. Each is based on very recent research and can thus claim some newsworthiness; but each also illustrates a particular fundamental point relevant for the plausibility of sustainable climate change adaptation: the capability of climate models to represent extremes (here: precipitation), the attribution of extreme events to human influence (here: marine heatwaves), and the probability of compounding extreme events (here: extreme heat in multiple breadbasket regions). While each example thus features strong reasons for inclusion here, we do not claim comprehensive coverage of the interplay of regional variability and extremes—hence the rather modest characterization of our set of examples as "eclectic".

Many examples of local manifestations relevant for sustainable adaptation challenges covered in Chapter 5 had to be left out here but hopefully can be covered in future editions. However, along the way and where appropriate we foreshadow the relevance of the physical processes and results for the adaption challenges that are assessed in Chapter 5. The Max Planck Institute Grand Ensemble (MPI-GE, Section 4.2; Maher et al., 2019) contributes to shaping international research on internal climate variability. New ensemble runs comprising 30 realizations with updated scenarios and much-enhanced output now enable us to analyze the interplay of internal climate variability and extreme events.

We explain in greater detail the concept of internal climate variability, how the new MPI-GE contribution was constructed, and what it can provide (Section 4.2). Section 4.3 investigates the extent to which the MPI-GE is able to represent precipitation extremes. This section gives insights into climate model capabilities and limitations, which is important information for the development of adaptation strategies. Section 4.4 analyzes marine heatwaves and the extent to which they can be attributed to human influence. Section 4.5 considers temporal compounding extreme events, here understood regionally in that the section investigates the probability of multiple breadbasket regions experiencing extreme heat simultaneously, also addressing implications for society.

4.2

Single-Model Initial-Condition Large Ensembles Quantify Internal Climate Variability and its Changes

Internal climate variability arises from the chaotic interactions within and between components of the climate system such as atmosphere, ocean, cryosphere, and land (e.g., Lee et al., 2021, WGI AR6 Chapter 4). The existence of internal climate variability potentially obscures signals in the climate system. For instance, internal climate variability impacts the global warming signal, leading to temporary acceleration, slowing down, or even reversal of global warming (e.g., Hedemann et al., 2017; Marotzke, 2019). These impacts on climate trends and variations act on global, regional, and local spatial scales, and on sub-daily to multidecadal and longer time scales (e.g., Maher et al., 2021). This makes understanding and projecting internal climate variability challenging. Specific tools to address this challenge are required. Single-model initial-condition large ensembles, hereafter just called large ensembles, are one such tool (Deser et al., 2020; Figure 4.1).

Large ensembles substantially improve the understanding and quantification of climate variability and change. The underlying idea is to sample the internal climate variability of the climate system by running the same climate model multiple times with slightly different initial conditions but the same external forcing, such as changes in atmospheric greenhouse gas concentrations from human-caused emissions or volcanic eruptions. The different initial conditions of each simulation create different climate trajectories that cause the simulations to diverge quickly, forming a spread of possible climates (Figure 4.1). The simulations are either started from different times of a pre-industrial control simulation (as in Figure 4.1) or from the same coupled model state but with slight perturbations at the level of round-off errors in the atmosphere or ocean at the start of each simulation. Any single ensemble member represents one conceivable evolution of the climate system, taking both external forcing scenarios and internal variability into account. This practice addresses the chaotic evolution of the climate system. The resulting set of simulations is called an ensemble. Ensembles may come in different forms and sizes, depending on the intended purpose. An ensemble is commonly named as "large" when the ensemble size is at least 30 (Milinski et al., 2020).

Large ensembles have enabled substantial progress in understanding the Earth system. They have been used to separate, with unprecedented precision, internal climate variability from the forced response of the climate system to external forcing. This was done to evaluate how well climate models capture the variability and forced changes in the historical observational record (Maher et al., 2019; Olonscheck et al., 2021; Suárez-Gutiérrez et al., 2021). This allows quantifying changes in the magnitude and spatial structure of climate variability related to global warming (Figure 4.1, global maps 1-7). Large ensembles have also been used to identify systematic differences between simulated and observed patterns of sea-surface temperature and sea-level pressure change, indicating which parts of the patterns are unlikely to occur due to internal variability alone (e.g., Olonscheck et al., 2020; Wills et al., 2022). Furthermore, recent developments in compound-event research, that is, the research on the occurrence of several extreme events at the same time, in close proximity (spatial compounding) and/or in quick succession (temporal compounding), highlight the importance of sufficiently sampling internal climate variability to robustly capture this type of extreme (Zscheischler et al., 2022; Section 4.5). Capturing compound events requires even larger ensemble sizes than univariate extremes (Bevacqua et al., 2023). The availability of large ensembles from multiple different global climate models further allows us to account for inter-model differences in their climate response.

Overall, large ensembles allow for a better quantification and differentiation between three main sources of uncertainties in present and future climate (Hawkins and Sutton, 2009; 2011; Deser et al., 2020; Lehner et al., 2020; Lee et al., 2021):

1. Uncertainty from internal variability: This uncertainty arises from the inherent chaotic nature of the climate system. Since some climate variations occur naturally due to this chaotic nature of the system, it is important to understand which portion of the diagnosed climate change is forced and which is internally generated. Sampling the full range of internal climate variability and their changes is therefore paramount for understanding, attributing, and projecting climate change (Jain et al., 2023). The uncertainty from internal variability is irreducible, making the exact evolution of the climate system unpredictable, no matter how much we understand about the system (Lorenz, 1963; Hawkins et al., 2016; Marotzke, 2019; Lehner et al., 2020). Large ensembles allow us to quantify this uncertainty in a climate model at better precision than ever before, and—importantly—also to quantify how internal climate variability might change over time under external forcing (Brown et al., 2017; Maher et al., 2018; Olonscheck et al., 2021). This is possible by quantifying the ensemble spread of the simulations at every time step, including projected future times. Since large ensembles are set up such that their spread covers observed climate system variability during the historical period, they represent this type of uncertainty to the best possible extent (e.g., Maher et al., 2018). Large ensembles also allow for an accurate quantification of the externally forced climate response. This forced climate response is represented by the ensemble mean. The ensemble mean is derived from averaging over all simulations for the historical period or one future scenario (Figure 4.1), which cancels out the internal climate variability.
2. Model structural uncertainty: This uncertainty arises from structural differences between models in their imperfect mathematical and physical description of the climate and in how the models respond to external forcing as is commonly shown in IPCC-type climate projections (Lee et al., 2021, WGI AR6 Chapter 4, their Figure 4.2). For example, differences in model resolution or their parameterization of sub-grid scale processes fall into this category (Section 4.3). As such, this uncertainty is reducible by improving how climate models describe the Earth system. Large ensembles from multiple global climate models allow us to quantify the uncertainty from structural differences of climate models in the light of the irreducible uncertainty arising from internal climate variability. A robust estimate of the forced climate response as provided by large ensembles is therefore required to precisely distinguish model structural uncertainty from internal climate variability.
3. Scenario uncertainty: This uncertainty is caused by our imperfect knowledge of how society will behave in the future, and primarily how this behavior reflects in the amount of future greenhouse gas emissions (Figure 4.1). Emissions scenarios are possible future pathways that cover different manifestations of future climates under the assumption of socio-economic decisions, the so-called shared socio-economic pathways (SSP, Riahi et al., 2017; Lehner et al., 2023). The scenario uncertainty is represented by different pathways of the greenhouse gas, aerosol, and land use change forcings to the climate system that may occur under different socio-economic assumptions. This uncertainty is considered irreducible from a natural climate science perspective. Here in the current Outlook we have assessed that the highest and the lowest SSP scenarios (Riahi et al., 2017) are not plausible (Stammer et al., 2021; Engels et al., 2023). The choice of the SSP emissions scenario governs a substantial portion of the magnitude of end-of-century climate change, as illustrated by the large differences in mean surface air temperature in the year 2100 between scenarios.

We here introduce the large ensemble that is most frequently used in this chapter: The Max Planck Institute Grand Ensemble in its so-called CMIP6 version (hereafter MPI-GE CMIP6, Olonscheck et al., 2023). This ensemble is run with the Max Planck Institute Earth System Model (MPI-ESM1.2-LR, Mauritsen et al., 2019). MPI-GE CMIP6 has 30 historical simulations covering the period from 1850 to 2014 and 30 simulations for five future emissions scenarios from 2015 to 2100 (Riahi et al., 2017). Thirty ensemble members are a sufficient ensemble size to adequately estimate the uncertainty of most climate variables (Milinski et al., 2020). The low-emission scenario SSP1-1.9 is in line with the goal to limit global warming to 1.5°C, whereas the high-emission scenario SSP5-8.5 represents a world almost 5°C warmer by 2100 compared to the second half of the 19^{th} century. The possible future climates between SSP1-1.9 and SSP5-8.5 are sampled in the three additional scenarios SSP1-2.6, SSP2-4.5, and SSP3-7.0.

The predecessor ensemble MPI-GE CMIP5, consisting of 100 simulations and with a monthly output, adequately sampled observed internal variability in temperature (Maher et al., 2019; Suárez-Gutiérrez et al., 2021). The 30 simulations with 3-hourly to daily output of MPI-GE CMIP6 in addition sample a large number of extreme events (Olonscheck et al., 2023). Since extremes are both rare by definition and strongly impacted by internal climate variability, an adequate sampling of internal climate variability is an important enabler of the study of extreme events (Suárez-Gutiérrez et al., 2021; Bevacqua et al., 2023). MPI-GE CMIP6 provides daily output for every parameter and output every three hours and every six hours for some key parameters. This high-frequency model output is central for capturing both short-lived extreme events, such as precipitation extremes, and the strongest intensities of other types of events such as heatwaves and storms (Olonscheck et al., 2023). MPI-GE CMIP6 is therefore suited to investigate short-lived, large-scale climate extremes. Another large ensemble that is used in Section 4.4 is CESM1-LE (Kay et al., 2015), operated by the National Center for Atmospheric Research in Boulder, Colorado, in the United States. CESM1-LE has similar capabilities to MPI-GE CMIP6 and provides single-forcing scenarios.

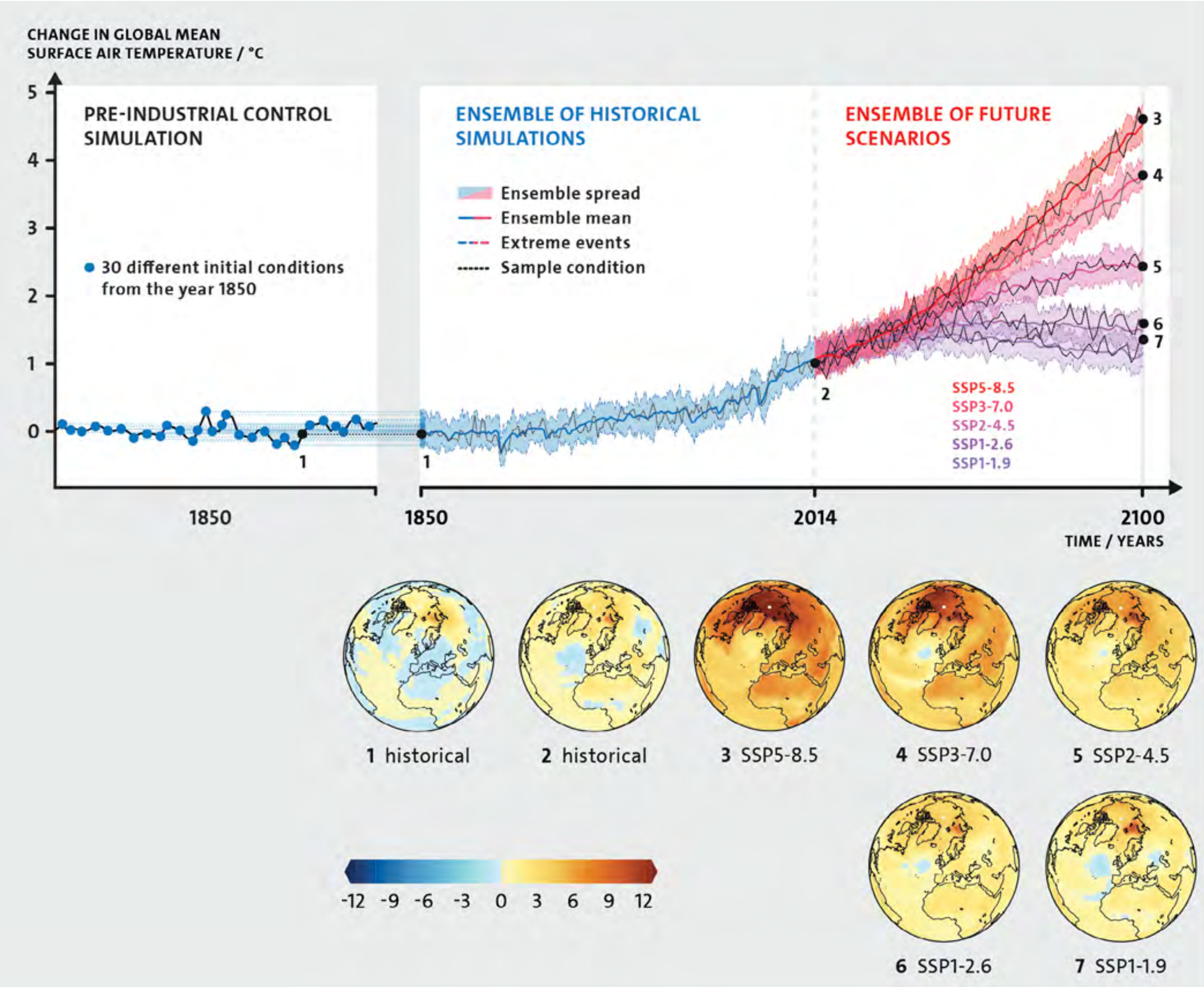

Figure 4.1: Schematic of the MPI-GE. Initial conditions (year 1850) for the 30 simulations are chosen from a pre-industrial control simulation and represent different conceivable climates for that year. The ensemble of 30 simulations for the historical period (1850-2014) span the possibility space of climate while considering internal variability (blue shading). The ensemble mean (blue line) estimates the forced response during that period. Five future scenarios (SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5) exist for all 30 ensemble members, covering the response of the climate system (red and purple lines), including uncertainty arising from internal variability (red-purple shadings). A single ensemble member is taken as an example (black line), starting from its own initial conditions in 1850 (1), which can be followed through the historical period (2) into five different futures, depending on the emission scenario (3-7). At different points in time, all ensemble members have their own climate state that represents a combination of forced response and internal variability. This is exemplified with the global temperature patterns from the first ensemble member shown at different points in time (global maps 1-7). The global maps 3-7 show the warming patterns in year 2100.

4.3

Are Recently Observed Heavy Precipitation Extremes Realistically Represented by State-of-the-Art Spatial Resolutions of Global Climate Models?

Precipitation extremes are among the most devastating events in terms of socio-ecological and economic losses, and their intensity and frequency are projected to increase with global warming, in part because warmer air can hold more water leading to increased precipitation intensity (Pendergrass et al., 2017; Myhre et al., 2019; Seneviratne et al., 2021; Thackeray et al., 2022). A global warming of 2°C would result in substantially more frequent heavy precipitation events than a global warming of 1.5°C, highlighting the potential to avoid substantial future increases in extreme precipitation by ambitious climate mitigation (e.g., Kharin et al., 2018). In addition to other risk determinants such as vulnerability, exposure, and local response measures, more intense precipitation extremes can significantly increase the risk of flooding and confront societies around the world with the challenge of adapting to the impacts of climate change to an even greater extent than is already required. Both rural and urban areas are affected by heavy precipitation extremes, but urban areas are particularly at risk of flooding due to their impermeable and sealed surfaces that do not retain water sufficiently (Revi et al., 2022; see also Sections 5.3 and 5.4). In addition, flooding risks are compounded by the location of settlements, with higher risks in cities located in low-lying areas and coastal zones (Dodman et al., 2022; see also Section 5.5).

In this section, we analyze how realistically the Max Planck Institute Grand Ensemble in its CMIP6 version (MPI-GE CMIP6, see Section 4.2) represents three recently observed record-shattering extreme events that impacted both rural and urban areas: the heavy precipitation extremes in western Europe on 14th July 2021, in the Western Alps on 2nd October 2020, and across the state of São Paulo, Brazil, on 10th February 2020. The extreme rainfall event on 14th July 2021 led to catastrophic flooding in western Europe, with urban areas along rivers of V-shaped notch valleys being particularly affected (Tradowsky et al., 2023). The heavy precipitation event over the Western Alps on 2nd October 2020 mainly affected south-eastern France and northern Italy and led to outages in electricity, telecommunications, water supply, and rail services, and also to significant infrastructure and environmental damages and at least 15 fatalities (Davolio et al., 2023). The heavy precipitation event on 10th February 2020 in the state of São Paulo, which hit São Paulo City during Carnival, a time when many tourists visit the city and many festivities take place, caused devastating floods, flash floods, and landslides that claimed dozens of lives and left thousands of people homeless (World Meteorological Organization, 2021; see also Section 5.4).

For the risk assessment, adaptation planning, and to evaluate what action is needed to address such challenges, robust and reliable local information on climate change is a prerequisite. The performance of climate models used to project future climate impacts is crucial to assess whether certain types of precipitation events (e.g., large-scale versus convective) will become more frequent or more intense over time. Therefore, we address the question: Do state-of-the-art global climate models capture recently observed extreme precipitation events?

Limits of state-of-the-art global climate models to simulate precipitation extremes

On top of significant biases in simulating mean precipitation, a realistic representation of observed heavy precipitation extremes by state-of-the-art global climate models is fundamentally limited because their simulations have 1) coarse spatial resolution (Slingo et al., 2022) and 2) substantial uncertainty from insufficiently sampling large internal climate variability (Deser et al., 2020). First, it is expected, and in part known, that higher spatial resolution of global climate models improves the simulation of extreme precipitation because higher-resolution models reflect smaller spatial scales and key processes such as atmospheric deep convection, and because ocean eddies are represented explicitly (Wehner et al., 2014; Iles et al., 2020; Kahraman et al., 2021; Kendon et al., 2021). Explicitly simulating how small and intermediate scales of motions couple to large-scale circulation systems, which allows us to circumvent problematic assumptions known as parameterizations, is expected to make a large difference at the kilometer scale

(Stevens et al., 2019; Slingo et al., 2022). However, kilometer-scale simulations are not yet available for multiple years or decades and so far do not allow for reasonable comparisons to observed climate trends. Second, properly characterizing internal climate variability is especially important for precipitation extremes. Increased precipitation variability can result in longer periods without precipitation and single heavy precipitation events. Extreme events are rare by definition, and robustly quantifying their occurrence substantially benefits from large sample sizes from many realizations, in particular at the local scale (Hawkins and Sutton, 2009; 2011).

Realism of simulating observed precipitation extremes – three case studies

To address the uncertainties from both internal climate variability and low spatial resolution, we use the MPI-GE CMIP6 (see Section 4.2) to adequately sample internal climate variability and to test whether higher resolution simulations of the same model version are better able to capture recently observed precipitation extremes in Europe than the low-resolution MPI-GE CMIP6. For this model evaluation, we focus on three events:

First, the extreme event in western Europe on 14th July 2021 (Figure 4.2, upper panel) that caused unprecedented flooding of the rivers Ahr and Erft and for which rapid attribution studies have shown high confidence that human-induced climate change has increased the likelihood and intensity of the events (Kreienkamp et al., 2021; Ibebuchi, 2022). The daily precipitation observed by the Europe-wide E-OBS data set (Klein Tank et al., 2002; Cornes et al., 2018) on 14th of July 2021 averaged across the western European domain is 47.7 mm, which represents the maximum daily precipitation in any summer during the 72-year long observed record. The extreme event was driven by an anomalously strong large-scale atmospheric circulation type with a mid-latitude cyclone over the North Sea and an anticyclone over the North Atlantic, enabling a band of westerly moisture fluxes to western Europe (Ibebuchi, 2022).

Second, the extreme event in the Western Alps on 2nd October 2020 (Figure 4.2, lower panel) caused devastating large-scale flooding and represents an unprecedented strong event in a region that shows a high frequency of precipitation extremes (Grazzini et al., 2021; Davolio et al., 2023). The daily precipitation observed by E-OBS on 2nd of October 2020 averaged across the domain in the Western Alps is 72.9 mm, the maximum daily precipitation in any autumn during the 72-year long observed record. This event was associated with an upper-level trough over the western Mediterranean basin, a large-scale pattern that is typical of heavy precipitation events on the southern side of the Alps, since it triggers a northward transport of large amounts of moisture interacting with the orography (Davolio et al., 2023).

Third, the extreme event across the state of São Paulo on 10th February 2020 (Figure 4.3). The daily precipitation of 123.0 mm/day on 10th February 2020 was the second-highest summer precipitation, surpassed only by the record-shattering event on 21st December 1988 with 151.8 mm/day (INMET, 2024). Marengo et al. (2020a) found that a significant increase in summer precipitation during the past 70 years is a key driver of increased risk, in association with precipitation-related hazards in São Paulo. This increase in heavy precipitation is at least partly caused by an intensification and southwestward propagation of the South Atlantic Subtropical Anticyclone that transports increased amounts of humidity to São Paulo City (Marengo et al., 2020b; see also Section 5.4).

We compare these observed events to simulations with three spatial model resolutions of MPI-ESM1.2. First, we use the 30 simulations of MPI-GE CMIP6 (Olonscheck et al., 2023) with a coarse spatial resolution of about 1.8° in the atmosphere, equaling a grid size of about 200 km. Second, we use 10 simulations of MPI-ESM1.2-HR (Müller et al., 2018), which has a spatial resolution of about 1.0° in the atmosphere, equaling a grid size of about 100 km. And third, we use a single realization of MPI-ESM1.2-XR (Gutjahr et al., 2019), which has 0.5° atmospheric horizontal resolution equaling a grid size of about 50 km. To quantify the time interval between two events of a given magnitude, we use return periods. We compare the return periods from the observed record of seasonal maximum daily precipitation in the respective regions with the simulations of different spatial resolution.

Realistically representing precipitation extremes depends on model spatial resolution

Our findings illustrate that the low-resolution MPI-GE CMIP6 is not able to simulate precipitation extremes as intense as the ones observed. However, the analyses show that the higher-resolution versions of the same model, MPI-ESM1.2-HR and MPI-ESM1.2-XR, capture the observed events much better. The extreme event in western Europe is captured by the single realization of MPI-ESM1.2-XR, which simulates a single daily summer precipitation as intense as the one observed with a more widespread but still similar pattern (Figure 4.2). The distribution of autumn daily maximum precipitation in the Western Alps is best represented by MPI-ESM1.2-HR. However, the magnitude of the observed extreme event on 2nd of October 2020 is within the range of the autumn daily maximum precipitation simulated by the mid-resolution version MPI-ESM1.2-HR and the high-resolution version MPI-ESM1.2-XR (Figure 4.2).

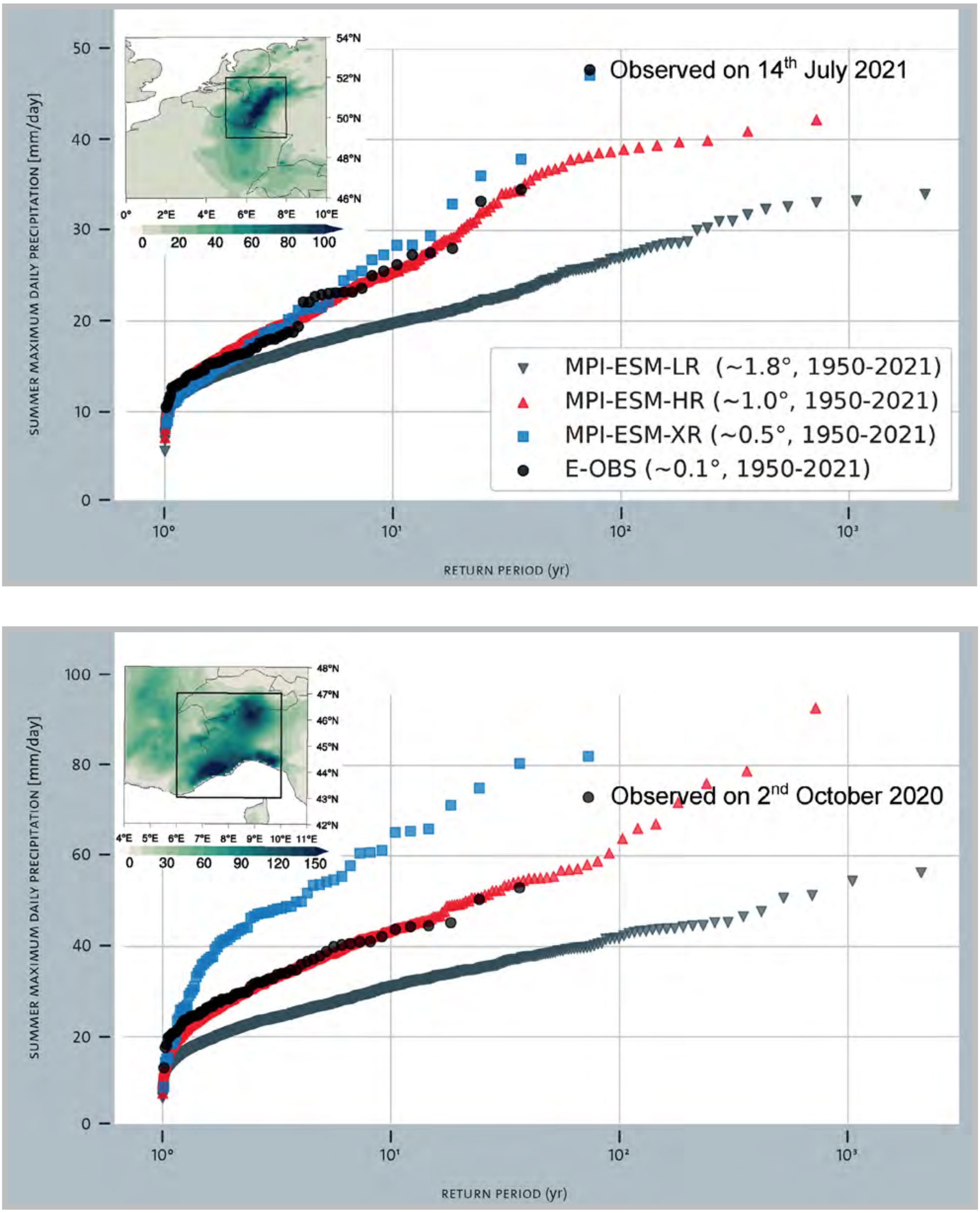

Figure 4.2: Representation of observed heavy precipitation extremes dependent on model spatial resolution: Return periods of (upper panel) summer (JJA) maximum daily precipitation averaged across the western European box, and (lower panel) autumn (SON) maximum daily precipitation averaged across the Western Alps box from 1950-2021 in three model resolutions from MPI-ESM1.2 and in observations. MPI-ESM-LR is based on 30, MPI-ESM-HR on 10, and MPI-ESM-XR and the E-OBS observations on only a single realization. Values of all summers or autumns and all realizations are merged for each ensemble (adapted from Olonscheck et al., 2023).

The finding that the higher-resolution simulations are able to capture the observed events is surprising because the spatial resolutions of 100 km and 50 km are insufficient to resolve important processes, such as moist convection. Our results suggest that the observed precipitation extremes investigated here are sufficiently large-scale to be represented by model simulations with 50 km or 100 km atmospheric resolution. We conclude that the available higher spatial resolution of MPI-ESM1.2 already substantially improves the representation of observed precipitation extremes, and that the required resolution strongly depends on the specific location and characteristics of the observed extreme event.

With the extreme event across the state of São Paulo, we push our model evaluation to the extreme case of comparing a locally measured precipitation amount to a spatial average of a model grid box. Our analyses show that the three different spatial resolutions of MPI-ESM1.2 are not able to simulate the observed magnitude and frequency of maximum summer precipitation measured in Mirante de Santana in São Paulo City. We find that higher spatial model resolution does indeed improve the simulation of both heavy precipitation magnitudes and frequencies. However, none of the three different resolutions is sufficient to represent the locally observed magnitude of summer heavy precipitation. This shows that local precipitation extremes cannot be captured by model simulations with grid sizes of 50 km and more because local topography is not accounted for, key physical processes are still parametrized, and local peaks of precipitation amounts are smoothed out by spatial averaging within a grid box.

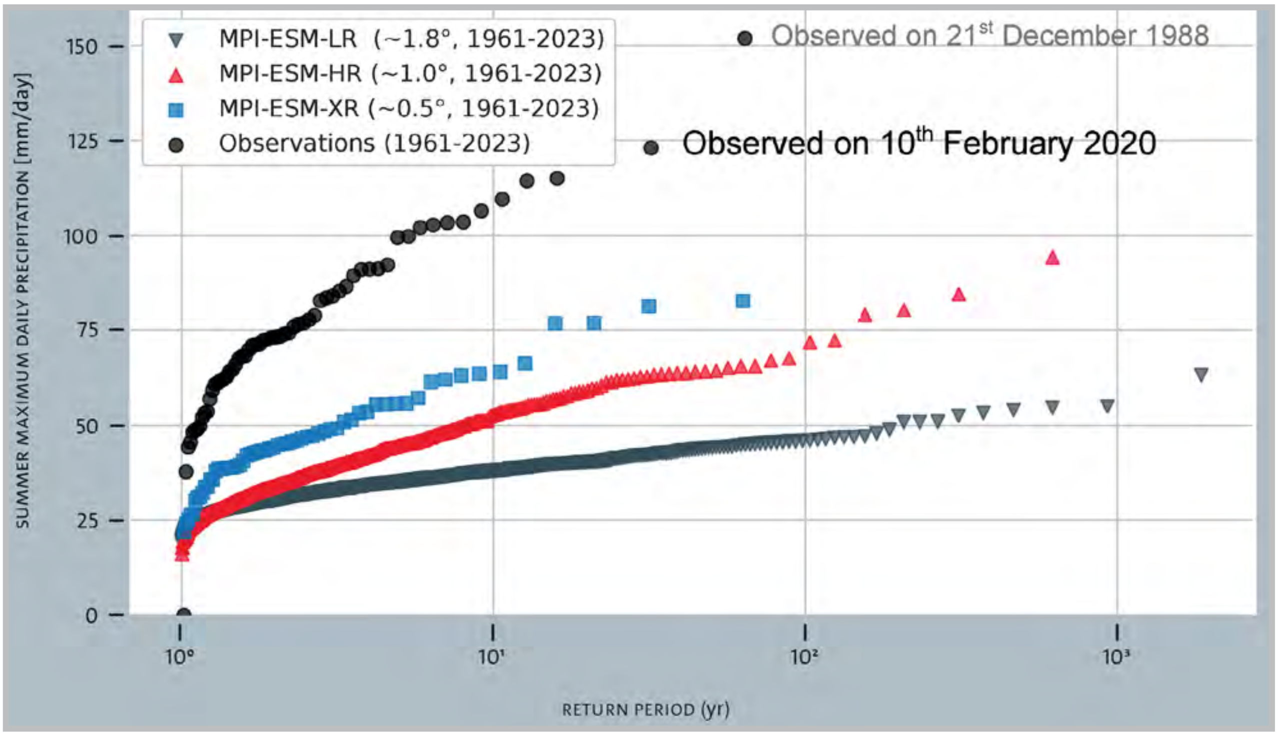

Figure 4.3: Representation of the heavy precipitation extreme observed in Mirante de Santana, São Paulo City, dependent on model spatial resolution. Return periods of summer (DJF) maximum daily precipitation averaged across the grid box that covers the measurement station Mirante de Santana at 23.5°S and 46.6°W in São Paulo City, Brazil, from 1961-2023 in three model resolutions from MPI-ESM1.2 and from the observed record (INMET, 2024). The weather station Mirante de Santana in São Paulo City is run by the National Institute for Space Research (INPE). Values of all summers (DJF for Southern hemisphere) and all realizations are merged for each ensemble. For comparison, the largest summer maximum precipitation on record, measured on 21st December 1988, is also labeled.

Consequences for adaptation

Constructing relevant and robust climate change information at the regional to local scale is key for integrated adaptation and mitigation planning and action (Revi et al., 2022). Climate models play an important role in providing a sound analytical basis for policymakers. Understanding the links between changes in extreme events and climate change and the impacts at local level is necessary for communicating the need for following ambitious adaptation pathways and thus effective local decision-making.

On top of climate change-induced increases in extreme precipitation events, other factors also determine the local impacts. For example, the current trend of urban development and further densification of urban areas toward increasingly impermeable surface fractions is expected to further exacerbate the climate change-induced risk of flooding (Skougaard Kaspersen et al., 2017). In addition, urban development policies on flood control may even exacerbate flood risk due to adverse consequences of adaptation or mitigation responses (Dodman et al., 2022), in particular in terms of health and well-being implications (Quinn et al., 2023). Understanding the need for (urban) transformations requires further exploration of current and future climate-related hazards, exposure to these hazards, as well as the vulnerabilities at the local scale (Revi et al., 2023). However, such an assessment of regional to local climate change impacts requires knowledge of projections of climatic variables at a very fine scale, much finer than the one provided by global climate models so far (Slingo et al., 2022). Nevertheless, the current absence of local information on future extreme events from global climate models should not impede local action to adapt to already observed changes in extreme events.

Conclusions

We show that the resolution of state-of-the-art global climate model simulations is still too coarse to adequately represent locally measured heavy precipitation events, but that higher-resolution simulations of down to 50 km spatial resolution substantially improve the representation of observed extreme precipitation events compared to simulations with coarser resolution. We conclude that the ability of global climate model resolutions to represent observed record-shattering extreme events depends both on the model spatial resolution and on the specific characteristics of the observed heavy precipitation extreme (e.g., location, temporal/spatial scale, causal mechanism, type of precipitation, i.e., large-scale versus convective) (see also Sections 5.3, 5.4, and 5.5). Our findings reinforce the expected benefits from ongoing efforts in climate science to simulate the Earth at kilometer scale for a more sound representation of the Earth system. They confirm the urgent need for kilometer-scale global climate simulations to investigate the effect of climate change on small-scale extreme events, especially in the case of complex topography and short-duration convective events (Poschlod, 2022). Because of the substantial computational costs of kilometer-scale simulations, a trade-off between such high-resolution simulations and large ensembles (see Section 4.2) will be required for adequately capturing extreme precipitation events. Kilometer-scale simulations will be a big step forward for direct comparisons to locally measured extreme events, for increased trust in local future projections of extreme precipitation change, and for targeted adaptation actions.

4.4

High-Impact Marine Heatwaves

The global ocean has warmed substantially over the past decades. Concurrent with a long-term warming trend, episodic periods of anomalously high sea surface temperature at a particular location, known as marine heatwaves, are becoming more frequent, longer-lasting, more intense, and more extensive (Collins et al., 2019). Studies have documented a diverse range of local drivers (such as advection of heat by ocean currents or changes in air-sea heat fluxes) and large-scale modes (e.g., El Niño Southern Oscillation, Pacific Decadal Oscillation), along with teleconnections through internal processes such as Rossby waves (Li et al., 2020) that contribute to the generation and evolution of these events (Collins et al., 2019).

Over the past 25 years, at least 34 marine heatwave events globally have been associated with socio-economic consequences (Smith et al., 2021). Marine heatwaves have been shown to be responsible for dramatic mass mortality of marine mammals and iconic species (Smith et al., 2023), widespread coral bleaching (Sully et al., 2019), loss of Kelp Forest (Wernberg, 2021), depletion of seagrass meadows (Arias-Ortiz et al., 2018), and proliferation of harmful algal blooms (Trainer et al., 2020). In addition, they represent an immediate and pressing threat to the integrity of coastal carbon stocks (Serrano et al., 2021). Collectively, these impacts have global and regional socio-economic significance (see also Section 5.10).

Extreme climate-related events such as marine heatwaves exert direct effects on marine ecosystems and can also induce disturbances within the ecosystem, leading to prolonged impacts that extend beyond the event's duration (Bastos et al., 2023). For instance, 36% of Shark Bay's seagrass meadows in Australia, which support the largest seagrass carbon stocks worldwide, were damaged following a marine heatwave in 2010/2011 (Arias-Ortiz et al., 2018). This damage could potentially lead to the release of CO_2 into the atmosphere over the subsequent years. Of significant concern are compound extreme events. For example, marine heatwaves coinciding with ocean acidity extremes (Burger et al., 2022) or extreme sea level (Han et al.,

2022) can lead to severe ecosystem service-related impacts that human societies depend upon.

In this section, we discuss the evolution of high-impact marine heatwaves across four case studies, focusing on regions at an especially high risk of increased severity in marine heatwaves. The vulnerable regions include the Mediterranean Sea as well as the Indian, Northeast Pacific, and Arctic Oceans. Their vulnerability arises from a combination of factors such as biodiversity hotspots, presence of species which hold ecological and commercial significance and/or face the threat of extinction, highly populated coastal communities that rely significantly on marine ecosystem for their livelihood, and other factors (Smale et al., 2019). In the case studies of the Arctic and the Northeast Pacific, we also present results on the extent to which greenhouse gas forcing has contributed to the severity of these events. Finally, we discuss why clear definitions of marine heatwaves are essential to enable coastal communities to adapt effectively.

The evolution of high-impact marine heatwaves

To identify marine heatwaves, we use the daily Optimum Interpolated Sea Surface Temperature (OISST) satellite data set at a resolution of 0.25° × 0.25°, for the period between the years of 1982 and 2022 (Reynolds et al., 2007). We define marine heatwaves as occurring when sea surface temperatures exceed a seasonally varying threshold, here the 95th percentile of sea surface temperature variations based on a 30-year climatological period (1983–2012), for at least five consecutive days.

In the case studies of the Arctic and the Northeast Pacific, we also discuss the extent to which greenhouse gas forcing has contributed to the severity of these events, based on data from Barkhordarian et al. (2022; 2024). We employ an extreme-event attribution technique and use daily sea surface temperature output from the NCAR CESM-LE (Kay et al., 2015), which provides large-ensemble members with fixed greenhouse gas forcing. We estimate the probabilities of marine heatwaves with specific characteristics (duration, intensity, and cumulative heat intensity) occurring in the presence and absence of greenhouse gas forcing. These probabilities are calculated for both actual (all-forcing includes anthropogenic and natural external forcing) and counterfactual (fixed greenhouse gas forcing) scenarios, using observations as threshold and model simulations. The estimated probabilities are used to calculate event-attribution metrics.

Northeast Pacific – the deadly “blobs”

During the decade between 2012 and 2022, the sea surface temperatures over the Northeast Pacific were the warmest ever recorded, characterized by the occurrence of extreme marine heatwaves known as deadly "warm blob" events. Among other impacts, these marine heatwaves caused dramatic mass mortality events in seabird species and major outbreaks of harmful algal blooms that produce extremely dangerous toxins (Smith et al., 2023). Barkhordarian et al. (2022) show that the Northeast Pacific warming pool is marked by concurrent and pronounced increases in the annual mean and variance of sea surface temperature, decreases in wintertime low-cloud cooling effect, and increases in atmospheric stability. Consequently, the greater exposure to heat and the lack of usual wintertime cooling leads to 4.5-fold more frequent, ninefold longer-lasting, and threefold more intense marine heatwaves in the past decade (2012-2022), in comparison with those occurring in the previous decades.

According to the study by Barkhordarian et al. (2022), based on OISSTv2 satellite data, up to 60% of the marine heatwaves detected in the Northeast Pacific over the past decade are either more intense and/or longer-lasting than could solely be attributed to internal climate variability in the absence of external climate drivers. Extreme-event attribution analysis presented in the paper further reveals that greenhouse gas forcing has virtually certainly (with > 99% probability) caused the multiyear persistent 2014-2015 and 2019-2021 marine heatwaves, in terms of both intensity and duration.

Arctic Ocean and its marginal seas

OISSTv2 satellite data reveals that the summer of 2007 was the beginning of a shift toward a new era of marine heatwaves over the shallow marginal seas of the Arctic Ocean. Barkhordarian et al. (2024) show that marine heatwaves in the Arctic are primarily triggered by an abrupt retreat of sea-ice, coinciding with the midsummer peak of downward radiative fluxes. In terms of frequency, an extreme marine heatwave with 140°C cumulative heat intensity (the integral of sea surface temperature anomalies over time for the duration of the event), which is a one-in-40-years event in a world without greenhouse gas forcing, turns into a one-in-5-years event under the influence of greenhouse gas forcing.

By utilizing an extreme event-attribution technique, Barkhordarian et al. (2024) demonstrate that any marine heatwave event over the shallow marginal seas of the Arctic Ocean with an intensity larger than 1.5°C has a less than 1% occurrence probability under no-greenhouse gas effect. Thus, for extreme marine heatwaves, such as those of 2007 with 3.5°C intensity and those in 2020 with 4°C intensity, greenhouse gas forcing is virtually certainly the cause. The study further shows that if greenhouse gas forcing continues to rise, along with the expansion of first-year ice extent, moderate marine heatwaves will very likely persistently reoccur. These changes are expected to have far-reaching consequences for global climate dynamics and the well-being of Arctic ecosystems and communities.

Mediterranean Sea

Despite its relatively small size, the Mediterranean Sea is known for its remarkable biodiversity and serves as a significant reservoir of marine species, representing between 4% and 18% of the total global marine species richness (Coll et al., 2010; Würtz, 2010). Our analysis, based on OISSTv2 satellite data, shows a rapid and non-linear escalation in the number of marine heatwave days in the region. In the western, central, and Adriatic basins, marine heatwaves are related to increased incoming solar radiation, along with reduced ocean heat losses, possibly due to warm and humid air intrusions (Simon et al., 2023). From 1982 to 2010, the region experienced an average of 15 marine heatwave days per year. However, between 2011 and 2022, this count has quadrupled, reaching an average of 70 marine heatwave days per year. As background sea surface temperature has increased linearly between 1982 and 2021 by 0.38°C per decade, corresponding to about three times the global ocean warming rate, the number of marine heatwave days does not follow a linear pattern but instead exhibits a non-linear response (Figure 4.4, upper panel).

This substantial and accelerated rise in marine heatwave occurrences highlights the escalating thermal stress experienced by the Mediterranean ecosystems and contributes, at least in part, to the onset of five consecutive years of widespread mass mortality events between 2015 and 2019 across the basin (Garrabou et al., 2019; 2022).

Indian Ocean (Maldives)

The Maldives are an archipelago in the Indian Ocean composed of 26 atolls surrounded by coral reefs, which provide habitat for a diverse array of marine life and play a crucial role in sustaining the local economy and society (Stojanov et al., 2017; Sully et al., 2019; see also Section 5.10). The Maldives have experienced several instances of coral-bleaching events triggered by marine heatwaves in recent years (Perry and Morgan, 2017; Shlesinger and van Woesik, 2023). In the Indian Ocean, the positive phase of the El Niño Southern Oscillation and the Indian Ocean Dipole mode are the dominant large-scale modes to influence marine heatwave occurrence (Holbrook et al., 2020). Strong El Niño years, such as 1997-1998, 2015-2016, and, to a lesser extent, 2009-2010, are clearly evident as peaks in the average number of marine heatwave days, with hotspots over the Arabian Sea and the western equatorial Indian Ocean (Figure 4.4, lower panel).

The non-linear amplification of marine heatwave days, which are generally considered representative for chronic heat stress exposure (Smale et al., 2019), signifies a shift in the region's thermal conditions that leads to mass coral-bleaching events. Coral bleaching poses a significant threat to marine ecosystems due to the critical role coral reefs play in preserving biodiversity, sustaining fisheries, and offering coastal protection (Shlesinger and van Woesik, 2023).

Precise definitions of marine heatwaves play an important role in effective adaptation for coastal communities

The most commonly used definition for marine heatwave has been developed by Hobday et al. (2016), who describe a marine heatwave as "a discrete prolonged anomalously warm water event". The question is: "What is anomalous"? The term "marine heatwave" can encompass two distinct interpretations: (1) it could refer to an extreme heat relative to historical temperature records, thus signifying relative heat; (2) it could refer to an extreme heat relative to an evolving "new normal" of rising temperature owing to climate change, signifying absolute heat.

As discussed by Amaya et al. (2023), a fixed baseline, which measures heat relative to historical temperature and thus characterizes "total heat exposure"—the combination of gradual temperature increase and short-term heat events—is useful when monitoring events like coral bleaching. Marine species with short life cycles may have some ability to adapt to gradual temperature increase, but they might not necessarily cope well with rapid heat shocks. By contrast, some corals may recover from immediate heat shocks but struggle with prolonged exposure to heat (Provost and Botsford, 2022). While the relative heat metrics has its merits, it fails to consider the underlying factor of climate change causing a gradual increase in ocean temperatures over time. By contrast, defining marine heatwaves relative to gradually increasing temperatures enables resource managers to differentiate between temporary fluctuations and long-term trends. For instance, the fishing industry could temporarily suspend fishing to manage a rapid heat shock. Adapting to prolonged warming may necessitate actions such as relocating to different fishing grounds, and/or targeting alternative species (Fisher et al., 2021).

Thus, different baselines (measuring absolute or relative heat) results in different interpretations of frequency, intensity, and duration of marine heatwaves. These would lead to varied outlooks and emphasizes the importance of accurate information for informed decision-making (Amaya et al., 2023).

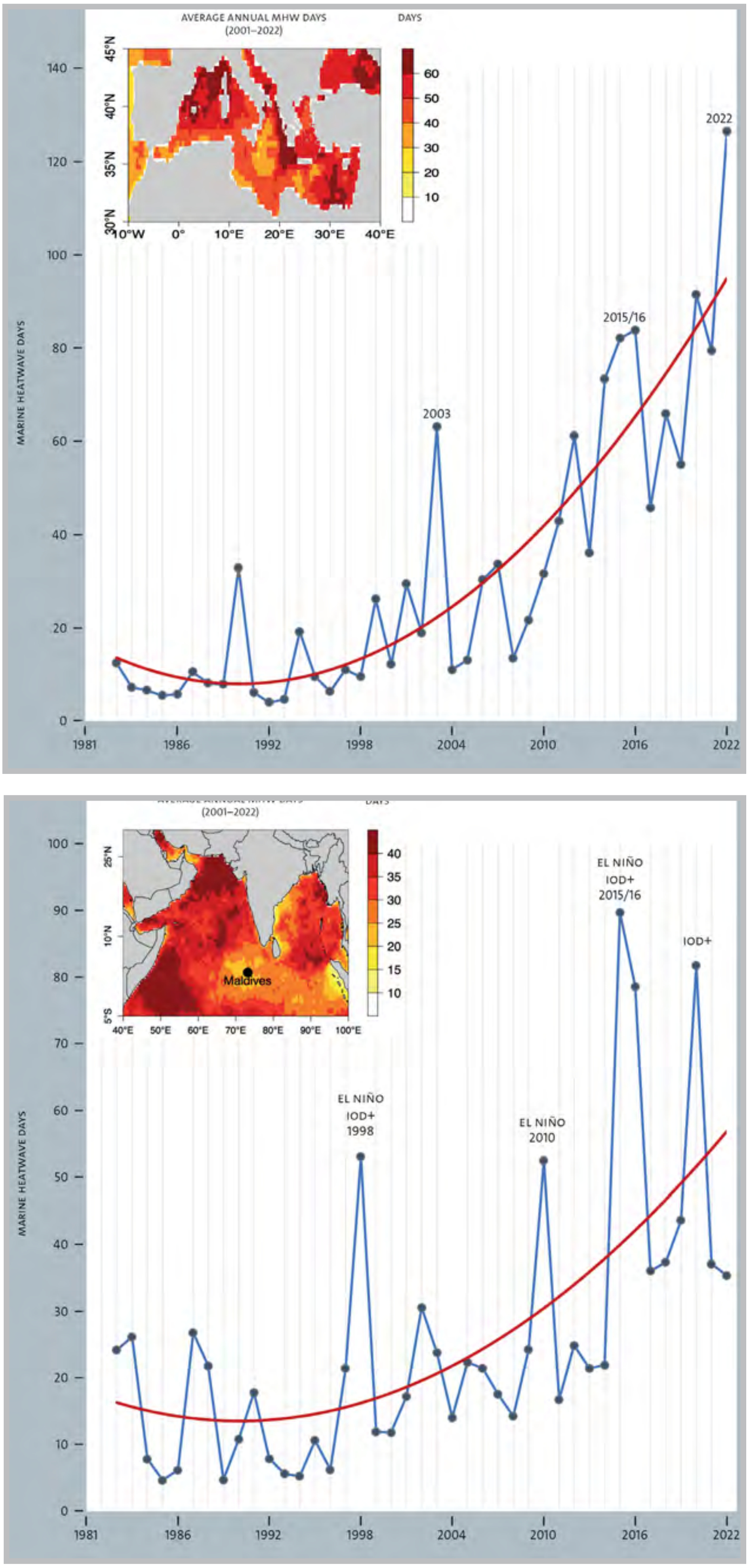

Figure 4.4: Time series of annual marine heatwave days between 1982 and 2022 over the Mediterranean Sea (upper panel) and the Indian Ocean (lower panel). IOD+ refers to the positive phase of the Indian Ocean Dipole mode. Red curves represent quadratic regression.

Conclusions

This section offers a worldwide view of the trends, impacts, and attribution of marine heatwaves, particularly focusing on four regions especially at high risk of increased marine heatwave severity. The accelerated (non-linear) increase in marine heatwave occurrences across vulnerable regions such as the Mediterranean Sea and the Indian Ocean underscores the escalating thermal stress on marine ecosystems that has resulted in significant impacts, including mass coral bleaching events across the Indian Ocean (Shlesinger and van Woesik, 2023) and five consecutive years of widespread mass mortality events between 2015 and 2019 across the Mediterranean Sea (Garrabou et al., 2019; 2022; see also Section 5.10). Over the Northeast Pacific, up to 60% of the high-impact marine heatwaves detected over the past decade are more severe than could solely be attributed to natural climate variability in the absence of external climate drivers (Barkhordarian et al., 2022). Over the Arctic Ocean, abrupt sea-ice retreat in the shallow marginal seas during the maximum of downward radiative flux has led to unprecedented marine heatwaves that have become much more likely as a result of greenhouse gas forcing (Barkhordarian et al., 2024). In summary, marine heatwaves, which are very likely to become more frequent and more intense due to human-induced emissions (Collins et al., 2019), cause extensive damage to marine ecosystems and the coastal communities that rely on them for goods and services. This highlights the importance of effective strategies for adaptation.

4.5

How Will Extreme Heat in the World's Breadbasket Regions Change in the Future?

A key challenge in adapting to anthropogenic climate change is ensuring food security. Understanding how food supply through agriculture may change under climate change is paramount to addressing this challenge. Extreme climate events such as heatwaves and droughts that occur in several regions in the same year may exacerbate potential crop yield losses (Raymond et al., 2022) and lead to individual years of extremely low yields if multiple important crop production regions, so-called *breadbasket regions*, are hit. Here, we take a climatic perspective to this problem and analyze how the likelihood of several breadbasket regions that together account for more than 55% of global maize production (Gaupp et al., 2020) experiencing a heatwave during the same maize growing season may change at 1.5°C and 2°C of global warming compared to pre-industrial climate.

There is extensive literature on the relationship between agricultural yields and climate (e.g., Lobell et al., 2011; Rosenzweig et al., 2014). Studies generally find effects of extreme temperature (Luo, 2011) and drought (Doorenbos and Kassam, 1979) on agriculture, emphasizing a strong combined effect of heat and drought for maize (Gaupp et al., 2020). Heat and drought affect the development of the plants during their growing season, which is typically in summer (Gaupp et al., 2020). As a first step toward projecting the changes in maize crop yields due to such threats, we here examine heat extremes. These may impact maize production by reducing the number of flowers, impairing pollen tube development during plant growth, and limiting pollen release and fertility during the plants' reproduction phase (e.g., Teixeira et al., 2013), or impairing the productivity of agricultural workers (de Lima et al., 2021; Orlov et al., 2021). These impacts may only partly be mitigated by irrigation of the crops (Siebert et al., 2017).

Previous work on projected changes of crop yields considered mean changes by the end of the 21st century (Franke et al., 2020; Jägermeyr et al., 2021). Such assessments showed conflicting results, but generally illustrated a global decrease of crop yields for maize (Jägermeyr et al., 2021). However, natural climate variations may also substantially affect regional and global crop yields, on at least two-thirds of the global cropland area (Heino et al., 2018). These variations are partly reflected in current crop yield projections as uncertainties in the end-of-century estimate (Jägermeyr et al., 2021) but are not considered explicitly, which hampers the representation of extreme climate events in crop yield projections.

Extreme events in the climate system are projected to change under global warming (Field et al., 2012; Suárez-Gutiérrez et al., 2020; Patterson, 2023). Heat extremes, for example, may change in their intensity, duration, and spatial extent, or even compound with further extremes such as droughts, exacerbating their impact (Zscheischler et al., 2018). Hot and dry compounds are not strictly separable since heat may drive increased evaporation that dries out the soils and plants, exacerbating further heating (e.g., Zscheischler et al., 2018). Extremes may also compound in time or space, meaning that long time periods or large areas may be affected by an extreme, again increasing their impact. As discussed above, such extremes may be detrimental for agricultural crop yields both locally and on a large scale, particularly in vulnerable communities. Taken together, these factors lead to the question of how extreme heat in areas with vulnerable communities as well as in the world's breadbasket regions may change under global warming.

An example of a region that is susceptible to agricultural disruption is rural northern Namibia: Communities there are heavily dependent on subsistence farming and are therefore particularly vulnerable to climate extremes that challenge crop production and may disrupt local food security. We analyze such a disruption of crop production here as a case study, while a case study in Section 5.8 addresses a further challenge of rural Namibia, namely the adaptation of pastoralists to climate change.

Raymond et al. (2022) used the MPI-GE CMIP5 to address the impact of extreme climate events on important maize production regions. They found that global warming increases the likelihood for hot-dry compound events to occur in several of these regions both individually (by 100-300%) and during the same growing season, indicating increased risk to the global food system. In this context, extremes in multiple of these breadbaskets may be teleconnected through atmospheric processes (Kornhuber et al., 2020; Meehl et al., 2022).

These studies leave the expected change of extreme events at different levels of global warming to be examined. Specifying the probability of extreme events according to global warming levels will not only be a useful policy tool to motivate mitigation efforts but can also inform the planning of adaptation strategies to ensure food supply under global warming. As a first step in this direction, we outline here the change of extreme heat events in the breadbasket regions at 1.5°C and 2°C of global warming compared to pre-industrial climate.

Analyzing compound heat extremes in crop-growing regions

We first analyze extreme heat at different levels of global warming in the crop growing regions of Northern Namibia as an example of a region with vulnerable subsistence farming communities. Second, we consider heatwaves in multiple breadbasket regions around the world during the same growing season. A basic assumption in our analysis is the lack of adaptation to increasing extreme events through the cultivation of better adapted crops so that our results represent an upper bound of potential impacts.

We apply the most recent version of the MPI-GE (see Section 4.2) because it allows for a thorough and representative analysis of climate extremes due to the large sample size (e.g., Bevacqua et al., 2023; Olonscheck et al., 2023). Global warming levels are identified for all ensemble members under the SSP2-4.5 scenario of the MPI-GE CMIP6 separately. This entails evaluating 30-year-intervals centered around the time global mean temperature first crosses the 1.5°C and 2°C warming levels with respect to the 1850–1900 mean.

A day is classified as extreme if its maximum temperature exceeds the threshold set by the top 5% of maximum temperatures across all ensemble members during the period of 1990 to 2020 for the corresponding calendar day. We then define a heatwave using spatial and temporal compounding, like in Raymond et al. (2022): If at least one-third of the area of the examined region is affected by a heatwave for more than three days in a row during the growing season, a heatwave is recorded for this region.

Projected heat extremes in one region—the example of northern Namibia

We illustrate the probability change of heat extremes under global warming using the example of northern Namibia. Low crop productivity is a pervasive problem in smallholder farming systems across Sub-Saharan Africa, primarily due to declining soil fertility, inadequate access to fertilizers, and climate extremes (Wall et al., 2013). In Namibia, rainfed agricultural production is constrained to the northern and north-eastern regions, where smallholder farms dominate and face challenges such as low crop yields and underdeveloped market chains and food processing. Traditionally, smallholders in this region have limited access to chemical fertilizers, manure, or other inputs, despite soil analyses indicating that sandy and low-fertility soils limit crop productivity (de Blécourt et al., 2019). Legumes play a crucial role in overcoming this limitation as they do not rely on mineral nitrogen, are relatively drought-resistant, and grow in low-fertility sandy environments (Vanlauwe et al., 2019; Becker et al., 2023). Furthermore, they provide nutrient-rich, high protein foods and are already a prominent food crop in Southern Africa (Vanlauwe et al., 2019; Rasche et al., 2023). Here, field studies have revealed that the optimal temperature for legume cultivation is often exceeded during the growing season (De Notaris et al., 2020). Measurements in northern Namibia have shown that soil surface temperatures already regularly exceed 35°C (SASSCAL Weathernet, 2024), surpassing the optimal temperature for plant growth and rhizobial nodulation, which results in reduced crop weight and number (Marsh et al., 2006;

Bhandari et al., 2017). Physical connections between heat and drought through increased evaporation (e.g., Trenberth and Shea, 2005) and interconnections between dry soil and heat (e.g., Seneviratne et al., 2010) can further exacerbate heat wave impacts on crop productivity in water limited regions. Increasing heat stress could thus limit a major protein source for local communities while also hindering potential adaptation strategies.

We used December until February as crop growing season in northern Namibia. During the period between 1990 and 2020, 2-7% of growing seasons experience heatwaves in the model (Figure 4.5). This means that heatwaves cover between 2% and 7% of the growing seasons in the different ensemble members (for "ensemble spread of probability", see Section 4.2). This result is expected since the 95% extreme threshold was defined based on this same time period. With 1.5°C and 2°C of global warming, the likelihood for a heatwave to occur is projected to increase from 5-14% and 10-22%, respectively (Figure 4.5). This means that in the MPI-ESM-LR Earth system model, extreme heat affects at maximum 14% of the growing season in northern Namibia if 1.5°C of global warming are reached. If the Paris Agreement temperature goals are breached and 2°C of global warming are reached, a heatwave on 10% of all days of the growing season is virtually certain in northern Namibia, and heatwaves may cover as much as 22% of the growing season. By the end of the century, a period characterized by around 2.25°C of global warming under the SSP2–4.5 scenario, 15-26% of days of the growing season experience a heatwave in our model.

Our findings illustrate the urgent need to mitigate any degree of global warming and highlights adaptation potential by preparing for a more frequent occurrence of extreme soil surface temperature.

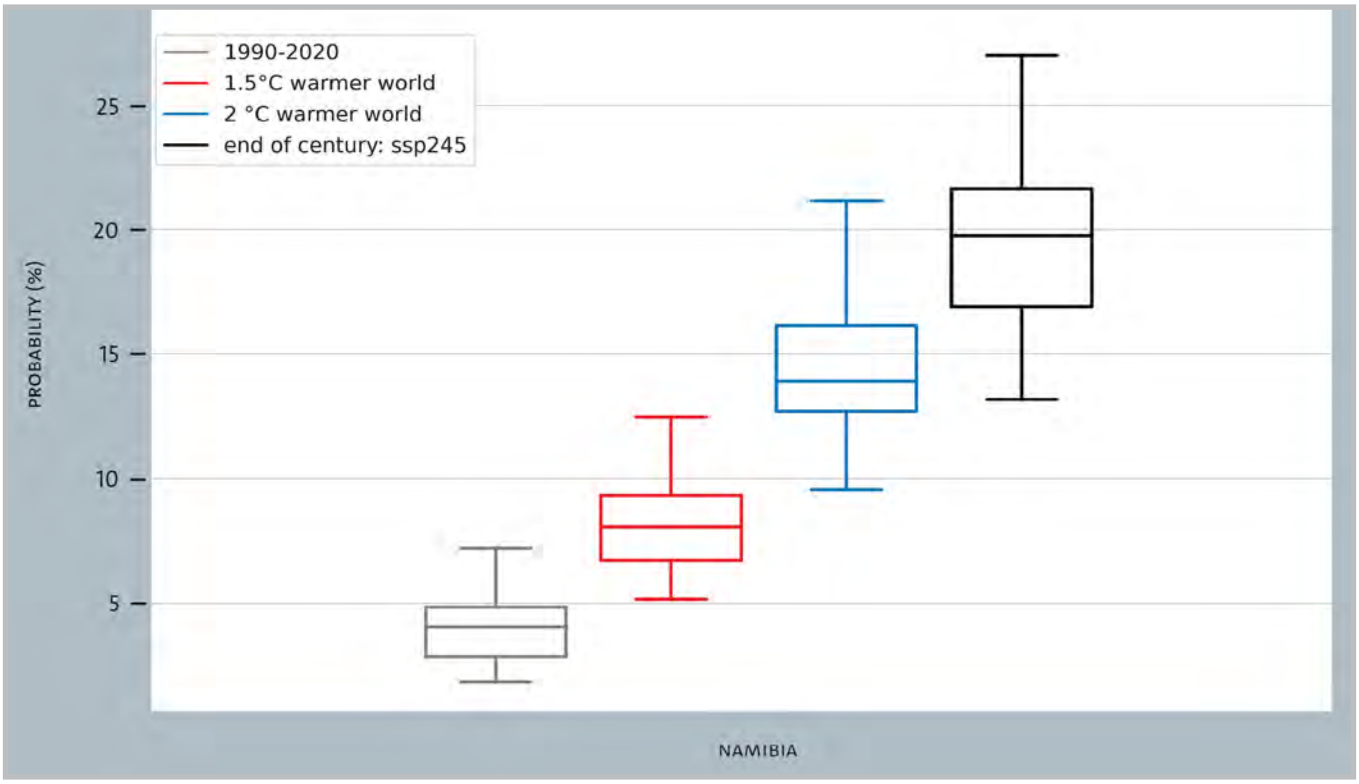

Figure 4.5: Ensemble probability for a heatwave to occur in Northern Namibia during the growing season, evaluated for the periods of 1990 to 2020 (gray) and 2070 to 2100 (black), as well as under 1.5°C (red) and 2°C (blue) of global warming. The future information is based on climate projection simulations with the MPI-ESM-GE CMIP6 under the SSP2-4.5 scenario.

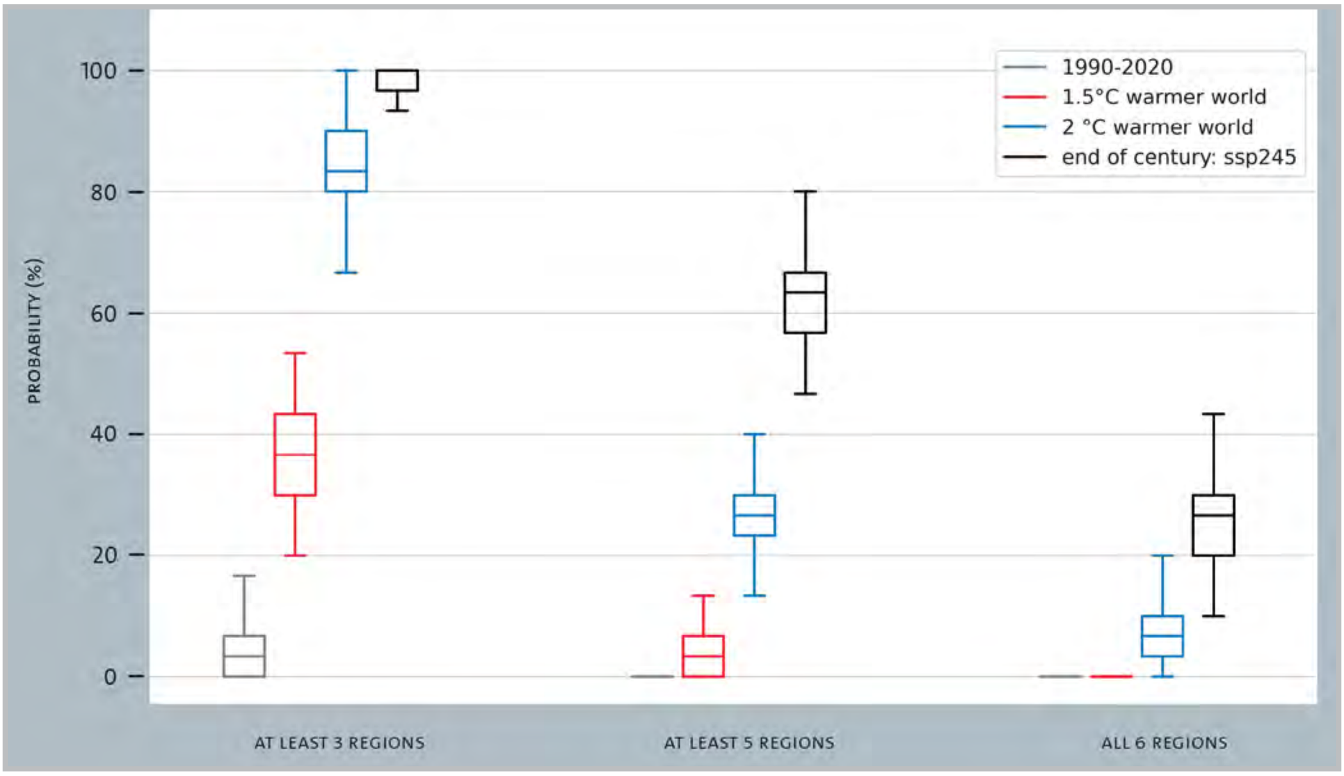

Figure 4.6: Ensemble probability for a heatwave to occur during the same maize growing season in at least 3, 5, or all 6 breadbasket regions, evaluated for the periods of 1990 to 2020 (gray) and 2070 to 2100 (black), as well as under 1.5°C (red) and 2°C (blue) of global warming. The future information is based on climate projection simulations with the MPI-ESM-GE CMIP6 under the SSP2–4.5 scenario.

Heat extremes in multiple breadbasket regions during the same growing season

Increasing global warming in the presence of internal climate variability not only increases the risk that individual regions experience a heatwave; it also increases the risk that several regions experience a heatwave during the growing season of the same year. To explore this risk, we now consider heatwaves in several breadbasket regions during the same growing season. Note that while 30 ensemble members used here are likely enough to accurately represent internal variability and thus heat extremes in individual regions (Milinski et al., 2020), capturing a compounding between multiple regions might require a larger ensemble. A detailed analysis of this effect is beyond the scope of what can be achieved here and thus left for a future study. We focus our analysis on the breadbasket regions used in Raymond et al. (2022), which are: Central North America, North-East Brazil, southern South America, Central Europe, East Asia, and South Asia, as defined in the IPCC Special Report on Extremes (IPCC, 2012). In these different regions, different growing seasons for the crops are considered. These are: May until November in Central North America, December until February in North-East Brazil and South South America, May until August in Central Europe, May until September in East Asia, and July until October in South Asia. A simultaneous extreme event in several of these regions may substantially impact crop yields, disrupting local and global food markets and jeopardizing food security (Raymond et al., 2022). We thus examine whether heatwaves compound between regions. To this end, the share of the six breadbasket regions affected by a heatwave during the same growing season (southern hemisphere summer preceding northern hemisphere summer) is calculated for every ensemble member. This yields the number of regions that experience a heatwave during the same harvest year, potentially affecting global cereal prices and food security, which could be avoided through further process understanding and careful adaptation to these kinds of events.

The risk for a heatwave to occur in at least three breadbasket regions at the same time has historically ranged from 0-7% (Figure 4.6). Assuming 1.5°C of global warming, such an event may occur in up to 50% of years, while 2°C of global warming increase the risk of a three-region-event to between 62% and 97%. By the end of the century, a three-region-event is projected to occur every year under the SSP2–4.5 scenario.

At present, heatwaves do not affect five or more breadbasket regions during the same growing season (Figure 4.6). This changes under global warming, when the probability reaches up to 7% at 1.5°C, between 12% and 42% at 2°C of global warming, and between 42% and 80% by the end of the century. These values highlight both the pronounced uncertainty that still exists in these estimates and the strong increase in extreme event exposure of maize crops with every additional increase in global warming. The interplay of anthropogenic climate change and internal climate variability alongside spatial and temporal compounding of extremes is characterized by numerous non-linearities that together may lead to profound potential impacts on our food system and society. Probabilities of all six breadbasket regions experiencing a heatwave during the same growing season underline this finding: While such events are not found under present climate conditions or 1.5°C of global warming, heatwaves occur in all six regions up to 19% of years at 2°C of global warming and reach probabilities of 10-40% by the end of the century.

Conclusions

This case study highlights how the interplay of non-linearities in the climate system that involve internal climate variability may exacerbate the impacts of anthropogenic climate change with potentially devastating consequences. Extreme events may compound in space and time (occur in quick succession or in several regions at once), which may increase the severity of their impacts. Agricultural systems, if left unmanaged, are particularly vulnerable to such extremes, which already now has pronounced impacts on society. Synchronized climate events, such as heat extremes that hit several breadbasket regions during the same growing season, pose an additional risk to global food security and supply chains (e.g., Mehrabi, 2020) that may particularly strongly impact import-dependent regions (Puma et al., 2015). Meanwhile, climate models underestimate the physical mechanisms that synchronize extreme events (Kornhuber et al., 2023). Therefore, on the one hand, the results presented here can be understood as a lower bound to the threats that climate change poses to food security. On the other hand, studies have shown that trade and storage of food can act as powerful buffers to mitigate impacts of climate extreme induced agricultural losses (e.g., Molina Bacca et al., 2023). Our findings underline the urgent need for rapid and effective mitigation of climate change. Since some of the extreme events considered here already occur at an increased likelihood, decision-makers, including individual households and subsistence farmers (Petzold et al., 2023a), should also consider efforts to prepare adaptation measures to these kinds of extremes, for example by mitigating short-term impacts on the agricultural sector through the establishment of irrigation systems (Siebert et al., 2017) or changes in crop variety.

4.6 Summary

Attribution studies have shown high confidence that anthropogenic climate change has increased the likelihood and intensity of extreme events. However, the power of (decadal) internal climate variability should not be underestimated. It can turn events that are currently considered extreme and that are expected to be normal at the end of the century due to global warming into events that are plausible to occur already within the next 20 years (Section 4.1). The assessments in Sections 4.3, 4.4, and 4.5 emphasize the need to explicitly consider internal climate variability in models to improve the understanding and the quantification of projected changes in extreme events. Especially the interplay between anthropogenic climate change and internal climate variability involves non-linearities that can amplify or attenuate changes in climate extremes on a regional scale. The outcome of the assessments reveals three aspects relevant for assessing the plausibility of adapting to climate change in a sustainable manner.

First, knowing the uncertainties and limits of climate models is key for assessing the quality of the observed extreme events' representation, and, in a second step, for predicting future extreme events. This, in turn, is crucial for setting effective and sustainable climate adaptation measures. Section 4.3 on precipitation extremes offers an insightful example. Here, both internal variability and coarse model resolution are challenges for producing realistic representations. The assessment shows two main points: First, that large-ensemble simulations with increased spatial resolution substantially improve the representation of the investigated precipitation extremes, and second that the required spatial resolution strongly depends on the specific location and characteristics of the extreme event. The outcome is that not all model simulations are fit for the purpose of providing high-quality information for adaptation. This has implications for affected communities planning adaptation measures to precipitation extremes and the following floodings, such as communities in water-scarce regions, regions with riverine systems or steep topography, and cities such as Hamburg and São Paulo (Section 5.3 and 5.4).

Second, while communities have to react to extreme events—no matter if they occur because of anthropogenic climate change or internal climate variability—, for the planning and development of climate change adaptation strategies, knowing what a community is adapting to is crucial. Attribution studies analyze to what extent high-impact events can be attributed to anthropogenic climate change or to internal climate variability. Thus, in the Outlook terminology, the field of extreme event attribution engages in identifying the driving forces that regulate the physical boundary conditions for society. This requires a sophisticated view on extreme events, considering that "extreme" means different things in different situations. Section 4.4 describes an attribution study and highlights the dominant role of anthropogenic climate change in the occurrence of extreme events. For example, marine heatwaves with an intensity larger than 1.5°C have less than 1% occurrence probability without greenhouse gas forcing, but the Arctic Ocean experienced marine heatwaves with 3.5°C and 4°C intensity in 2007 and 2020, respectively. Thus, for both events greenhouse gas forcing is virtually certainly the cause, in a necessary causation sense. In terms of frequency, an event that is a one-in-40-years event in a world without greenhouse gas emissions turns into a one-in-five-years event with greenhouse gas emissions (Section 4.4).

Third, the assessments in Section 4.3, 4.4, and 4.5 emphasize that the interplay of non-linearities can lead to ecosystem and socio-economic disruptions, with potentially devastating consequences. Compound extreme events can become particularly dangerous. Section 4.5 assesses the change in the probability of compound extreme heatwaves with increased warming and the implications for cropland areas. The probability that extreme heatwaves occur in three breadbasket regions during the same year increases from a historical 0% to 7%, to 50% at 1.5°C global warming, to between 62% and 97% if the Paris Agreement temperature limit is breached and 2°C of warming are reached, to one event every year at about 2.25°C of global warming by the end of the century (Section 4.5). In a potential combination with concurrent dry spells (Raymond et al., 2022), such events may cause crop-yield losses with impacts on local and global cereal prices and supply chains, resulting in threats for food security. While studies indicate that trade and storage may buffer shocks to the food system to some degree (Molina Bacca et al., 2023), the spatially compounding nature of the studied heat events poses new challenges to constructing a climate-resilient food system. Also, precipitation extremes and severe floodings are among the most devastating and costly events, damaging infrastructure, private property, and even causing fatalities (Section 4.3). Marine heatwaves are powerful catalysts of ecosystem disruption (Section 4.4). Being responsible for escalating thermal stress experienced by ecosystems, mass mortality, coral bleaching, and Kelp Forest loss, marine heatwaves disrupt the delivery of marine ecosystem goods and services to coastal communities that rely on them, and beyond that have an impact on economy and coastal protection needs against increased erosion (see Section 5.10).

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Sustainable Climate Change Adaptation: Insights and Reflections from the Field

5

5

Sustainable Climate Change Adaptation: Insights and Reflections from the Field

5.1

Introduction

Despite the many extreme events occurring all over the globe and the media coverage reporting on climate change impacts in terms of droughts and flooding, progress toward properly addressing climate change is still slow (IPCC, 2022; UNEP, 2023; Pagnone et al., 2023, pp. 33-50; see also Sections 3.12 and 4.6). This can only partly be explained by deep uncertainty and the still incomplete understanding of the relationship between climate change causes and their outcomes. Challenges with understanding the where(s), when(s), and how(s) of incidents and emerging problems also make understanding and tackling current and future mitigation and adaptation needs a difficult task. Against this background, it has proven difficult in various socio-cultural contexts to unite actors around the decisions that need to be made on local and regional adaptation strategies and mitigation measures. And yet, while climate change mitigation agendas are still being debated, social and ecological systems already need to cope with very tangible losses and damages caused by climate change impacts—not to mention the need to prepare for future impacts (Hoegh-Guldberg et al., 2019; Puig, 2022; Seneviratne et al., 2021). Exploring climate adaptation strategies and assessing their opportunities and limitations has thus become an urgent task in the context of designing sustainability pathways (Gresse et al., 2023). Interfering with or acting in societal systems with their various social, cultural, spatial, temporal, and natural environments represents a challenging and even daunting task with its own opportunities and limitations. This results in the overarching research question for the current Outlook: "Under which conditions is sustainable climate change adaptation plausible?" This Chapter builds on the preceding chapters and provides empirical key insights into climate change adaptation.

Given the local and regional nature of climate change adaptation, this chapter empirically scrutinizes the contextual conditions that affect the plausibility of sustainably adapting to climate change in various geographical localities and regions. We use an inductive rationale that builds on an assessment of nine case studies, aiming to connect new research to recent developments with regard to climate impacts. Our investigation is interdisciplinary, grounded, and involves scientists from various disciplines such as anthropology, linguistics, geography, sociology, environmental economics, environmental law, urban planning, forestry science, soil science, agricultural science, climate science, biology, chemistry, physics, and coastal engineering. The case studies examine, analyze, and assess barriers to sustainable climate change adaptation across different regional contexts, providing empirical insights into the current state of the art of adaptation in urban, rural, and coastal settings.

The chapter is divided into the following sections and sub-sections: Section 5.1.1 provides a brief meta-review of documented climate change adaptation research around the world, depicting the emergence of climate change adaptation as a key topic and different disciplinary takes on this. It explains the emergence of climate change adaptation as a key topic; it also briefly considers what climate change adaptation actually represents, on which scales it takes place, what challenges are involved and what research gaps still exist. In Section 5.1.2, key concepts of climate change adaptation are presented and contextualized against the background of existing literature. Section 5.1.3 provides an outline of the methods used in the case study assessment. Section 5.2 then turns to the case studies as the empirical core of the chapter. Section 5.12 completes the chapter with a conclusion and an assessment of the plausibility of sustainable climate change adaptation.

The nine case studies aim to identify key contextual conditions for sustainably dealing with climate change impacts. They were selected to reflect the different realms of urban and densely populated areas, rural-agricultural areas, and coastal zones. Furthermore, it was important to reflect different continents and the northern and southern hemispheres in the broadest way possible (see Figure 5.1). Individual case studies were selected based on existing expertise in Hamburg, working contacts and cooperative relationships with scientists in the case study areas. Based on these criteria, the three urban areas of Hamburg, São Paulo, and Ho Chi Minh City were selected, as well as the three rural areas of northern Lower Saxony (Germany), Kunene (Namibia) and the Nepal Highlands and the three coastal areas of the German North Sea coast, the Taiwanese coast, and the island state of the Maldives.

Climate Change Adaptation: a Meta-Review of Current Research

The relevance of societal adaptation in responding to climate change was first formally acknowledged in the Rio Declaration developed in 1992 at the United Nations Conference on Environment and Development. In recent decades, climate change adaptation has repeatedly been raised in several reports of the Intergovernmental Panel on Climate Change (IPCC), for example in its 2001 report on Impacts, Adaptation and Vulnerability (Massey and Huitema, 2013). The 2018 report on the Impacts of Global Warming of 1.5° above Pre-Industrial Levels (IPCC, 2018) explicitly addresses the importance of public participation in climate change adaptation, while societal adaptation is also raised in the recent Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change 'Climate Change 2022: Impacts, Adaptation and Vulnerability' (IPCC, 2022).

Looking back at the period from 1992 to today, it is clear that climate change adaptation has come to represent a central topic in the field of climate science, reflected in the vast number of publications addressing the subject. There has been exponential growth of publications on climate change adaptation over the past two decades (Callaghan et al., 2020; Haunschild et al., 2016; Nalau and Verrall, 2021), with a doubling occurring every five to six years between 1980 and 2014 (Haunschild et al., 2016). From 1978 to the mid-2020s, an average annual increase of 28.5% was observed in climate change adaptation publications; this rate had doubled by early 2022 (Nalau and Verrall, 2021). Looking at general publication trends from a disciplinary perspective, more than 60% of the literature is published in natural science journals that specifically address climate impacts and adaptation issues, while the social sciences and humanities concerned with the socio-cultural aspects of adaptation are lagging behind. Quantitatively speaking, within the past three IPCC assessment periods (2001-2018), adaptation may thus have become a fast-growing topic but the disciplinary perspective shows a persistent gap with respect to the social dimensions of climate change adaptation. It is interesting to note that climate change adaptation is the most widely addressed topic in relation to the baseline literature identified (Callaghan et al., 2020).

The bulk of academic publications deals with behavioral responses, followed by technical, infrastructural, and institutional responses (Nalau et al., 2021; Hunter et al., 2020). Adaptation planning is recognized globally and documented as undertaken by most nations (Berrang-Ford et al., 2021; UNEP, 2023), but this only refers to reported adaptation intention and planning and not necessarily to adaptation measures actually taking place (Berrang-Ford et al., 2021; Petzold et al., 2023a). All these different aspects are also mirrored in the number of scientific disciplines engaged in climate change adaptation research, ranging from the natural sciences (e.g., engineering, geophysics, climatology) to the social sciences (e.g., political science, sociology, economics, geography, anthropology) and humanities (e.g. philosophy, linguistics). Each discipline and its fields of research have developed their own theoretical, methodological, empirical, and sometimes interdisciplinary rationales for climate change adaptation. A point of convergence is the framing of climate change as a wicked or multifaceted problem (Hulme, 2009; 2021). Overall, work on climate change adaptation has often been devoted to conceptual issues, with empirically driven or even applied studies only starting to catch up during the past decade (Bouwer, 2022). On a grander level, however, there is still a lack of converging key concepts and practical application.

Contextualization: Key Concepts of Climate Change Adaptation

As shown above, climate change adaptation is a multidisciplinary concept that often lacks precise definition and conceptual consistency. It is for this reason that this chapter uses the globally agreed and guiding definition provided by the IPCC Sixth Assessment Report. Here, climate change adaptation in human systems is described as "the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities" (IPCC, 2022). This aspect is complemented by the inclusion of natural systems for which adaptation is described as "the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects" (IPCC, 2022, p. 2898). Drawing on the definition established in the previous Outlook, we frame sustainable climate change adaptation "as the process of adjusting to actual or expected climate change and its impacts by minimizing trade-offs and exploiting synergies between climate action and other sustainable development goals" (Gresse et al., 2023, p. 65). In this vein, adapting to climate change in a sustainable manner means accounting for the broader range of societal goals and socio-ecological transformations involved in designing, planning, and implementing adaptation responses. Hence, a sustainable adaptation response has to necessarily address the various ranges of climate action while also fostering sustainability transformations, that is, multi-sectoral and system-wide shifts that foster human development while protecting and upholding the resilience of Earth's life-support systems (Gresse, 2022; Messner, 2015; Salomaa and Juhola, 2020). If adaptation measures are not properly tailored to the environment or situation at hand, the risk of misplaced or inappropriate adaptation increases. So-called maladaptation is defined as "an action taken ostensibly to avoid or reduce vulnerability to climate change that impacts adversely on, or increases the vulnerability of other systems, sectors or social groups" (Barnett and O'Neil, 2010, p. 211; see also IPCC, 2022; Barnett and O'Neil, 2013; Juhola et al., 2016; Magnan et al., 2016). Assessing maladaptive effects of adaptation action, however, is tricky as it requires ex-post analysis either after a longer period of time or following a disastrous event. As far as sustainable climate change adaptation is concerned, maladaptation can be observed at the local scale in the short term if adaptation measures lead to negative environmental or socio-economic impacts shortly after their implementation, making people and communities even more vulnerable to climate change (Schipper, 2020).

Conceptually, adaptation responses can be classified into three analytical categories: (1) coping, (2) incremental adaptation, and (3) transformative adaptation (Fedele et al., 2019). Within this conceptual landscape, coping strategies take the form of temporal, immediate, and reactive responses to climatic impacts on socio-ecological systems. Coping strategies do not aim at long term systemic change and can be constrained by limited technical and financial resources; they can also risk lock-ins in existing risk awareness and understanding (Kates et al., 2012; Perrings, 2006; Fedele et al., 2019, p. 118). Incremental adaptation, in turn, entails a stepwise approach along beaten paths, that is, "doing slightly more of what is already being done to deal with natural variation in climate and with extreme events" (Kates et al., 2012). Such an approach focuses on sectoral or context-specific adjustments resulting in a minor disturbance of systemic stability, which in the long run holds the danger of consolidating unsustainable systemic states (Adger and Jordan, 2009; Kates et al., 2012; Fedele et al., 2019; Wakefield, 2019). Finally, transformative adaptation intends to encourage fundamental changes in situations where incremental changes no longer suffice (Kates et al., 2012). It differs from the previous strategies by encompassing broader and deeper actions directed at the root causes of vulnerabilities while at the same time envisioning long-term systemic shifts. Characterized as a path departure, it combines ruptures that carve out spaces for interstitial and symbiotic approaches to change. Wright (2010, p. 298) points out that "both deliberate and unintended processes of social change are crucial for emancipatory transformation", which suggests that transformation is better conceived of as a continuous and messy process of change that cannot be controlled and managed within existing paradigms (Termeer et al., 2017). By enabling direct abrupt changes, or through the cumulative effects of indirect incremental adjustments, this type of strategy recognizes and addresses the need to fundamentally alter socio-ecological systems and human-environment relationships (Adger and Jordan, 2009; Adger et al., 2011; Kates et al., 2012; Fedele et al., 2019; Feola, 2015; O'Brien, 2012; IPCC, 2013).

Importantly, however, none of these three responses mean that the pathways adopted are necessarily sustainable. Nevertheless, coping and incremental adaptation have been more frequently related to unsustainable adaptation pathways, thus underlining the relevance of transformative adaptation strategies if progress is to be made toward sustainable climate adaptation.

Methodological Approach for the Assessment

The present chapter is designed as an empirical study grounded in case studies. It builds on frameworks, key concepts, and findings established in the two previous editions of the Outlook (Stammer et al., 2021; Engels et al., 2023). Methodologically, all case studies use inductive reasoning that draws on qualitative data collected by means of expert elicitation, literature reviews, document analysis, systematized interview studies, guided round table discussions, and on-site exploration of local and regional places. Unlike the social driver assessments (Sections 3.2 to 3.11), the case studies do not explore potential drivers of change and their respective enabling and constraining conditions. Rather, they focus on the plausibility of sustainable climate change adaptation by analyzing different types of adaptation responses and addressing the extent to which socio-ecological systems are able to adapt to climate change, that is, the context-specific limits of adaptation (Bouwer, 2022; Thomas et al., 2021; Berkhout and Dow, 2023). For this to be investigated among the overall group of the case studies, each author team was asked to fill out an initial questionnaire to organize, systematize and align their content. Invited experts from the case study regions then took an active part in organizing the comparative analysis and contributed to the writing process. This ensured content and empirical accuracy while at the same time widening the conceptual and empirical scope of each case study assessment.

Based on the agreed general framework, each team explored their case study's specific empirical evidence and then reflected on its findings at a more theoretical level. The expert elicitation among those involved in the case studies focused on an agreed-upon textual structuration to comparatively tackle the various dimensions of climate change adaptation in the different case studies. To ensure coherence with respect to the content of each case study, the following questions were chosen as a framework for orientation:

- What does climate change adaptation actually mean in the current case study?
- Who, where, how, and what is adapted to which specific features of climate change and impacts?
- Who initiates, structures, negotiates, and steers the adaptation process in what way?
- Who implements adaptation with whom under the existing framework conditions and takes decisions?
- And what are the resulting possible and plausible adaptation options, if any?

Delving into the rich empirical data provided by the case studies allows us to investigate which barriers and opportunities exist for sustainable climate change adaptation and which types of response are prevalent in dealing with climate change (i.e., the extent to which coping, incremental, or transformative adaptation is apparent in the cases investigated). In the case studies, we assess the context conditions affecting the plausibility of achieving sustainable climate change adaptation drawing on the definition and plausibility framework of previous assessments (Stammer et al., 2021; Engels et al., 2023).

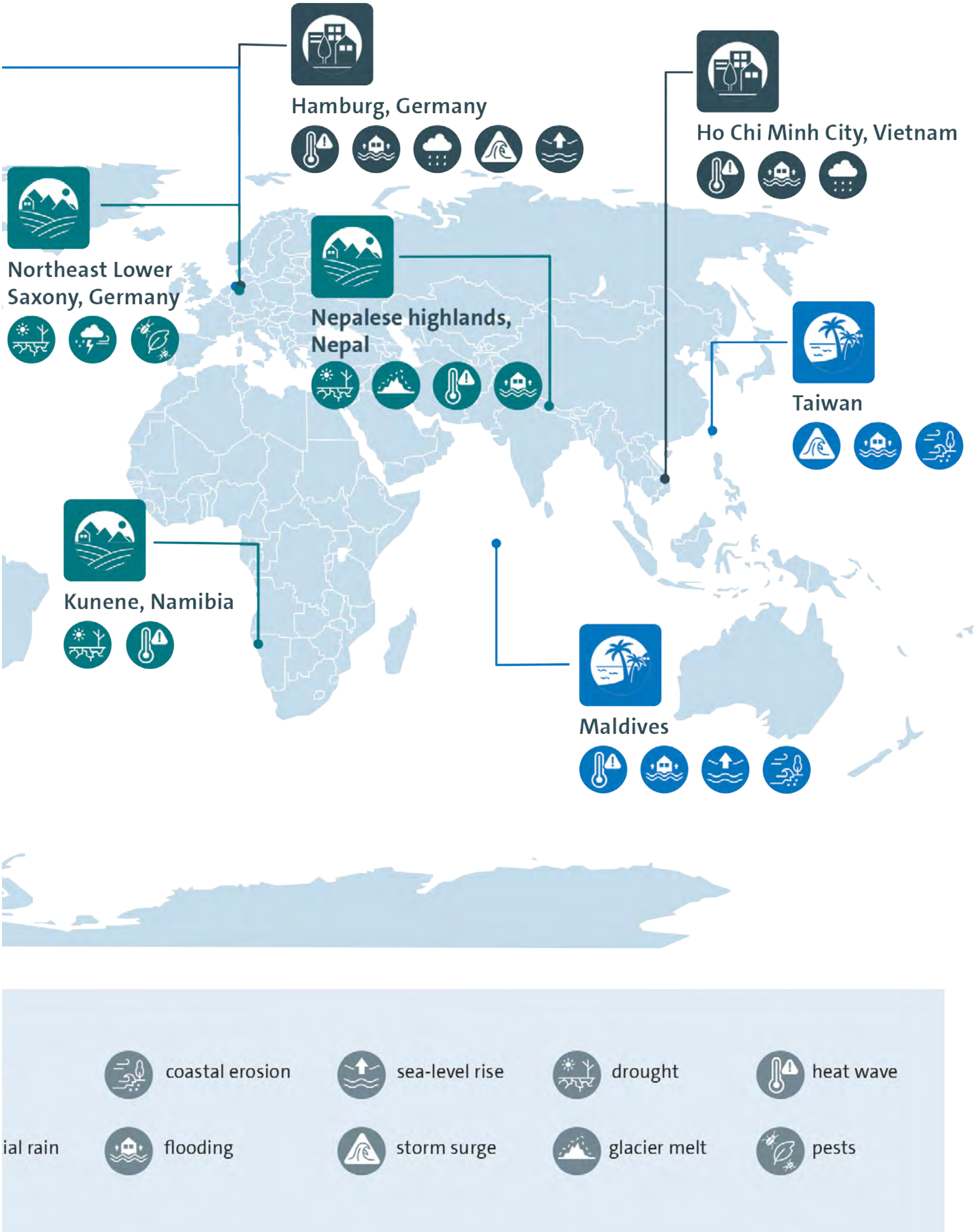
This approach was collectively prepared during two moderated workshops in which 25 organizing and co-authors participated and where the scope and the conceptual procedures for the assessment were cooperatively developed, assessed by a steering group, and discussed among all authors. All empirical analyses for the case studies—including data acquisition—were carried out between 2019 and 2023. Content-based feedback to organizing authors of each case study secured consistency while the peer-review by external reviewers assisted in securing scientific quality and comprehensibility. In brief, the chapter develops nine empirical case studies from the three general categories of urban areas, rural areas, and coasts. The structuring logic was to start with a European perspective and then explore (sustainable) climate change adaptation issues in various non-European regions and places. Analytical emphasis was put on the context conditions of climate change adaptation in each region with the aim to explore convergences and divergences among them. Thematically, the case studies focus on local climate change impacts, the societal and governance framing of climate change adaptation endeavors and context-specific conditions for sustainable climate change adaptation. These aspects were then assessed more generally to consider limits and limitations of the various ways of doing climate change adaptation. So-called take-home messages summarize key lessons drawn from each case study.

5.2

Toward Plausible Sustainable Climate Change Adaptation in Urban, Rural, and Coastal Areas

The case studies demonstrate that climate change adaptation is a multifaceted, tricky, and wicked problem where social, political, and natural processes permeate each other. Such multifariousness obviously does not allow for one-size-fits-all solutions. Rather, it calls for a more contextualized perspective that investigates and considers the site-specific interconnections of climate change, climate change adaptation, people, place, politics, administration, law, and science. This represents a conceptual, methodological, empirical, and above all practical challenge for which more and better scientific knowledge is only of limited help. Other enablers, which are more fully explored in the case studies below, are needed. Taking these aspects into serious consideration would also help to overcome the problem that climate change adaptation has so far largely remained conceptual and is still waiting for place-based application. We synthesize and discuss the key findings of this chapter in Section 5.12.

Figure 5.1: Case study locations and climate change effects



Hamburg, Germany
Ho Chi Minh City, Vietnam
Northeast Lower Saxony, Germany
Nepalese highlands, Nepal
Taiwan
Kunene, Namibia
Maldives
coastal erosion
sea-level rise
drought
heat wave
ial rain
flooding
storm surge
glacier melt
pests

TABLE 5.1

Case studies – Basic information

Region	Area size	Population	Topographical context / Climatic zone
Hamburg (Germany)	755.3 km² [1]	1.9 Mio. [2]	**Topographical context:** coastal city and seaport in a transitional estuarine coastal zone, connection to the North Sea coast through the Elbe, Northern Germany **Climatic zone:** temperate, maritime climate, average temperature: 9.8°C, average annual precipitation: 720 mm
São Paulo (Brazil)	1521 km² [3]	11.45 Mio. [3]	**Topographical context:** Brazilian southeast region, 760 m above sea level **Climatic zone:** humid subtropical climate, average temperature: 20.4°C, average annual precipitation: 1658,3 mm
Ho Chi Minh City (Vietnam)	2095.4 km² [4]	>10 Mio.* (*pop. of the mega city exceeding administrative borders), according to Stat. Yearbook 2022 = 9.389 Mio inhabitants [4]	**Topographical context:** first mega city of Vietnam, northeastern edge of the Mekong Delta, large parts just 0.5 meters above sea level **Climatic zone:** tropical monsoon climate
Northeast Lower Saxony (Germany)	47614 km² [5]	7.9 Mio. [5]	**Topographical context:** rural northeastern Germany, Lower Saxony, Wendland, low altitude, sandy soils, agricultural production: grains, maize, potatoes, sugar beets **Climatic zone:** temperate climate, transition between the Atlantic and continental climate zones, average annual precipitation: 550–750 mm
Nepalese Highlands	122400 km² [6]	13.5 Mio. [6]	**Topographical context:** mountain region **Climatic zone:** (sub)temperate to tundra
Kunene, Namibian Pastoralists	115239 km² [7]	86856 (census 2011) [7]	**Topographical context:** northwestern Namibia **Climatic zone:** (semi)arid, average annual precipitation: 100 – 300 mm, transformation to drier conditions
North Frisia, German North Sea Coast	441 km of coastline and 5 islands [8]	169000 (2022) [9]	**Topographical context**: part of the Wadden Sea Region, which stretches from Den Helder in the Netherlands along the German coast up to Blåvands Hook in southern Denmark; low lying coastal region, tidal mudflats and marshlands **Climatic zone:** oceanic (moderate) climate, average temperature: 8.5–9°C [5], Average annual precipitation: 750 mm [5]
Maldives	298 km² land area, 923322 km² total [10]	561631 (2022) [10]	**Topographical context:** indian Pacific, 1196 islands south of India, average land elevations ranging from 0.5 m to 2.3 m above sea-level **Climatic zone:** dry season with winter northeast monsoon and rainy season with summer southwest monsoon, average annual precipitation: 2,540–3,810 mm, temperatures rarely below 25°C
Taiwan	36197 km² [11]	23.3 Mio. [11]	**Topographical context:** flat to gentle plains in the west, mostly forest-covered mountains in the eastern area, geologically very active area **Climatic zone:** subtropical, tropical climate on the south, monsoon climate, typhoons in summer, average annual precipitation: 2200–3800 mm

Additional Sources: [1] Neumann, G. (2018). Hamburg- Location, Size and Population. Hamburg Marketing. https://marketing.hamburg.de/facts-and-figures.html (Last access: 11.03.2024), [2] Statistisches Bundesamt (2023). Städte (Alle Gemeinden mit Stadtrecht) nach Fläche, Bevölkerung und Bevölkerungsdichte am 31.12.2022. Available online: https://www.destatis.de/DE/Themen/Laender-Regionen/Regionales/Gemeindeverzeichnis/Administrativ/05-staedte.html. (Last access: 26.02.2024), [3] IBGE (2022). População. Instituto Brasileiro de Geografia e Estatística (IBGE). Available at: https://cidades.ibge.gov.br/brasil/sp/sao-paulo/panorama. (Last access: 06.03.2024), [4] General Statistics Office of Vietnam (2023). Statistical Yearbook of 2022. Statistical Publishing House, Hanoi. https://www.gso.gov.vn/wp-content/uploads/2023/06/Sach-Nien-giam-TK-2022-update-21.7_file-nen-Water.pdf (Last access: 21.02.2024), [5] Lower Saxony State Chancellery (2016). State Chancellery of Lower Saxony. Home of Diversity. Niedersachsen. Klar. https://www.niedersachsen.de/download/116564/Broschuere_Heimat_ (Last access: 23.11.2023), [6] Government of Nepal (2023). National Population and Housing Census 2021 (National Report). National Statistics Office, Kathmandu, Nepal, p. 614.

Political context	Climate change phenomena featured	Who adapts?
City, municipality, and Federal State in the Federal Republic of Germany, parliamentarian democracy	Heat waves, groundwater flooding, riverine flooding, coastal flooding, storm surges, pluvial flooding, torrential rain, coastal erosion, sea-level rise	Public bodies (politics, administration), business sector (e.g., Chamber of Commerce), housing industry (e.g., SAGA and cooperatives), citizens
City, capital of São Paulo federal state, Democratic Republic of Brazil	Torrential rain, inundation, flooding, landslides, droughts, heat waves	Local government, public administration (environment/climate-related secretariats), civil society, academia
Most populous city in the Socialist Republic of Vietnam, one-party state, authoritarian style	Heat waves, flooding, torrential rain	Public bodies (politics), households (micro-scale, such as elevated doorways)
Region in the Federal State of Lower Saxony in the Federal Republic of Germany, parliamentarian democracy	Drought, water shortage, decreased soil water availability, storm, damages in forests, pests: bark beetle infestations in forests	Farmers, forest owners, public bodies (politics on regional, national and EU level)
Region in the Federal Democratic Republic of Nepal, parliamentarian democracy	Droughts, glacier melt, flooding, heat waves	Indigenous people and local communities (IPLCs), households, local government
Region in the northwest of the Republic of Namibia, democracy	Droughts (impact on vegetation growth and livestock farming) leading to resource scarcity and food insecurity, heat waves	Pastoralists, local level households
Region in the Federal State of Schleswig-Holstein in the Federal Republic of Germany, parliamentarian democracy	Storms, storm surge, sea-level rise, coastal erosion	Inhabitants of the islands and the mainland; various interest groups (e.g., farmers, diking associations), local communities, parishes, nature conservation, and the relevant authorities
Republic of Maldives, presidential representative democratic republic	Heat waves, flooding, sea-level rise, coastal erosion	Maldivian government, Ministry of Environment, Climate Change and Technology
Difficult status: officially Republic of China (ROC) but considers itself a sovereign state with its own democratic system (government, military, and constitution); most countries recognize China rather than Taiwan diplomatically	Storm surge, flooding, coastal erosion	Taiwan Central Government, National Science and Technology Council (Disaster), Ministry of Transportation and Communications (Infrastructure), Ministry of Economic Affairs (Water Resources), Ministry of the Interior (Land Use and Coast), Ministry of Agriculture (Agricultural Production and Biodiversity), local governments

(7) Kumene Regional Council, Government of the Republic of Namibia (2015). Kumene Regional Development Profile 2015 – The ultimate frontier. Opuwo, https://kunenerc.gov.na/documents/53359/0/Dev_profile.pdf/e20fcb44-46e3-effa-6344-2189605e1c7f (Last access: 13.3.2024), (8) Schleswig-Holstein (2022). Kreise und kreisfreie Städte in Schleswig-Holstein https://www.schleswig-holstein.de/DE/landesportal/land-und-leute/kreise-kreisfreie-staedte/kreis-nordfriesland/kreis-nordfriesland_node.html (Last access: 31.01.2024). (9) Statistik Nord (2022). Bevölkerung insgesamt Nordfriesland. Tabelle aus Freier Datenauswahl für Schleswig-Holstein. Statistikamt Nord: Meine Region – Erzeugte Datentabelle aus der eigenen Zusammenstellung für Schleswig-Holstein (statistik-nord.de). (Last access: 11.03.2024), (10) Country economy (2022). Maldives GDP – Gross Domestic Product. https://countryeconomy.com/gdp/maldivas. (Last access: 11.03.2024), (11) Ministry of Foreign Affairs, Republic of China (Taiwan) (2024). Government Portal of the Republic of China (Taiwan), about Taiwan. https://www.taiwan.gov.tw/about.php (Last access: 20.02.2024)

5.3

Hamburg, Germany

Hamburg is the second largest city in Germany with 1.9 million inhabitants. The Free and Hanseatic City of Hamburg is one of Germany's 16 federal states, politically a city state, and a municipality. Hamburg has seven districts to which local tasks are assigned. These districts are further divided into 105 urban quarters (Statistisches Bundesamt, 2023). The Senate is the state government, consisting of the First Mayor, who leads the government, and the Senators, who oversee the ministries. Some public activities have been delegated to public corporations, such as water supply and waste water disposal, waste treatment, and port management. Hamburg's Metropolitan Area includes neighboring counties from the federal states of Lower Saxony, Mecklenburg-Vorpommern, and Schleswig-Holstein. This metropolitan region is home to about 5.4 million people (IKM, 2023).

Hamburg is a port city with one of the largest ports in Europe (Schubert, 2020). The city has a long tradition of trade and of political freedom from aristocratic and religious authority. Sovereignty of the Hamburg traders and citizens was granted in the 12th century and has resulted in multiple forms of self-organization and participation to manage the local community, for example a high degree of citizenship organization and of philanthropy. Hamburg has suffered severe disasters with strong impacts on the city's development and its preparedness for shocks (Paech, 2008), for example the Great fire in 1842, which destroyed about one third of the old town; a cholera epidemic in 1892 with more than 8500 deaths; and the North Sea flood of 1962 with massive destruction of buildings and technical infrastructure as well as 340 fatalities (von Storch et al., 2008). While most European river-port cities have undergone a major transition in recent decades towards a service-centered rather than an industry-oriented metropolis, Hamburg is one of the few river-port cities that have opted for port expansion (Grossmann, 2008). In recent years, Hamburg has been challenged by economic structural change questioning the role of the port and other sectors (e.g. the aircraft industry), and proposing more efforts for digitalization, services, and creative industries (Kulke, 2023).

Climate, climatic change, and society in Hamburg

Hamburg is located at the river Elbe, about 80 km south-east of the North Sea, with the biggest German harbor located in the core of the city. Besides the river Elbe there are a number of smaller rivers, for example the Alster, Bille, and Wandse, that feed into the Elbe. The city has a maritime climate with an average annual temperature of 9.8°C (DWD, 2021). The area average of the total annual precipitation for Hamburg is around 720 mm, with maximum rainfall during summer (around 220 mm) and minimum rainfall during spring (around 150 mm; see Meinke et al., 2014; 2018).

Hamburg's proximity to the North Sea distinguishes the city as a coastal city in a transitional riverine and estuarine coastal zone, posing distinct climate change-compounded risks (Glavovic et al., 2022). Climate-related threats stem from rising sea-levels and the associated rise in groundwater (i.e., groundwater flooding), severe storm surges causing coastal flooding, heavy and prolonged rainfall causing riverine flooding, and an increasing vulnerability to pluvial flooding due to increasing high-intensity rainfall events (Schlünzen et al., 2010; Schlünzen et al., 2018; Poschlod and Ludwig, 2021). In addition, these risks are exacerbated by the increasing sealing of urban surface areas as a result of growing construction activities.

The city of Hamburg is characterized by an urban heat island (UHI; urban-rural temperature difference in the surface near atmosphere), which, according to measurements (Bechtel et al., 2011, Wiesner et al., 2014), is up to 1.2°C on average (city center and HafenCity). The largest UHI values are found at night, with up to 2.7°C in the central district in summer compared to a rural measuring station (Wiesner et al., 2018). With climate change, the number of hot days and tropical nights in Hamburg is expected to increase, and summer heat waves will occur more frequently and probably last longer (DWD, 2021).

These physical hazards interact with non-climatic drivers of exposure and vulnerability. In Hamburg, social welfare, education, and age must be considered in order to identify particularly vulnerable population groups (von Szombathely et al., 2023). These groups are often disproportionately affected by negative environmental influences (EEA, 2019). In case of a water hazard, Hamburg-Wilhelmsburg, an Elbe island district characterized by numerous low-income residential areas, shows higher social vulnerability compared to neighborhoods in the north of the city, which are characterized by a predominantly high social status. The management of flood risk by the City of Hamburg has potentially huge implications for ensuring social, climate and environmental justice, and offers an opportunity to counteract unfair distribution effects (Driessen et al., 2018). However, the hazard at hand must also be taken into account when calculating exposure (Mason et al., 2020).

Overall, vulnerability, exposure, and the climate-related hazards mentioned generate a compound water-from-four-sides flood risk for Hamburg (Hanf et al., 2024, under review). In particular, the combination of heavy rainfall and storm surges in the greater Hamburg area can cause multi-hazard situations or so-called compound events (Zscheischler et al., 2018). For example, the storm series in February 2022 caused extreme wind gusts, storm surges, and heavy precipitation within a week, and led to long-duration high water levels of the Elbe river in conjunction with high river discharges in the Elbe tributaries (Mühr et al., 2022).

Awareness about climate change is quite high among the people of Hamburg. A long-term annual population study in Hamburg shows that the proportion of Hamburg residents who consider climate change to be a major or very major threat to the city ranges between 61% (2008) and 67% (2023). According to 56% of the respondents, the consequences of climate change are already being felt in Hamburg today, and the greatest threats to the city are attributed to storm surges by 63% of the respondents (2023). The assessment of being personally affected by a natural disaster in Hamburg increased from 2008 (46%) to 2023 (62%) (Ratter and Scheunpflug, 2023). This results in a high level of acceptance for adaptation measures within the society.

Climate change responses

Climate adaptation in Hamburg is part of a complex multi-level regulatory framework, including European law (e.g., Water Framework Directive), national law (e.g., Water Resources Act; Waterways Act), and Hamburg legislative competencies (e.g., Hamburg Water Act). Hamburg has enacted its first Climate Protection Act in 1997 (Hamburgisches Klimaschutzgesetz: HmbKliSchG), which was also the first Climate Protection Act in Germany. Comprehensive amendments were implemented in 2020. The Act was amended again in December 2023. Climate adaptation is not the focus of the Climate Protection Act. However, the Act contains some provisions that refer to it. The City and all its entities must take climate adaptation into account in all its plans, measures, and decisions (§1 HmbKliSchG). This applies particularly to plans and investments (§2 HmbKliSchG). Preventive flood protection as well as urban and landscape planning instruments are explicitly mentioned as adaptation measures (§5 HmbKliSchG). It is planned to set up a separate Climate Adaptation Act within the next few years. The legislative activities of the city must be seen in the context of national legislation. Germany adopted the first Climate Protection Act in 2019, with amendments made in 2021 following a groundbreaking decision of the Federal Constitutional Court that defined and underlined the constitutional significance of climate change mitigation and adaptation (BVerfG, 2021). In 2023, the federal government passed the Climate Adaptation Act (Bundes-Klimaanpassungsgesetz: KAnG), which will come into force in 2024. §10 of the Climate Adaptation Act requires the federal states to develop adaptation strategies that must be based on climate risk analyses. Furthermore, there is a general rule for taking climate adaptation into account when implementing federal law (§8 KAnG).

Mitigation and adaption efforts have a long history in Hamburg. In the early 1980s, a special office for environmental protection was created. When Hamburg signed the Charta of Aalborg in 1996 to promote sustainable development against the background of the Rio Declaration of 1992, responsibility for climate mitigation and adaptation was transferred to the Ministry of Environment, Climate, Energy and Agriculture (BUKEA: Behörde für Umwelt, Klima, Energie und Agrarwirtschaft). In 2007, the Convenant of Mayors was invited to the city, leading to the declaration of a comprehensive document concerned with climate protection. In 2011, Hamburg was appointed as the second European Environmental Capital because of best practices in various areas of environmental and climate policies. In 2015, the first Climate Plan was launched that brought together climate mitigation and adaptation. In 2019, this plan was revised with an expansive part on adaptation. In the next revision in 2023, a strategic change took place as climate change adaptation was separated from the Climate Plan. A separate climate adaptation strategy for Hamburg is currently being developed. Such an independent Climate Adaptation Plan is intended to emphasize the importance of the issue, although disconnected from climate mitigation. This strategic change correlated with a reorganization of the climate change issues in BUKEA. In 2021, climate adaptation was shifted from BUKEA's climate coordination office in the energy and climate department to a newly established adaptation management unit in BUKEA's water department.

In addition to the operational competency of BUKEA on environmental issues, climate issues have been organized in an integrative way in the Hamburg administration. The First Mayor is the head of a committee for climate and mobility, assembling the relevant ministries for decision-making. Below this level, numerous cross-sectoral steering and project groups deal with specific climate-related topics. Furthermore, in the fields of climate mitigation and adaptation, the Senate receives advice from a Scientific Advisory Board, and stakeholder activities contribute to the decision-making and implementation process, for example the Chamber of Commerce, the Chamber of Crafts, NGOs like Friends of the Earth (BUND), Nature and Biodiversity Conservation Union (NABU), or Future Council Hamburg.

In the academic field, Hamburg benefits from a strong branch of climate science within its universities. Regarding climate adaptation, the interdisciplinary KLIMZUG NORD research project generated diverse knowledge on the consequences of climate change for the city and developed strategies and measures for adaptation. In the context of the Cluster of Excellence CliSAP (2007-2018), the 'KlimaCampus' was initiated, bringing together universities, research institutes, the city administration, and federal administrations located in Hamburg to exchange and further develop knowledge on climate mitigation and adaptation. The current research Cluster of Excellence CLICCS (since 2019) builds on the CliSAP cluster's many years of climate research in Hamburg.

Hamburg is implementing a mix of adaptation measures to counter the multiple climate risks and increase resilience to water and heat stress in the long term. However, Hamburg is not giving all climate-related hazards equal attention. Storm surge protection is safely in the hands of the state and its institutions, which the population completely trusts in and relies on. Protection against other water-related hazards such as heavy rainfall events and related pluvial flooding, however, is mainly dependent on the actions of individuals (de Guttry and Ratter, 2022).

Against the backdrop of the traumatic storm surge in 1962, dike protection and traditional flood management (i.e., "hard" infrastructure) became the main strategies to prevent similar disasters. In fact, the storm surge and the subsequent flooding in 1962 marked a turning point in Hamburg and German coastal protection, which has since then been fundamentally overhauled. Today, storm surge protection in Hamburg includes dikes, flood protection walls and flood gates, flood barriers, sluices, private polders, base structures, escape routes, terps, public education, and improved warnings by the authorities and institutions involved (de Guttry and Ratter, 2022). Hamburg has a long history of citizen engagement for dike protection. Flood protection communities organize the coastline-dwellers that are exposed to storm surges to ensure that the dikes and other infrastructures are maintained (Fellmer, 2014). The city continuously adjusts the reference water levels and dike heights – also in consideration of the expected changes due to climate change (Müller and Gönnert, 2018).

However, in recent years, debates have promoted aspects such as "living with water", "water-sensible city", and "sponge city", which have put more emphasis on the integration of water issues into urban development. Together with the public enterprise in Hamburg that is in charge of water supply and wastewater disposal, the city launched the project Rain Infra Structure Adaptation (RISA, 2009-2015), which has created a solid theoretical basis for the implementation of sustainable adaptation of urban rainwater infrastructure (HW, 2023). In numerous pilot projects throughout the city (e.g., Germany's first rain playground, heavy rainwater-adapted school yards, and a sports pitch with underground storage elements for rainwater retention), new concepts were tested and implemented. In this context, green and blue infrastructure has gained more relevance, and the city has consequently set up programs to foster roof and facade greening. The RISA approach and urban greening strategies offer synergies with the heat and drought issues as secondary climate change-related stressors (HSE and BUE, 2015). As a co-benefit, urban greenery provides cooling for the city and its citizens. Green roofs were identified as one of the most promising adaptation measures by the Hamburg government (Bürgerschaft der FHH, 2014). In fact, Hamburg was the first major German city to launch a comprehensive green-roof strategy. The vision for Hamburg is to green at least 70% of new buildings and flat roofs under renovation (see Figure 5.2) in order to achieve cooling effects for densely built-up urban areas and to increase the rainwater retention capacity of the city (climate adaptation) while saving energy costs (climate mitigation).

With regard to urban development, the International Building Exhibition (IBA) 2013 focused on living with water and water-adapted buildings. The IBA took place in Hamburg-Wilhelmsburg, the core area of the 1962 flooding disaster. The exhibition presented models of how water can be integrated into new housing and how urban waterways can be used for housing. The new HafenCity district, the redevelopment of a former industrial harbor site which is claimed to be one of Europe's largest urban regeneration projects, was the first urban development outside the dike-line (Restemeyer et al., 2015). As of 2001, technical approaches were implemented that allow to live close to the water whilst still being able to react in time in the event of severe storm surges. HafenCity is an example of an urban development project in Hamburg that has attempted to replace the traditional flood management of "controlling and fighting water" with means of "adaptive flood risk governance", that is, adapting to the water through strategies such as space for the rivers and managed retreat to reduce the impact of flooding (Mees et al., 2014). There is a mix of innovative strategies: building on elevated plots with heights of +7.5 meters, elevating all infrastructures above street level to allow access during storm surges, and introducing built-in flood resistance such as flood doors and walls. Apart from these technical solutions, a clear division of responsibilities between public and private actors is an important innovation. This includes the formalization of private responsibility for flood preparation through the institutionalization of civic flood protection communities (HmbGVBl, 2002) among property owners and residents. These communities are responsible for flood prevention (financing of elevated building, flood gates, reserving the first floor for activities other than housing), timely alerting in the event of flooding, and operating mobile flood gates in case of storm surges (Mees et al., 2014).

Figure 5.2: Hamburg, Germany: Hamburg's vision of the implementation of the green roof strategy in the city center. The city of Hamburg is the first major German city to develop a comprehensive green roof strategy. The aim is to cover a total of 100 hectares in the city with green roofs. Photo: ©BUE, TH Treibhaus Landschaftsarchitektur, Luftbild Matthias Friedel.

Enabling and constraining factors

As a city-state, Hamburg has the option to pass its own laws. Within the national legislative framework, it has the power to legislate in the field of climate change. This gives the city the freedom to regulate climate adaptation according to its specific requirements. Simultaneously, it has access to federal legislative decision-making. As a federal state, Hamburg is represented in the German Federal Council, the second chamber of parliament at national level, and has the right to launch legislative initiatives.

The city's internal organization and the district structure can be seen as two-fold. On the one hand, the seven districts with their own councils serve as change agents for innovation in climate adaptation. There is some political competition between the districts' most practical solutions. On the other hand, due to the Hamburg Constitution the districts have only limited competencies and budgets that constrain their function as game changers.

Adaptation to storm surges (coastal flooding) and riverine flooding has a long tradition in the city of Hamburg. Thus, climate adaptation in the field of water exposure can build on knowledge, administrative capacity, and a cultural basis among decision-makers, stakeholders, and citizens. The pilot project RISA exemplifies this: It applied the administration's traditional competencies of water management to explore and establish a new strategic approach of water sensitive urban development with view of adapting to fluvial and pluvial floods (HSE and BUE, 2015). However, this long tradition in water or flood protection, which primarily involves making use of technical infrastructure (in particular dikes), has created a kind of path-dependency. Political strategies, administrative routines, and priorities and expectations of citizens have been locked-in on that technical, and expensive, path. This has constrained competing strategies that question the dike-strategy and are in favor of alternatives like "living with water" or "sponge city" (Zevenbergen et al., 2010; 2018). However, recent developments have shown that new approaches have been integrated into the city's adaptation strategy as a result of various impulses from within and outside the administration. For example, it can increase coping capacity if the city provides targeted subsidies for private homeowners who live in potential hazard areas (Mees et al., 2014).

Another innovation strategy can be found in special institutions such as International Building Exhibition Hamburg (IBA) and HafenCity

Hamburg (HCH). Although owned by the city, privately organized companies stand outside administrative routines, which facilitates exploring innovative solutions. Both used this freedom to establish water-sensitive building (IBA) and flood protection outside the dike line (HCH). Nevertheless, it seems to be a challenge to transfer knowledge of such specific structures into the planning and implementation routines of public administration. The reasons for this lack of mainstreaming may be competency, competition, or missing interlinkages to pass knowledge forward. In addition, institutional logics and the sector-oriented character of public agencies, including the problem of silo-budgeting, impede climate adaptation planning and its sustainable enhancement of urban resilience in Hamburg (Hanf et al., 2024, under review).

Further constraints to sustainable adaptation arise from land conflicts between housing and economic development on the one hand and climate adaptation, mainly the preservation of urban green, on the other hand. Due to high demand in the housing market, Hamburg has been pursuing an ambitious new building strategy for several years with the goal of approving 6000, and later even 10,000, housing units annually (BSW, 2021). This has put a high pressure on available land, and even protected green spaces have been mobilized for housing. Re-densification in existing housing stock from the 1950s and the 1960s seems appropriate from an urban design point of view at a first glance but can contradict water-sensitive development and further the loss of green space. Re-densification in already densely built neighborhoods has negative consequences with regard to heat exposure. In addition, re-densification, including the vertical extension of buildings, is associated with higher density urban living, which is increasingly criticized for its negative side effects on subjective well-being (Holden, 2019).

For the housing industry, the requirement for water-sensitive buildings poses the challenge of meeting affordable housing standards. The city's housing strategy has set the additional quantitative target of building at least 35% of apartments as social housing (BSW, 2021). Standards such as roof and facade greening or rainwater adaptation on the estate are often opposed as an additional burden, not only by the real estate industry but also by tenant associations who fear rising rents.

Take-home message

Hamburg is an example of a multi-level system that provides enabling and constraining factors for sustainable adaptation to climate change. Linkages between local, federal, and international responsibilities and activities must be considered crucial for successful adaptation policies. Furthermore, the nexus of adaptation and mitigation needs exploration to better use potential synergies and to avoid incompatibilities; for example, the densification of housing should be weighed against the goals of green infrastructure for water and heat adaptation. As compound events become more likely with climate change, a comprehensive and system-oriented risk assessment that considers the interactions and dynamics of various sectors of the urban system is a prerequisite for sustainable adaptation planning in Hamburg. With regard to adaptation governance, the role of different modes of governance and the instruments applied (formal, informal, networking, economic, etc.) are crucial for understanding and supporting local adaptation processes. In addition, the organizational side of local climate adaptation, for example through the interplay of classic administration and public enterprises, enriches and fosters adaptation strategies. This is important for breaking long-time path dependencies with path-breaking activities. Overall, the increasing implementation of sustainable water sensitive urban design through isolated RISA pilot projects, the exploration of co-benefits and synergies between climate adaptation and mitigation through Hamburg's green roof strategy, and the innovative strategies for adaptive flood risk governance characterized by attempts to shift from "government to governance" (Mees et al., 2014) in the HafenCity urban regeneration project are approaches with a transformative character. However, for the city of Hamburg to adapt to climate change in a sustainable way, greater attention must be given to issues of climate justice, synergies and co-benefits with other Sustainable Development Goals, and more participatory models of democracy in urban development.

5.4

São Paulo, Brazil

São Paulo is a culturally diverse, thriving megacity of historical prominence due to its economic power and regional leadership. It is often at the vanguard of social and technological developments in Brazil, a feat sometimes attributed to its industrious vocation, technical capacity, and cosmopolitan positioning. At the same time, São Paulo is a city with deeply rooted social inequalities. Economic and political interests are strongly intertwined and frequently overrule technical criteria in administrative decision-making processes (Back et al., 2022). These characteristics synthesize and explain some of the dynamics that have influenced the city's development in the past and continue to do so in the present day, especially with regard to climate change responses (Kohler et al., 2021; Schmidt et al., 2024). This case study addresses these processes and dynamics from a multidisciplinary perspective. It draws on a sociological analysis of historical events and recent empirical observations as well as on the expertise of climate adaptation experts from São Paulo. In terms of data, it builds on both new empirical research and existing literature.

Almost all (99.1%) of São Paulo's 11.45 million inhabitants live in urbanized areas that make up 60% of its 1521 km² territory (IBGE, 2022; SEADE, 2023a). The city constitutes the center of a global metropolis (São Paulo Metropolitan Region), which is composed of 39 municipalities with double the population of São Paulo and five times its territory (SEADE, 2023a). Single-handedly, São Paulo municipal's gross domestic product (GDP) represented 9.2% of Brazil's total GDP in 2021 (IBGE, 2023; SEADE, 2023b). Due to its population size and economic power, São Paulo is a global megacity of considerable influence in Latin American and international contexts.

São Paulo's wealth and influence originate from its past as an agrarian power based on coffee production and trade in the late 19th century. This status was maintained throughout the 20th century as the city transitioned into an industrial power by means of a condensed process of urbanization, industrialization, and expansion (Carlos, 2004; Francisconi, 2004). By the turn of the century, following a trend observed in other global cities, São Paulo transitioned into an economic power acting as a service and business hub: As of 2020, 83% of the city's GDP derives from the tertiary economy (SEADE, 2023b). Influenced by social processes that go back to the city's historical origins and more recent processes of accelerated industrialization and aggressive urban expansion, São Paulo's geographical space production engendered a territory with extreme levels of social inequalities, segregation, and environmental injustice (Dos Santos, 2011; Souza, 2004). Despite the city's high average human development index (0.805), this development is very unevenly distributed across its territory. A closer look at socio-economic data reveals considerable levels of inequality and segregation (PNUD, 2013; RNSP, 2022), which has important implications for climate change adaptation.

Climate, climatic change, and society in São Paulo

The city of São Paulo is located in the Brazilian southeast at 23°33'S 46°38'W at an approximate elevation of 760 m above sea level, 65 km away from the coastline (IBGE, 2010). The city has a humid subtropical climate. It is characterized by two pronounced seasons (dry winter from April to September and humid summer from October to March) with considerable daily temperature fluctuations that typically exceed the 9.7°C amplitude around the yearly average temperature of 20.4°C (IAG-USP, 2023; Rolim et al., 2007; Kottek et al., 2006). Monthly accumulated rainfall varies from a 62.8mm average during the dry winter to 214.6mm average during the wet summer, totaling a 1658.3mm yearly average (INMET, 2022).

São Paulo has historically faced important water-related challenges. The city is exposed to both floods and droughts in different seasons of the year. The water crisis experienced in São Paulo in 2014 demonstrated the importance of recognizing the political dimension of water security to develop effective strategies for climate change adaptation in any metropolitan region. In addition to the longstanding and continuous pollution of watershed regions and the inadequate management and planning of natural resources, the lack of transparency and limited opportunities for social involvement in water governance are significant factors that account for water insecurity (Jacobi et al., 2019). São Paulo has also experienced an increase in the number of days with heavy rainfall, which often leads to inundation, flooding, and landslides (Marengo et al., 2020). The stark contrast of socio-environmental living conditions ingrained in São Paulo's territory is clearly reflected in the differing levels of vulnerability to climate change impacts observed amongst its population (Roncancio and Nardocci, 2016). Extreme rainfalls frequently cause deaths in the São Paulo Macrometropolis region due to insufficient infrastructure and highly uneven risk exposure of the population (Travassos et al., 2020; see Figure 5.3).

Climate projections indicate that the state of São Paulo will have to deal with climate change in multiple ways. Projections considering the period between 2020 and 2050 were produced in 20 km resolution, using downscaling techniques through a regional model, under two different climate scenarios from four different climate models. The results were presented in terms of deviations of the future period (2020-2050) in relation to the historical period (1961-1990). All models used for both scenarios and their lower and upper limits point to a warming of the atmosphere. In the Representative Concentration Pathways (RCP) 4.5, the range of variation of the air temperature deviation, between the maximum and the minimum projected, lies between 0.5°C and 2.5°C. All models project a reduction in the duration of cold waves as well as an increase in the duration of heat waves. Regarding annual precipitation and related extreme events, there is no consensus of trend among the models (Armani et al., 2022). A trend of drier climate is also projected using indexes based on daily precipitation, which reaches annual rainfall reductions of more than 50 % in the state of Rio de Janeiro and between 40% and 45% in São Paulo and Santos (Lyra et al., 2018).

Climate change is expected to continue to aggravate environmental and urban problems and increase associated risks, especially for communities already living in vulnerable conditions (Nobre and Young, 2011; Di Giulio et al., 2018). The stronger warming projected by fine resolution simulations suggests more uncomfortable days and nights in the metropolitan area, high demand on cooling equipment, and consequently an increase in energy consumption. This scenario implies potential health risks for the poor and the elderly population (Lyra et al., 2018). In this context, the city must prepare to deal with changes in the distribution, intensity, and geographic frequency of risks related to climate events such as extreme and extended heat, extreme precipitation, which threaten to exceed its capacity to absorb losses and recover from climate-related impacts (PBMC, 2014; Nobre and Young, 2011). Already in 2023, the city faced an unprecedented heat wave with several negative consequences for human health (Valverde and Rosa, 2023).

Figure 5.3: São Paulo, Brazil: Torrential rainfall event within a short period of time on 5th March 2024 caused waves and led to the severe flooding under the Minhocão Viaduct in the city center of São Paulo, Brazil. Photo: Mathilde Missioneiro/FolhaPress.

Climate change responses

São Paulo's engagement with climate action agendas dates back to the mid-2000s. In an effort to foster cooperation between cities, local and regional governments on climate and urban governance, the city had joined several networks, including the United Cities and Local Governments (UCLG) in 2004, the global network Local Governments for Sustainability (ICLEI) as well as the C40 Cities in 2005, and, more recently, the Urban 20 (U20) in 2017 (for more details on how such transnational initiatives affect climate action, see Section 3.3). Since then, several climate action initiatives have been enabled or carried out in São Paulo and other Brazilian municipalities with technical and financial support obtained from these cooperation networks (Setzer et al., 2015). In São Paulo, examples of relevant initiatives include the elaboration of emissions inventories (D'Almeida Martis and Ferreira, 2011) and, more recently, the launch of São Paulo's Municipal Climate Action Plan 2020-2050 (Municipality of São Paulo, 2020a). Debates have been raised about the overall net effect of these external influences of global networks on local climate change adaptation (Setzer, 2009; Barbi and Macedo, 2019), but, regardless if positive or negative, São Paulo's role in constituting the cooperation networks is a testament to how the city's global reach and influence could be leveraged to promote climate change adaptation. The municipality of São Paulo promulgated its Climate Change Policy law in 2009, six months before the federal government and four months before the state government, becoming the first Brazilian city to have a specific law addressing climate change (Brazil, 2009; State of São Paulo, 2009; Municipality of São Paulo, 2009). This law committed São Paulo to the United Nations Framework Convention on Climate Change (UNFCCC) goals, with a focus on promoting climate change mitigation to secure food production and sustainable economic development (Municipality of São Paulo, 2009). In fact, the city established no measurable goal for adaptation and only one explicit goal for mitigation, which relates to greenhouse gas emissions, namely reducing emissions from the public transport sector by 10% each year from 2009 to 2018 (Municipality of São Paulo, 2009, ex.: art. 50). The law's climate change mitigation and adaptation directives and strategies have broad scopes and generic goals (Municipality of São Paulo, 2009, ex.: art. 12), and they depend on complementary legislation (Municipality of São Paulo, 2009, ex.: art. 14, 15 and 21). São Paulo's Climate Change Policy law also establishes either unspecified shared responsibilities between public administration, private initiative, and civil society for their implementation (Municipality of São Paulo, 2009, ex.: art 19 and 20) or ties climate action directives to economic gains (Municipality of São Paulo, 2009, ex.: art. 18, items III and IV). The law also consolidates the existence of the Municipal Committee on Climate Change and Eco-Economy, a collegiate organization founded with the aim of uniting several social agents to propose, stimulate, and supervise the implementation of the municipalitýs climate change-related laws, plans, programs, and actions (Di Giulio et al., 2018). However, this committee has only an advisory role, without direct means of interfering in the municipalitýs decision-making processes, which could limit its effectiveness.

Between 2010 and 2020, São Paulo steadily elaborated on its climate change mitigation agenda, mainly focusing on reducing transport and mobility related emissions. In 2018, the former municipal Climate Change Policy law (2009) was replaced by a new one, which has weakened the city's only measurable climate mitigation goal by postponing the emissions reductions deadline by two decades (Municipality of São Paulo, 2018). The adaptation agenda had a different, even more troubled trajectory (Di Giulio et al., 2018). In 2011, through a collaborative effort involving technical personnel from the Green and Environment Municipal Secretariat and non-state actors from the Municipal Committee on Climate Change and Eco-economy, the generic climate mitigation and adaptation strategies outlined in the city's Climate Change Policy were transformed into sector-specific proposals. These proposals were subsequently published as Directives for the Action Plan Towards Climate Change Mitigation and Adaptation in the city of São Paulo (Municipality of São Paulo, 2011). This document later served as a foundational stone for the expansion and improvement of the collaboration between technical branches of the municipality and non-state actors in the development of São Paulo's climate action plan, a two-year endeavor that began in 2018 out of a commitment established with the C40 Cities network and Local Governments for Sustainability (ICLEI). The initiative resulted in the launch of São Paulo's Municipal Climate Action Plan 2020-2050 (Municipality of São Paulo, 2020a). Although this remained the municipality's key action plan dedicated to both climate change mitigation and adaptation, other sectoral action plans that might benefit climate adaptation have been developed during the same period by the municipalitýs technical branches without taking adaptation needs into account. Examples range from the Municipal Atlantic Rainforest Plan to protect green areas (PMMA; see Municipality of São Paulo, 2017) to the Urban Mobility Plan (PlanMob; see Municipality of São Paulo, 2015), which the latter provides incentives for installing bike lanes, bicycle parking spots, roads with some priority for public transport, and exclusive bus lanes (Di Giulio et al., 2019). While the Municipal Atlantic Rainforest Plan may contribute to the reforestation and restoration of ecosystems that deliver multiple services which help to reduce climate change exposures and potentially delivers a set of economic, social, and environmental co-benefits that go beyond climate adaptation (e.g., reducing urban heat and flooding), the PlanMob helps to promote a low-carbon and a more inclusive and diversified transportation system.

São Paulo's Green and Environment Municipal Secretariat led or coordinated several technical studies that resulted in the publication of action plans mostly focused on biodiversity protection and the management of green areas (recovery, implementation, maintenance, protection, and conservation) or on overall and strategic improvement of urban greening. These include, besides the Municipal Atlantic Rainforest Plan, the Municipal Plan on Recovery and Conservation and Recovery of Environmental Services Providing Areas (PMSA; Municipality of São Paulo, 2020b), the Municipal Plan on Green Areas and Free Spaces (PLANPAVEL; see Municipality of São Paulo, 2022), and the Municipal Plan on Urban Arborization (PMAU; see Municipality of São Paulo, 2017; 2020b; 2022; 2020c). Although these initiatives might indicate important efforts that try to connect adaptation to sustainability, improving the well-being of human subjects and ecosystems, they are not directly tied to the climate adaptation discourse, indicating that there is still a local government hesitancy to use the term climate change and a resistance to accept and internalize climate issues in many local decisions (Di Giulio et al., 2017).

In 2010, São Paulo's Subprefecture Coordination Municipal Secretariat partnered with the Technological Research Institute (IPT) to update and extend the city's previous geological risk areas mapping, which dated back to 2005. Since 2018, this has continuously been updated by the Urban Safety Municipal Secretariat (Municipality of São Paulo, 2023). In 2011, the Earth System Science Centre of the Brazilian National Institute of Space Research (INPE), along with the Population Studies Center of the State University of Campinas, published the report Brazilian Megacities' Vulnerability to Climate Change: São Paulo's Metropolitan Region. The report indicates that around 20% of São Paulo's Metropolitan Region would be exposed to rain-related weather risks due to climate change by 2030 (Nobre and Young, 2011). In 2013, the Municipal Civil Defense Coordination started developing a yearly preventive action plan to reduce flooding during São Paulo's wet season, publicized as Summer Rain Prevention Plan (Morais, 2019).

While these developments indicate advancements in climate change adaptation initiatives in some fields of urban planning in the form of guidelines and intentions, most of the initiatives were strictly technical, carried out by technical branches of the municipality in cooperation with non-state actors, such as academics and civil society representatives, and supported by cooperation networks or foreign governments (Di Giulio et al., 2018; 2019). The difficulties arise in the process of implementation, when the initiatives are exposed to divergent political agendas, choices, and priorities. Considering that part of the technical branches of the municipality consist of politically appointed staff members, planning or implementation processes depend on the composition of the municipal government and are thus often exposed to discontinuity, instability, and also to lobbying by economic interest groups.

Throughout the past decades, changes in the municipality's elected officials often led to changes in appointed positions within the municipality's departments and secretariats, many of which bear decision-making or managerial responsibilities, thus compromising the continuity of planned actions. One of the major impacts observed was the Climate Change Executive Secretariat starting in June 2021, linked directly to the Mayor's office, with the aim of implementing the São Paulo's Municipal Climate Action Plan 2020-2050 (Municipality of São Paulo, 2020a). While predominantly composed of nominated positions, and thus more exposed to political interests, for the first two years this new Executive Secretariat took over most of the climate change-related responsibilities led by the Green and Environment Municipal Secretariat, a department composed predominantly by technical career professionals that had led several multi-secretariat initiatives with positive outcomes. However, upon the publication of the first PlanClima SP monitoring report in 2021 by the Climate Change Executive Secretariat, the effects of this change have not been clear, as the report does not provide much clarification on the progress achieved toward the attainment of the planned goals.

Another aspect that severely constrains sustainable climate change adaptation in São Paulo is the reliance of its Climate Change Policy on complementary sectoral legislation, such as the city's executive master plan, land use law, and building code (Municipality of São Paulo, 2014; 2016). While both pieces of legislation were revised in the years that followed the promulgation of the Climate Change Policy in 2009 in ways that included the consideration for climate change mitigation and adaptation amongst their directives and strategies, these inclusions are no more than general recommendations with no practical effect. Meanwhile, other aspects of both laws were revised and have fostered urban expansion and verticalization in ways that catered to the lobbies of private investors, real estate agents, and the construction industry, mostly based on grey infrastructure (i.e., carbon-intensive infrastructures based on traditional engineering approaches) with considerable negative effects to the quality of the urban environment and of climate change adaptation goals (Back et al., 2021; 2022). These alterations sparked the outcry of scholars and civil society actors such as environmentalists, neighborhood associations, and housing rights movements, resulting in a legal dispute that halted the law's approval and is still ongoing (Back et al., 2022).

Enabling and constraining factors

São Paulo is a megacity with the potential of playing a leading role in regional and global climate governance. However, the implementation of climate change adaptation measures is lagging far behind, despite the engagement of the city with different collaboration networks for climate action as well as the accumulated experiences in dealing with extreme weather events and climate-related risks and vulnerabilities and the support of civil society actors, scholars, and strong scientific institutions for ambitious climate action. Empirical studies point out that the perception that cities and individuals are at a greater risk of damage in the future is one of the main motivations for initiating adaptation planning and implementation at the local level (Ryan, 2015; Runhaar et al., 2018; Di Giulio et al., 2019). In the case of São Paulo, a recent empirical research project conducted by Rede Nossa São Paulo (2022) indicated that most of the interviewees who live in the city are very concerned about climate change and that 75% of them believe that climate change highly affects their quality of life. A recent assessment of cities' readiness to deal with climate change in the state of São Paulo concluded that the city of São Paulo has a comparatively high institutional adaptive capacity (Neder et al., 2021). However, there are key social dynamics inhibiting the design and implementation of adaptation strategies in São Paulo. In particular, unstable political dynamics at national, state, and local scales, high social inequalities, and the lack of political support for climate action and sustainability transformations constitute fundamental barriers for transformative strategies and sustainable climate change adaptation in the city and its metropolitan region. The observed adaptation measures implemented so far relate mostly to planning and networking, while the implementation and concrete action remain insufficient. This is mostly driven by political constraints and economic pressure as well as by lobbying efforts of powerful societal actors, in particular from the construction and real estate sectors (Calderon, 2022; Jacobi and Trani, 2019). Despite the existence of projects promoting the diffusion of knowledge on transformative pathways to urban sustainability and climate change adaptation (Moreira et al., 2022), the incremental changes that have been observed rather relate to climate change mitigation only (e.g., incentives for mobility shifts through the wide implementation of bus and bike lanes). Besides, in order to generate more sophisticated indicators than the crude, generalized ones currently used for the entire city, which neglect the high spatial and socio-economic disparities within the megacity, it is imperative to look closer at the significant inequalities among the 96 districts in São Paulo, to cross different layers of spatialized data, and to fuse socio-economic data with remote sensing and GIS data. Linking remote sensing and GIS data with city life at neighborhood and street scale, in the sense that the US National Research Council (1998) envisaged for a "people and pixels" perspective, would show a very different picture than the general official data currently offers as an average for the entire city (see also the discussion of the influence of grid size to simulate local precipitation extremes in Section 4.3).

By now, the city is mostly coping with extreme weather events and climate-related impacts rather than elaborating and implementing adaptation measures that could provide synergies between sustainability goals. These would include side-benefits such as improved housing and living conditions, supporting initiatives for review of regulations and technical standards for buildings and urban planning and design with a view to promoting resilient urban infrastructure, ensuring conveniently-located housing for low-income families living in situations of vulnerability. Hence, in light of the implementation gaps and political conflicts, sustainable climate change adaptation in São Paulo is currently not plausible. To become plausible, the very first step is the elaboration and implementation of a climate change adaptation plan that establishes clear actionable indicators, measurements, and responsibilities for their implementation as well as mechanisms for monitoring and evaluating established goals and targets. Moreover, land planning and the governance of water resources need to be integrated with land-use regulation, building codes, and transportation infrastructure plans, all of which requires a new level of coordination across sectors and policy levels.

Take-home message

São Paulo demonstrates a clear mismatch between the city's engagement with climate action initiatives at different scales of governance. At the global and regional scales, São Paulo plays a leading role in transnational initiatives for climate action, and the city is a pioneer in Brazil in terms of law-making and adaptation planning. However, when it comes to climate action at the local scale, there are remarkable implementation gaps, especially in terms of climate change adaptation. Engaging in transnational initiatives for climate action and establishing climate change policies, laws, and adaptation plans are crucial steps toward sustainable climate change adaptation. For São Paulo, overcoming persistent political conflicts, social inequalities, and other structural challenges at the local scale are key, inasmuch as they fundamentally hinder the implementation of climate change adaptation measures. The local government in power and its political agenda have a substantial influence on the implementation of climate adaptation measures (or lack thereof). In particular, the numerous political changes in the local administration in São Paulo, along with the lack of clarity with regard to responsibilities, results in an important mismatch of adaptive capacities and local climate vulnerabilities. There is an enormous need (but maybe also potential) for societal mobilization and the co-production of knowledge for sustainable climate change adaptation, drawing on the historical, accumulated experiences in dealing with extreme weather events and climate-related risks and vulnerabilities.

5.5

Ho Chi Minh City, Vietnam

Ho Chi Minh City, formerly Saigon, is Vietnam's biggest, most globalized city and the most important economic hub of this dynamically developing emerging country. Located on the northeastern edge of the Mekong Delta within a zone of tropical monsoon climate, the metropolis is the engine of social and economic change in the country and contributes about a quarter of Vietnam's GDP. Per capita income is about 1.5 times higher than the national average (GSO, 2023). Due to the economic boom, the spatial metropolitan growth has transgressed its administrative boundaries, so that an urban agglomeration with more than 10 million inhabitants has emerged. Ho Chi Minh City can thus be described as Vietnam's first megacity (Waibel, 2013).

The administration of Ho Chi Minh City struggles with the difficulties a megacity in an emerging country typically faces (Waibel, 2016). The planning authorities are overwhelmed by the high dynamics of population growth, for example. This is, among other things, related to the massive immigration from the other provinces. In the near future, Ho Chi Minh City is also expected to receive a huge influx of climate change refugees coming from the increasingly flood-prone adjacent Mekong Delta (Saunders, 2023). Like many other megacities in the region, the metropolis also suffers from massive environmental problems, such as rising air pollution, chiefly due a tremendous increase of car-related traffic. In addition, major infrastructure projects, be it sewer rehabilitation, bridge, airport, or subway construction, can usually only be carried out with the help of foreign investors such as the World Bank or the Japanese Development Bank (Waibel, 2019). This ongoing dependency on foreign donor organizations with specific (often parallel, but sometimes diverging) interests limits effective implementation – also in the case of municipal climate change adaptation (Waibel, 2016).

Climate, climatic change, and society in Ho Chi Minh City

Ho Chi Minh City is considered one of the 10 major cities in the world most affected by global climate change (ADB, 2010). First of all, this is simply due to its topography. Almost half of the city area is no more than 0.5 m above sea level (Waibel, 2019). Therefore, the city's main challenge is its vulnerability to urban flooding (Scheiber et al., 2023), particularly in the case of heavy rainfall in combination with high tidal events. A third of the metropolis is already now affected by regular flood events. The situation will get worse because the rate of extreme rainfall events is expected to increase in the future (An, 2021). It is predicted that by 2070, Ho Chi Minh City will have about 9.2 million people directly exposed to the impacts of climate change (such as floods, sea level rise, rain, storms, etc.), with estimated accumulated losses of about USD 650 billion (An, 2021).

However, the flooding within the settlement body of the metropolis is currently less directly attributable to global climate change than to deficits in urban planning: The growth of settlement areas in the course of urban spatial expansion in low-lying marshlands led to former wetlands being filled and transformed into new urban development areas such as Phu My Hung or Thu Thiem (Waibel, 2016) (see Figure 5.4). This resulted in an enormous loss of open and green spaces. With this area sealing, substantial retention areas got lost, leading to urban flooding in case of heavy rains that overload the inadequate drainage system.

Wide-spread land submersion is further aggravating the flooding issue: Like in other cities of the region such as Jakarta or Bangkok, the increasing building mass is pressing upon the soft alluvial sediments of the city surface, leading to land submersion of several centimeters per year in some areas, a process which is further exacerbated by groundwater extraction (Waibel, 2019). One means to fight land submersion and so to decrease the flooding risk at a building site would be the elevation of its land by sand. At this juncture, this is indeed a frequent adaptation practice. However, due to excessive sand extraction in the past and rising erosion, there is now a serious lack of sand (Anh, 2023). The lack of sand combined with rising sea levels also increases the issue of increasing salinization of the ground and the groundwater, threatening the water supply of the urban population.

Another serious problem is the increase of heat stress for the urban population. As a consequence of climate change, the heat will also last longer during the dry season. This particularly affects the densely populated and often informally built urban areas without green spaces. There, due to increasing surface sealing and the associated change in albedo, more solar radiation is converted into heat. Urban heat islands are forming, which are being intensified by the increasing use of energy-intensive air conditioning systems. Their growing use is also a consequence of changing demands of thermal comfort among the rapidly emerging urban middle class with increasingly resource-intensive lifestyles (Waibel, 2009). Heat stress seriously endangers the health of the most vulnerable urban populations (i.e., young and old people) (Katzschner and Burghardt, 2015), with thousands of heat deaths currently being reported in Ho Chi Minh City each year (Nguyen and Waibel, 2021).

As a result, it can be said that the increasing threats of global climate change intertwine with the effects of unsustainable urban development, all of which impose multiple serious problems onto policy makers.

Figure 5.4: Ho Chi Minh City, Vietnam: Aerial view of the highly vulnerable Thu Thiem new urban area opposite the Central Business District of Ho Chi Minh City, Vietnam. Photo: Michael Waibel.

Climate change responses

Following the national framework on environmental and climate change actions, especially the "National Climate Change Adaptation Plan (CCAP) for 2021-2030, vision to 2050" and the Vietnam Law of Planning No. 21. 2017.QH14 (promulgated in 2017), the municipal government issued its own "Climate Change Adaptation Plan 2021-2030 (CCAP-HCMC), vision to 2050" in 2021. The CCAP-HCMC is considered a joint umbrella for various actions dealing with climate change adaptation in the city. According to a leading representative of a local think tank, this plan will also guide the "Ho Chi Minh City Spatial Plan (Master Plan) to 2040, vision to 2060". This CCAP-HCMC will be integrated from 54 sectoral development plans, including economic, technical, and social infrastructure development plans as well as 23 territorial development plans (one each for the 23 administrative units of Ho Chi Minh City).

In this context, the municipal government has assigned the Department of Natural Resources and Environment (DoNRE) to assume prime responsibility and to coordinate with relevant departments and agencies in synthesizing information with a view of building and publishing updates on the progress of the CCAP-HCMC. DoNRE also holds the leading position of the so-called City Climate Change Steering Committee for implementing the Climate Change Adaptation Action Plan, a cross-departmental board that is regularly updating information to the public by means of a bulletin (HCMC Department of Planning and Architecture, 2016).

Specifically, the municipal government aims to strengthen resilience to reduce climate-related risks such as drought, heat, heavy rain, and sea level rise; and to improve natural disaster risk prevention, conservation biodiversity, food security, social security, healthy communities, and sustainable development (HCMC People Committee, 2021a).

Key sectors targeted in the CCAP-HCMC include urban planning, agriculture, energy, and, in the field of industry, commerce, construction, transportation, tourism, and land and water resources. The CCAP-HCMC defines key tasks and lists of potential initiatives for each sector including, for example, climate change impact evaluation, capacity building in the field of public management, public awareness raising, digitalization, etc. (HCMC People Committee, 2021b; Luu, 2023).

Enabling and constraining factors

The suggested measures for Ho Chi Minh City are mostly very ambitious, but it is not always clear where the funding to implement these plans could come from. Also, it can be criticized that there was a strong focus on expensive structural adaptation measures, such as the construction of the ring dike, of multiple flood gates, and of pumping stations instead of soft adaptation measures such as blue-green infrastructure solutions (ADB, 2010; C40 Cities Climate Leadership Group, 2016; Scheiber et al., 2023).

Another point to criticize is that there is a lack of specific and measurable targets even though the CCAP-HCMC contains specific goals, which are mostly of qualitative nature. It also contains no indicator system to monitor and evaluate the progress achieved. The role and responsibilities of the public sector, which should, among other things, lead efforts to achieve replication effects among urban citizens, for example in the field of green (public) buildings, is not clearly defined, either. Furthermore, the whole action program contains no specific gender component although women have been specifically identified as a highly vulnerable group (Hagedoorn et al., 2021; Hong and Downes, 2023).

Further challenges remain on questions such as:

- How to develop specific policies, legislation, and regulations that create favorable conditions for the implementation of adaptation projects and activities?
- How to increase the low general awareness among urban citizens about the municipal Climate Change Action Plan, which is regarded as a prerequisite for more civil engagement and for behavior change toward more sustainability?
- How to increase capacity with regards to the mainstreaming of climate change adaptive urban planning, the lack of which is a major reason for wide-spread gaps between plans and reality?

Past adaptation strategies have mainly focused on large projects with the aim to reduce hazard exposure, meaning that (too) much investments have gone into hard infrastructure such as dikes, sluice gates, and seawalls (ADB, 2010; UNRISD, 2019). In contrast, measures to promote blue-green infrastructure solutions making use of ecosystem-based services have only recently become part of the public planning discourse. As of now, there are only limited knowledge and skills in the field of nature-based solutions in Vietnam, especially when it comes to multi-sectoral planning (Lan et al., 2023).

Given the foreseeable lack of sand, which is needed for the construction of hard infrastructure, and the huge spatial dimensions of climate change affected areas within the whole megacity region, the implementation of blue-green infrastructure solutions is regarded as the most promising, resource-efficient, and cost-effective option of climate change adaptation.

A good-practice example of this is the recent construction of the Phu Xuan wetland park as a soft adaptation measure in the suburban district of Nha Be, characterized by many natural rivers and canals. The park was designed to preserve the existing 4600 m^2 water coconut tree area and even to extend it by approximately 3000 m^2. Besides its function to store rainwater temporarily, Phu Xuan Park provides attractive spaces for leisure activities. In this way the park is following the sponge-city concept. As a nature-based solution, it further serves as a demonstration project for soft climate change adaption in Ho Chi Minh City (HCMC Party Committee, 2022).

Evidently, the various challenges of climate change adaptation and sustainable urban development in Ho Chi Minh City require multiple measures from all levels of the government, but have to engage the private sector and urban citizens, too, if only to decrease the mismatches between state and non-state adaptation action (Garschagen et al., 2015).

It has become clear that climate change adaptation measures cannot be treated as separate from measures of sustainable urban development. While climate change adaptive capacity in urban planning needs to increase (Eckert and Waibel, 2009), it is also obvious that mainstreaming climate change adaptation into the local spatial planning systems can only be one component of adapting to climate change in a sustainable manner.

Successful sustainable climate change adaptation in Vietnam requires more crosscutting integrative transformative planning with less focus on expensive hard adaptation measures but more promotion of ecosystem based services. A very promising concrete countermeasure would be the creation of blue-green infrastructures, as shown in the good-practice example of Phu Xuan wetland park. Also, the potential of other decentralized rainwater detention solutions such as green roofs with multiple other sustainability benefits has not been fully exploited yet (Nguyen and Waibel, 2022).

In general, a shift in local planning culture, where it is more understood as a continuous multiple stakeholder dialogue and joint learning experience, is crucial. This would also support the (re-)gaining of trust of urban citizens and their local decision-makers as a precondition of a comprehensive transformation.

From the policy side, an increasingly integrated approach of regulations and decrees with (economic) incentives as well as the implementation of more participatory learning tools could foster the implementation of adaptation projects and signify a shift away from top-down-style authoritarian planning (Waibel, 2014; Schwede et al., 2016).

More such transformative adaptation approaches would involve a fundamental change going beyond technical solutions to reduce hazard exposure and address processes and structures that exacerbate vulnerabilities. In this way, transformative adaptation requires more process-orientated, co-constructive, and cooperative approaches as well as the development of inclusive people-led visions for the future (UNRISD, 2019). However, given the authoritarian political environment in Vietnam, its further implementation will remain a challenge.

From a governance perspective, the process of developing a municipal or urban district climate change adaptation plan could already become a transition-management instrument in itself. This could happen by communicating the progress of the action plan to the public in a transparent way during the whole process and by involving multiple stakeholders. Despite potentially being more time-consuming, such a procedure would surely increase civic engagement of the involved parties, support the development of action knowledge, potentially identify funding sources, and consequently increase the plausibility of much needed implementation on the ground.

Take-home message

Ho Chi Minh City is considered one of the world's most vulnerable cities to climate change impacts (Katzschner et al., 2016). Measures of sustainable climate change adaptation must go hand in hand with measures of sustainable urban development to tackle the multiple intertwined challenges. Successful sustainable climate change adaptation requires more crosscutting integrated planning as part of a wider process-orientated transformative adaptation process. A stronger involvement of the urban citizens, which goes beyond the mere raising of awareness, is regarded as essential to enhance private engagement and to close existing implementation gaps.

5.6

Rural Areas of Northeast Lower Saxony, Germany

This case study analyzes climate change adaptation in the rural northeast areas of Germany's federal state of Lower Saxony. Agricultural and forest enterprises are important economic sectors here and occupy about 50% and 25% of the area, respectively. More than half of the irrigated agricultural land in Germany is located in Lower Saxony, and two-thirds of it are located in the northeast region (Ostermann, 2019). Agricultural farms cultivate mostly grains, maize, potatoes, and sugar beets. Grassland use is generally limited to valley floodplains and lowland moorland sites, as well as dry hillsides. Without human intervention, oak and beech forests would dominate the landscape. Today, the region is predominantly characterized by managed forests in which the proportion of conifers was increased to facilitate renewable material production.

Climate, climatic change, and society in Lower Saxony

The region's temperate climate is located at the transition between the Atlantic and continental climate zones. Typical years receive between 550 mm and 750 mm of precipitation. Podzols, Cambisols, and occasionally Arenosols are formed on sandy substrates of different geological origin (Holocene and Pleistocene). The depressions and floodplains on Holocene sediment are dominated by Fluvisols, Gleysols, or bogs (Heger et al., 2021; Vásconez Navas et al., 2023a). The predominantly sandy soils have a low water capacity of less than 50 mm in the effective root zone (Schickhoff and Eschenbach, 2018). If plant-available water falls below 30–40% of the field capacity, plant growth is severely limited. This was evident during an unusually strong drought in 2018, which reduced crop yields in Northern Germany by 26% (BMEL, 2022) and caused financial losses to German farmers of EUR 770 million (BMEL, 2022). In forestry, severe storms during the springs of 2018 and 2022 combined with extreme drought and high summer temperatures in 2018–2020 and 2022 significantly damaged tree health. To date, 245 million solid cubic meters of calamity wood have been recorded for the period between 2018 and 2022. Over 20% of the spruce stock identified nationwide in the 2012 Federal Forest Inventory has accrued as unscheduled calamity wood. The forest area to be reforested is over 450,000 hectares in size (BMEL, 2023).

Climate projections for the region show temperature increases between 1°C (RCP 2.6) and 3.3°C

(RCP 8.5) by the end of the century compared to the 1978–2018 period. Under the RCP 8.5 projection, there will be more precipitation in fall, winter, and spring, but a decrease in summer precipitation. The associated increase in evapotranspiration can result in a net water deficit during the growing season from April to August (Valencia Cotera et al., 2022). Climate change, in particular the increase in drought during the summer months, is likely to reduce the vitality of trees and increase mortality. A reduced biomass growth also lowers carbon sequestration rates. Studies in hardwood floodplain forests of the river Elbe showed that soil organic carbon levels varied between 99 and 149 tonnes per hectar and that they are strongly controlled by the hydrologic situation of the floodplain (Heger et al., 2021). Sap flow measurements of oaks and elms in hardwood floodplain soils, which reflect a high spatial and temporal variability of water availability, revealed notable differences between tree species in reaction to drought (Vásconez Navas et al., 2023b). Disturbances due to drought are often the starting point for further damage, especially bark beetle infestation (Bayerisches Staatsministerium für Ernährung und Forsten, 2023; Senf et al., 2017; Senf et al., 2020). It was shown that future extreme events will negatively affect the resilience and survivability not only of spruce, but also of beech, oak, and pine, and consequently large-scale removals for these tree species can be expected as well (Martes et al., in print).

Figure 5.5: Lower Saxony, Germany: Irrigation of potato plants as a coping measure against drought conditions in Lower Saxony. Photo: Angela Riedel, LWK Niedersachsen.

Farming and forest enterprises in the northeastern region of Lower Saxony are severely influenced by policies and societal developments. Relevant policies include the EU's Common Agricultural Policy, environmental policies for nature and biodiversity preservation, fertilizer regulations, regulations to foster the transition to renewable energy, and the German National Climate Action Plan (Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, 2016). While governmental subsidies are essential to sustain agricultural businesses, they pose severe restrictions on farming and require detailed business reports. In recent decades, increasingly tight restrictions have led to farmers' protests against fertilizer and wildlife regulations as well as other policies. Public debates have raised awareness of climate change and environmental impacts of agricultural and forest systems among a broader public in Germany (Feindt et al., 2019). Increased concerns about healthy food, animal welfare, and the environment stand in opposition to the efforts for financial profitability of production, income security, and affordable consumer prices (Dannenberg and Follmann, 2023). The continuing globalization and immense political influence of European (e.g., EU agricultural subsidies) and national policies (e.g., energy transition) have fundamentally changed the agricultural sector in Germany in recent decades (Dannenberg and Follmann, 2023).

Climate change responses

Adaptation to climate change includes short-term and long-term adjustments of different magnitudes, many of which are already being made by some farmers (Wiedergrün, 2022). Short-term measures help to cope with the acute impacts of droughts and other extreme events. For arable farms in this case study's region, acute coping measures against droughts consist of irrigation (see Figure 5.5) and adjustments of planting and harvesting dates. Mobile irrigation systems may be used on farms where other irrigation infrastructure is lacking. In dry years, farmers may skip the planting of a catch crop (Wiedergrün, 2022). Incremental adaptation options include improving soil fertility and water storage capacity, cultivation of better-suited crop varieties and crops, redesigned crop rotations, and investment in irrigation infrastructure (Valencia Cotera et al., 2022). Soybean, for example, is seen as a possible new crop for northern Germany under a warming climate regime. Soybeans combine drought tolerance, nitrogen fixation, and soil carbon improvements. Increased domestic cultivation of soybeans in Germany would also lower demands for imports from environmentally sensitive regions such as Brazil. So far, soybean yields in experimental trials in Lower Saxony are still too low to financially compete with wheat or corn (Schreuder and Visser, 2014). The decision on crop changes depends also on the possibilities to integrate a certain product—crop and livestock—into the entire production system (e.g., as fodder for own cattle) of the whole farm as well as on the technical equipment and manpower available (Wiedergrün, 2022).

Agricultural adaptation options also include transformative adaptations. These constitute fundamental changes to the farming system, such as the adoption of organic farming or precision agriculture, or the implementation of novel agro-environmental monitoring systems. The change from conventional to organic farming can improve agroecological impacts, food quality, and soil fertility, and, to some degree, resilience against unfavorable weather events (Gomiero et al., 2011; Lorenz and Lal, 2016; Lotter et al., 2003). These benefits need to compensate investment costs for new equipment, training efforts, and increased cost of plant control. Somewhat similarly, precision agriculture supports resource friendly land management but comes at high investment cost. Combining geographic information with machine sensors can optimize fertilizer applications, plant control measures, and reduce the environmental burden of nutrient emissions (Grunwald and Böhner, 2022; Wendland et al., 2023). Novel monitoring systems for agro-environmental services and disservices would employ state-of-the-art scientific simulation models to quantify detailed environmental impacts of farms (Schneider et al., 2019). Very high measurement costs of non-point source emissions could be avoided and replaced by model estimations. The accounting of environmental impacts would take place on a protected server, to which farmers could link their bookkeeping software. Participating farmers would benefit financially and through decision support but would have to disclose detailed land management data at farm level. Non-participating farmers would be subjected to a less favorable default accounting of environmental impacts. Such transformative adaptations are often linked to a generation change in farm leadership and the more progressive production philosophy of the new farm leader.

Future climate change makes it essential for forest enterprises to adapt to changing site conditions. Various adaptation options are being discussed. Nature conservation circles favor process conservation. This involves reducing human intervention to a minimum and relying on nature's self-healing capacity (Geyer et al., 2017). This approach can lead to forests entering a decay phase, which can lead to the entire forest ecosystem's collapse (Burschel and Huss, 2003; Otto, 1994). Examples of this can be found in the Harz National Park. Other approaches emphasize adaptive forest management. Here, silvicultural measures and the cultivation of climate-adapted tree species or provenances are recommended to adapt forests to changing environmental conditions (Högberg et al., 2023; Kauppi et al., 2022). Another issue concerns the role of forests as carbon sinks on the path to climate neutrality. Forests are a significant sink for atmospheric CO_2. The question of how to deal with the carbon pools of forests is discussed contradictorily. It is frequently advocated to refrain from wood utilization with the aim of preserving these carbon pools. The decisive factor here is the permanence of carbon storage. Another view on the matter highlights the carbon sequestration capacity rather than the level of carbon storage of forests. Nagel et al. (2023) studied beech stands that have not been managed for over 100 years. These stands have a similar total carbon pool as such stands that have not been managed for only 50 years, but they contain significantly larger amounts of deadwood and less living biomass. Better management of existing forests can improve forest growth and help mitigate climate change by increasing the forest carbon sequestration rates and by storing carbon in wood-based materials, substituting fossil carbon-based materials or other CO_2-emission-intensive materials. Martes and Köhl (2022) showed for the Metropolitan area of Hamburg that managing forests and harvesting timber actually leads to higher carbon offsets than the full conservation of timber.

Enabling and constraining factors

Ultimately, adaptation of agricultural and forest enterprises in the northeast of Lower Saxony is in the farmers' and foresters' own interest. Dialogues with land owners confirmed their genuine interest to maintain or improve soil fertility, keep forestry viable, and produce commodities in an environmentally friendly way (Jantke et al., 2020; Valencia Cotera et al., 2022; Wiedergrün, 2022). Interviews with farmers also revealed a general awareness of climate change, as manifested in changing precipitation patterns and increasing temperatures, leading to shorter and warmer winters and hotter summers. However, while many stakeholders acknowledged CO_2 as important determinant for climate change, they did not fully link droughts to climate change. Almost all farmers underlined the importance of soil organic matter for water and nutrient holding capacities, resilience to droughts, and crop yields. Land owners also emphasized that adaptation requires adequate resources, reliable decision support tools, and stable prospects to achieve economic viability. Livestock operations (cattle, pigs, horses) in Lower Saxony increasingly experience labor shortage, a situation that seems less problematic for machinery-intensive arable farms. Stronger competition for suitable farmland and increasing land use restrictions due to environmental policies reduce the scope of adaptation opportunities, especially for smaller enterprises. Forest systems, on the other hand, are particularly constrained by their long-time horizon and the uncertainty of future climate and environmental conditions. Adaptation to climate change requires various enabling conditions, such as the choice of tree species, shorter rotation periods, or preserving the canopy closure. All investments in a new land use technology or a new enterprise system require planning security for several decades. With frequently changing regulations, investment benefits will be uncertain and less attractive.

Agricultural stakeholders also expressed their views on governmental regulations and the public image of farmers within society. While financial subsidies are still vital for commercial survival, many farmers would prefer not to depend on them. Governmental regulations are often perceived as a threat for business rather than a support. Regulations change frequently and have become increasingly bureaucratic. The governmental aid offered after the 2018 drought was perceived as both too small and too slow. To make matters worse, these ineffective payments amplified an already negative public image of subsidy-dependent farmers. Farmers feel unfairly treated in the media, which, in their view, are overly critical of agricultural businesses for their alleged negative climate impacts, but hardly acknowledge the challenges of agricultural production in highly industrialized countries. Farmers also shared some frustration about the typical consumer who demands more environmentally friendly products but does not want to pay a higher price.

Take-home message

Climate change in northeastern Lower Saxony is likely to increase dry periods during the summer months. Storms may also intensify; however, there is less scientific agreement on the extent of this change. Efficient and effective adaptations to these impacts in agricultural and forestry systems imply changes beyond coping and incremental measures. However, in deciding adaptations, stakeholders must consider many business interests as well. Uncertainties and information deficits, lack of trust in policy, and a hard break with many business habits are currently major hurdles to transformative adaptation.

5.7

Rural Communities in Nepalese Highlands, Nepal

Nepal is highly exposed to climate change impacts such as glacial lake outbursts, droughts, floods, and landslides because of its geographical fragility and altitudinal variations from lowlands to high mountains. The combination of extreme orography, fragile ecosystems, impoverished socio-economic conditions, and limited adaptive capacity has rendered Nepal one of the most vulnerable countries to the impacts of climate change (Chaudhary and Aryal, 2009; Eckstein et al., 2021). The Germanwatch Long-Term Climate Risk Index 2021 identified the country as one of the 10 most affected countries by the impacts of extreme weather events over the past two decades (Eckstein et al., 2021). Nepal falls within the group of countries that are affected by extreme events on an ongoing basis. A World Bank report suggests that the extreme weather events are all projected to intensify over the 21st century (World Bank Group, 2021a).

This future risk exposure is amplified by elevation-dependent warming. Already in the recent past, observational records feature a widespread warming over Nepal, which is more pronounced over mountainous areas than in valleys and lowlands (Karki et al., 2020). Large-ensemble and high-resolution (~60 km) projections reveal abruptly increasing temperature signals over the upper reaches of the Hindukush-Karakoram-Himalaya ranges (Ishii and Mori, 2020), exceeding the respective global averages by far (Böhner and Hasson, 2023). This database on future climate change is used for policy decision-making and is designed for climate change risk assessments (Ishii and Mori, 2020). Accelerated warming rates over the world's highest and largest mountain system, often referred to as the Earth's Third Pole, suggest amplified future changes of highland-lowland interactions and resource flows, which are essential for the functioning of Nepal's social and economic systems. Although projections reveal almost no or only moderate changes in precipitation, the significant elevation-dependent warming and its impact on the cryosphere (permafrost degradation, glacier retreat) as well as deducible changes of hydrometeorological systems and runoff regimes in the Hindukush-Karakoram-Himalaya region may affect more than 200 million people (Schild, 2008; Schild and Sharma, 2011). The resulting need for robust, spatially explicit projections of climate change and environmental impacts, however, demands very high-resolution (i.e., convection permitting) model setups to account for Nepal's topographic complexity and heterogeneity (Böhner and Hasson, 2023; Karki et al., 2017), thus far only insufficiently represented by the few available and still coarse (~25 km) resolution climate projections of the CORDEX-CORE EXP-I initiative.

Global warming induced changes in the dynamics of regional climate change and variability and glacier retreat have extensive effects on regional hydrological cycles, ecosystem resilience, and communities' well-being. The changes affect the availability and delivery of the critical goods and services which the mountain ecosystems provide to its millions of inhabitants and billions living in the downstream areas. In general, poverty is higher in mountain regions, and people are often at a higher risk than the people living in lowlands. The Food and Agricultural Organization (FAO, 2015) draws attention to the estimation that one out of every two rural mountain people in developing countries is vulnerable to food insecurity. To sustain the mountain ecosystems and livelihoods in these (mostly downstream) regions, it is imperative to understand the drivers of change affecting mountain sustainability. The recognition of the substantial shift in climate and its impacts on mountain ecosystems and socio-economic settings is crucial for the timely development of effective policy responses to cope with the change (Qi-Bin and Ouya, 2020).

Climate, climatic change, and society in Nepalese highlands

Indigenous Peoples and local communities have an intuitive understanding of the local atmosphere over long periods ever since they started to feel and distinguish environmental changes. Data collected within CLICCS show how local people use their adaptation measures proactively against experienced impacts based on their individual perception of climate change gained from consistent engagement with surrounding environment, including daily weather patterns (Darjee et al., 2022). Local communities in the highlands of Nepal have keenly observed and experienced changes in the climate. They have experienced shifts in the growing seasons of agricultural crops such as rice, wheat, maize, lentils, and mustard. While the locals outrightly noticed the disappearance of the Himalayan Bulbul (Pycnonotus leucogenys) and the House Sparrow (Passer domesticus) in the middle hills, they observed an increase in their population in the high mountains. The locals claimed that the changes are caused by the rise in temperature.

The people perceived changes in rainfall patterns, including early onset and early cessation of the monsoon, and in rainfall distribution, with reduced duration of drizzling and increased instances of intense rainfall. They observed a decrease in the number of rainy days and an increase in prolonged dry episodes. They confirmed that such changes led to a reduction in water sources, including mountain spring water, wells, ponds, and lakes (Darjee et al., 2022). The local perception of climate change largely aligned with meteorological analyses of the past three decades (Darjee et al., 2022). The analyses estimated that the temperature has risen at a rate of 0.061°C and 0.063°C yr^{-1} in the mountains and mid-hills, respectively. In contrast, there has been a reduction in rainfall, with decreases by -9.7 mm and -3.6 mm yr^{-1} in the respective regions. Approximately 88% of the local respondents acknowledged the rise in temperature, while 74% of them noticed the decline in rainfall. Moreover, the locals observed reduction in snow cover, retreat of glaciers, as well as the enlargement and increased number of glacial lakes. They attributed these phenomena to the rising temperature. These findings suggest that Indigenous Peoples and local communities possess a strong awareness and understanding of climate change. Such cognition plays a pivotal role in driving their responses to the impacts induced by climate change.

Climate change responses

The participatory development of a Community Adaptation Plan of Action is a well-established practice across Nepal. Several Community Forest User Groups, a formally recognized organization type, have developed Community Adaptation Plan of Action in the mountain region along with their Community Forest Operational Plan. The Community Forest User Groups expressed that their experience with the development of the Community Forest Operational Plan has been supportive for the Community Adaptation Plan of Action development and its implementation. The Community Adaptation Plan of Action process involves collecting information and context analysis; stakeholder consultations; participatory evaluation of the likelihood of climate change impacts, vulnerability, and adaptive capacity; identifying, prioritizing, and operationalizing actions for the future; and making informed decisions for their livelihood options and risk reduction strategies. These are critical skills which underpin adaptive capacity and enable people to use their knowledge and experiences to manage the risks associated with a changing climate (CARE, 2015).

We found that a large number of households in the studied Community Forest User Groups in Nepalese highlands has implemented both proactive and reactive adaptation measures in response to local climate change impacts. However, they do not necessarily label them as adaptation but rather see them as survival strategies. We registered more than 50 proactive adaptation measures related to agricultural diversification (25%), shifting from agriculture to livestock (16%) or cash crop and agriculture-based small enterprises (10%), trade in agriculture products (8%), and disaster risk management (30%) (Darjee et al., 2023). Agricultural diversification measures include changing crops, changing varieties and cultivars of the cereal crops, switching to local varieties, kitchen garden, off-season vegetable cultivation, and changing seed varieties for two to three year rotation. Examples of the disaster risk management measures include partial drainage of glacial lakes (see Figure 5.6), tree planting in landslide prone areas, riverside bamboo plantation, drainage construction around the house, and livestock insurance. Community-based seed banks, a pro-poor hill leasehold forest and forage development program, and community learning centers are innovative examples of good practices.

Figure 5.6: Lake Tsho Rolpa, Nepal: Artificial outlet of the Tsho Rolpa lake to reduce the pressure on the moraine dam, Nepal. Photo: Udo Schickhoff.

Enabling and constraining factors

Rural communities of Nepal are aware of the changing climate and the increasing risks it poses. They proactively utilize their traditional and local knowledge to adapt to these changes. This local understanding serves as a valuable complement to the limited observational data and provides guidance to the design of appropriate adaptation measures tailored to the local circumstances.

The Climate Change Policy 2019 (GoN, 2019), the National Adaptation Program of Action (MoE, 2010), the Provincial Adaptation Program of Action (MoITFE, 2019), and the Local Adaptation Plans for Action (MoE, 2011) frameworks guide and support the development and implementation of adaptation actions at community levels in Nepal. These policies and frameworks share a common goal to reach the vulnerable communities. The National Adaptation Program of Action recognizes the significance of local community groups in its implementation and specifically emphasizes the importance of integrating local adaptation priorities for the most vulnerable communities through community-based adaptation. Moreover, the recognition of appropriate implementing entities (e.g., Community Forest User Groups) for the Community Adaptation Plan of Action enabled a broader acceptance of and eventually facilitated the desired outcomes outlined in the climate change policies and adaptation plans.

The local communities have demonstrated their ability to democratically elect their representatives and to make important decisions in community-based forest management since the 1990s. Community Forest User Groups have a prominent institutional setup for adaptation planning and have proactively implemented adaptation practices aligned with the Community Forest Operational Plan and climate change policies. Such an institutional memory of suitable practices have been instrumental for the preparation and implementation of Community Adaptation Plan of Action and Local Adaptation Plans for Action processes. The Community Adaptation Plan of Action process supports the narrative of "Adaptation is generally locally led" and ensures a bottom-up planning process.

Adaptation is an ongoing process and, therefore, the national adaptation goals and associated actions must be dynamic as well as linked to both capacity to adapt and the degree of impact risks. Moreover, the choice of metrics, indicators, and methodologies to develop adaptation plans at different levels needs immense knowledge. Community Forest User Groups have been developing the Community Adaptation Plan of Action using participatory tools and techniques. However, many methods do not offer conditions for exploiting innovative opportunities and assessing scenarios in the process (Khadka et al., 2018). Adequate and predictable financial and technological support, including support for capacity-building, are major constraints for the development, implementation, and adaptive management of the action plans at all levels.

Although Nepal's policies and practices show a commitment to involving local communities in climate change adaptation, there are significant gaps in policy coherence and in the localization of national policies. While the Provincial Adaptation Program of Action and Local Adaptation Plans for Action emphasize the role of local government institutions, the National Adaptation Program of Action focuses on existing community-level organizations.

The integration of community-based climate change adaptation in local development planning processes in order to deal with different ecosystem-based adaptation options along with the identification of climate change scenarios, impacts, trade-offs, synergies, and the sensitivity of management problems, is established policy in Nepal's high mountain areas (CARE, 2015). Lack of integration hinders the effective coordination and collaboration between community-level initiatives and local government efforts. Concerted efforts are needed to integrate adaptation planning and well-functioning institutions into the development planning processes of local governments, which also require the critical skills, and thus capacity development, to ensure that their activities and plans are resilient to climate change and support adaptation by communities.

In sum, one can say that global warming induced changes in the dynamics of regional climate change and variability and the consequences such as glacier retreat, snow melt, and prolonged draught have extensive effects on regional hydrological cycles, ecosystem's resilience, and the well-being of the mountain dwellers and downstream communities. Local communities possess a strong awareness and understanding of climate change and complement the scarce observational data. Both together play a pivotal role in driving the responses to climate change induced impacts. There is no monopoly on knowledge related to climate change, and local knowledge merits greater attention from science and policy.

The highlanders implemented more than 50 proactive adaptation measures that are no standalone measures but embedded within broader sectoral initiatives. Many of them combine adaptation and climate change mitigation and have the potential to contribute to Sustainable Development Goals (SDGs) by reducing food insecurity, enhancing food sovereignty, and increasing the extent of forest and agrobiodiversity.

The national government is highly visible within and influenced by UN climate governance (see also Section 3.2). The country has promulgated several climate-related policies and frameworks at national, provincial, and local or community levels. High-level policies to improve horizontal (between line ministries) and vertical (between adaptation plans implementation at the different levels) coordination, to better align decentralized government and community actions, eliminate institutional inertia, and break silos are crucial to achieve the adaptation goals. Stronger integration of community adaptation planning into development plans at all levels and the convergence of adaptation, disaster risk management, SDGs, and resilience-building priorities are important areas to be improved.

During the past decade, weather induced disasters in Pakistan, Myanmar, and Nepal, as well as the regularly occurring extreme events prove the urgency of scaling-up climate adaptation and resilience in Asian highlands. So far, adaptation efforts in affected countries have been mostly reactive and incremental, while transformative community-led climate change adaptation measures need increased and commensurate investments. However, the COVID-19 pandemic and reduced economic growth exposed the countries to severe debt vulnerabilities and limited fiscal space, which has sidelined the issue of climate change adaptation in the national agenda. Despite persistent efforts, grant-based financial arrangements have yet to materialize.

Take-home message

In Nepal, adaptation most often takes place on a small-scale community basis. The challenges are to measure, monitor, and communicate the adaptation efforts taken in such small-scale and remote geographical areas. This, in turn, limits the lessons that can be learned and shared. We are only beginning to grasp the extent of climate change impacts in the "third polar region", and significant uncertainty remains. The sustainable use of limited resources in highland countries and the enabling of climate benefits at the lowest possible cost is crucial for adjusted, plausible, and desirable adaptation measures.

5.8

Pastoralists in Kunene, Namibia

Namibia is one of the most sparsely populated countries in the world and home to about 2.6 million people. In 1990, Namibia gained independence from South Africa and has since established itself as a stable democratic nation. The country's economy is largely based on mining, agriculture, and tourism. Socio-economic inequalities in the upper-middle-income country remain, however, extremely high (Worldbank, 2023).

Climate, climatic change, and society in Kumene

Namibia is one of the driest countries in sub-Saharan Africa, and climate change has a significant impact on the region. Observed temperatures exceed global averages by about 7°C, mean precipitation levels decrease while heavy precipitation and pluvial flooding increase, and severe droughts occur more frequently, having increased by 220% between 1961 and 2016 (Engelbrecht et al., 2015; Yuan et al., 2018; Trisos et al., 2022). Projections indicate a high probability that this situation will exacerbate by a further rise in temperatures, increasing aridity due to reduced precipitation and soil moisture, and further increases in agricultural and environmental droughts (Ranasinghe et al., 2021). Extreme heat waves are projected to occur much more frequently in the near future (see also Section 4.5).

The projected expansion of arid regions puts pressure on the already vulnerable agricultural systems, affecting food security and the livelihoods of rural communities. About three quarters of Namibian households engage in smallholder agriculture. These farming households have limited or no access to mineral fertilizers or irrigation infrastructure. Namibia still suffers from substantial malnutrition and child mortality (von Grebmer et al., 2022), which will be exacerbated by climate change. Climate change adaptation is therefore crucial to enhance the resilience of rural communities.

Global stock-takes of actual climate change adaptation found that drought and precipitation variability are the most critical climate hazards in Africa against which adaptation measures are already being implemented. Individuals or households were identified as the key actors implementing appropriate measures, with rural areas being a focus of action (Berrang-Ford et al., 2021; Petzold et al., 2023a). Namibia's National Climate Change Policy established a legal framework to guide the development, implementation, surveillance, and assessment of climate change adaptation initiatives. Examples of adaptation objectives outlined in the policy encompass the promotion of climate-smart agricultural practices, diversification of the economy and livelihoods, implementation of smart irrigation and water management systems as well as the improvement of climate data, weather forecasting, and early warning systems (Ministry of Environment, Forestry and Tourism, 2021).

Climate change responses

The aim of this case study is to explore how pastoralists in the Kunene region of northwestern Namibia adapt to climate change (see Figure 5.7). The Kunene region is about 144,000 km^2 in size and, according to the latest census in 2016, has roughly 100,000 inhabitants. Due to the adverse climate conditions of the area, it has a very low population density of 0.68 people per km^2.

Figure 5.7: Kunene, Namibia: Pastoralist herding goats and sheep in Kunene, Namibia. Photo: Michael Schnegg.

Climatic context

Kunene is partly semi-arid and partly arid, with precipitation falling between 100 mm and 300 mm per year. In the past, the area had two rainy seasons, one in October and November and the second more extensive season between February and May. However, precipitation during the rainy seasons is patchy and uncertain. Some areas receive a considerable amount of precipitation while others receive much less (Schnegg and Bollig, 2016).

Both meteorologists and local communities agree that precipitation and its distribution have changed significantly over the past decades (Schnegg, 2021b). Firstly, the rainy season in October and November has become weaker and less reliable. The rain both starts later and ends earlier, making the rainy season much shorter than is used to be. This has consequences for vegetation growth. The vegetation growth period has become so fleeting that grasses essential to pastoralists' livelihood cannot be sown. This, in turn, negatively affects the following years' vegetation cover. Moreover, people observe that the intensity of droughts has increased.

Colonial context

The Kunene area is mostly inhabited by Otjiherero-, Khoekhoegowab-, and Oshivambo-speaking people. To understand the effects of climate change on their livelihoods, a look into colonial history is necessary. Namibia was occupied by the German Reich in the second half of the 19th century and became a German colony. To establish political power in the vast country, the most fertile parts were turned into commercial farmland on which German settlers, often former soldiers, were settled. With strong financial, political, and military support from the German state, they established a commercial cattle economy.

This had several important consequences. Indigenous Peoples were forced to live on marginal lands. Right from the start, however, it was clear that the carrying capacity of these marginal lands was not sufficient to maintain the population. This was a deliberate policy because it forced people to work for very low wages on the commercial farms or in the mines. Through doing so, a migratory regime was established, which is common for many parts of southern Africa. It also meant that stocking rates on the communal areas were so high that they became enormously vulnerable to droughts (Schnegg et al., 2013). Against the backdrop of these colonial and climatic conditions, it does not come as a surprise that Indigenous Peoples often say "there is no drought on the White man's land."

Economic context

Most people in the rural area of Kunene mainly rely on pastoralism for subsistence. Most of them own relatively few cattle, between five and 20, and some small stock, sheep, and goats. Animals are kept on the open communal pastures. They return to the community every evening because there are few open wells, and water is pumped from boreholes for human and animal consumption. In addition to livestock, a significant number of wildlife inhabit the area, including a quickly increasing elephant population (Schnegg and Breyer, 2022).

While many people maintain livestock, only some can live from it alone. Most often, households combine a variety of strategies as part of which some members work on commercial farms, in mines, or, increasingly, in town, while others maintain the household and animals. Moreover, children of those who work outside the rural communities tend to stay at their grandparent's house in the hinterlands. As people retire or lose jobs, they often return to their rural homes.

How climate change affects people

Further rising temperatures and increasing aridity are projected for the region. There are two major effects on Indigenous pastoralists. The first relates to the effect of changing patterns of precipitation on vegetation growth and livestock farming. Most significantly, the number of droughts and their intensity have drastically increased. During the last major drought that began in 2015, almost 70% of the livestock in the area died. This is a tremendous loss given that people often do not own any larger assets other than their livestock (Schnegg and Bollig, 2016). To put this amount into perspective, it helps to consider that a piece of cattle is worth about EUR 400, while a laborer makes about EUR 4 a day.

In addition, the changing patterns of precipitation have increased human-wildlife conflicts. The elephants in Kunene, whose numbers have increased significantly, typically stay in the dry river beds where they used to find sufficient food and water. With climate change, however, water levels in these ephemeral rivers have lowered so much that many trees close to the rivers have died, and it has become difficult for elephants to dig for water during the dry season. Because of this, they have to leave the rivers and come to the communities to seek water, often destroying water infrastructures (Schnegg and Kiaka, 2018).

Knowing climate change

Because weather changes have such a significant impact on people's livelihoods, they are salient in everyday talk. As something which is strange and not understood, people spend a great deal of time and effort to make them meaningful. These attempts are partly informed by scientific knowledge and partly by knowledge from Indigenous or religious registers (Schnegg, 2021a; Schnegg, 2021b). In this vein, it is commonly assumed in this area that weather change is caused in the region or in Namibia. People would also not say that weather changes have anything to do with the remote past; instead, they are associated with current wrongdoings in society. This is because in Namibia, as in most other parts of the world, the weather is part of an animated moral universe that encompasses humans, spirits, winds, and rains. All these entities have subjectivities, so when the rains fail to come and the weather is unforgiving, this is likely because people misbehaved (Schnegg et al., 2021).

Importantly, while these Indigenous and scientific ways of knowing are different, they also co-exist and even merge. In some situations, people draw on a particular understanding that is in part related to the way the weather and its changes are experienced in an embodied sense (Schnegg, 2021a; Schnegg, 2021b). While scientists and Indigenous communities thus observe similar tendencies of environmental change, they make these changes meaningful in different ways. This depends largely on their ways of *being-in-the-world* and of perceiving the world as scientists or pastoralists, connecting observations to different entities and for different ends, ultimately leading to different explanations of environmental change.

Adaptation at household and community levels

While people do feel the increasing threat of weather change, and many have lost significant amounts of their livestock, this is actually not considered entirely out of the ordinary. The collective memory retains other incidents of severe droughts. Animals dying and rotting in the fields are part of their narratives, tales, and—for the elders—past experiences. This explains why even during extreme weather change, people do not panic. What is more, many have survived drastic political and economic turnovers that they tend to classify as more severe than the current climate change. Also, many have developed a worldview in which natural events are perceived as simply befalling individuals, who have relatively little agency to influence them (Schnegg, 2023a; Schnegg, 2023b).

At the household level, there are few means to adapt to climate change within the pastoral economy. One option is migration, which is practiced to some extent but also increasingly leads to conflicts. On the one hand, the Namibian state has guaranteed its citizens the right to freedom of movement since independence in 1990; on the other hand, land is still issued by traditional authorities which are ethnically homogeneous and often hesitant to grant grazing rights to people who do not speak their language because they belong to a different ethnic group.

In addition to migration, diversification is a main strategy. However, we know of extremely few cases in which this has worked in the long run. This has to do with the fact that households have relatively little access to cash, and many economic strategies beyond pastoralism require some cash flow, when, for example, fodder needs to be bought or transported to the marketplace. Because clients often do not pay on time or at all, most of these activities fail. Where they work in commercial environments, it is mostly because there is cash and workers can be exploited to such a degree that production becomes profitable.

As a consequence, many of the organized attempts to diversify fail, which we have seen firsthand with communal gardens, fish farming, and comparable development efforts.

One of the problems with most of these efforts is that they require groups to do something jointly whilst people have little confidence in organizing economic activities beyond the household. In all cases that we were able to observe, this led to conflict and thus failure. Another contributing factor is that many of these development efforts are built on the idea that formal institutions, including committees, can govern them. This ignores the fact that in small, face-to-face communities, people interact in multiple roles, including kinship, which makes it often very difficult to apply formal rules and sanctions to, for example, elder kin, because such behavior would not only be considered rude, it would effectively cut someone off from long-term social and economic ties that are essential for survival (Schnegg, 2018).

Enabling and constraining factors

In rural areas of Namibia such as Kunene, people are constrained to adapt to climate change on the household level because they lack infrastructure and capital. While the state and NGOs encourage and try to enable some transformations, these are often based on assumptions that contradict local norms and values, making it not plausible that they will become a long-term adaptive strategy. However, while livelihoods have indeed worsened due to global warming, most people in such marginalized economic and political environments experience plenty of ups and downs in their lives regardless of climate change, making the situation emotionally more easily bearable, at least from what we observe.

Take-home message

Rural communities in Namibia are highly vulnerable to climate change due to their heavy dependence on natural resources. As the region faces more frequent droughts and heat waves that threaten food security and rural livelihoods, climate adaptation measures are urgently needed. However, the adaptive capacity of these communities is limited by economic marginalization and a legacy of colonialism.

5.9

Coastal Adaptation in North Frisia, Germany

North Frisia is situated in the northwesternmost part of Germany along the North Sea coast, where it adjoins the North Frisian Wadden Sea. The Wadden Sea extends along the entire German Bight coastline, stretching from the northern Netherlands up to Blåvands Hook on the southwestern tip of Denmark. Geologically speaking, the formation of the North Sea, and in fact the entire North European region, is shaped by past ice ages and glacial deposits. The extent of the North Sea we see today results from developments after the last ice age when the then dry area of the North Sea Basin was flooded by water released from the ice shields (Stadelmann, 2008). In the post-glacial climate between 7000 and 5000 B.C., the ice was melting quickly, causing an average sea level rise of 1.25 m per century (Behre, 2008). After this rapid rise, sea level change slowed down, allowing the relocation of sediments in the area of the Wadden Sea. This led to the formation of the first tidal flats (MELUR, 2015), which still characterize the coastal landscape in the Wadden Sea today. The natural origin of the Wadden Sea can thus be dated back to some 4000 years ago when the rate of sedimentation exceeded sea level rise.

Against the background of this natural development, early settlers in the North Frisian Wadden Sea were exposed to the dangers of storm surges from the North Sea without any protection (Brandt, 1992; Knottnerus, 2005). To be able to sustain a living under these difficult circumstances, they had to adapt to their coastal environment. Hence, people along the coast developed measures and structures to secure their lives and belongings from the floods; in particular, they began to construct small dwelling mounds and dikes (Küster, 2015). This century-long interaction with the challenging waters and the ensuing socio-historical settlement process resulted in a perspective on coastal protection and the coastline in North Frisia that is still characterized by the proverb "God created the sea, the Frisians the coast". The natural environment was partly tamed, influenced to one's advantage, gradually turning the coast into a more cultural environment (e.g., man-made brushwood fences and stalk plantings, to strengthen and secure the natural dunes as shown in Figure 5.8).

Figure 5.8: Amrum, Germany: Fresh stalk plantings and sand trapping fences to secure and further build up the coastal dunes that protect the island of Amrum, Germany. Photo: Philipp Jordan.

The sea represents a risk to the people in North Frisia, and fear of the sea is deeply ingrained. Over the past centuries, this initiated an innovation boost during which techniques of diking and other measures of coastal protection were developed (Fischer, 2021). The present image of the "free Frisian" is based on the constant battle with coastal waters (Rieken, 2005; Rheinheimer, 2003); it is also mirrored in the regional and local sense of place or "Heimat", which reflects a deeply rooted interrelationship between the coastal inhabitants, the landscape, and the dikes (Ratter and Gee, 2012; Döring and Ratter, 2015; 2018; 2021; Steensen, 2020; Holzhausen and Grecksch, 2021).

Today, the region of North Frisia has to cope with demographic change, a declining agricultural sector, a practically no longer existing shipping sector, and a shrinking fishing industry. Renewable energy production represents a new and promising area for unprecedented economic growth. In the future, the whole region may come to rely on both tourism and energy production in the form of wind power and hydrogen production.

Climate, climatic change, and society in North Frisia

North Frisia's climate can be characterized as an Atlantic climate that is showing the effects of climate change. Numerous studies show a warming of about 0.8 °C in northern Germany within the reference period of 1961–1990 (Meinke, 2020). Along with this, the frequency of extreme events has also changed. In particular, summer days (> 25°C) and hot days (> 30°C) have become more prevalent during the summer months. In winter, ice and frost days have decreased significantly, and the thermal growing season has lengthened considerably. More than 120 regional climate scenarios have been evaluated as part of the North German Climate Atlas; they all agree that the warming already taking place in northern Germany will continue in the 21st century. Depending on future greenhouse gas emissions, northern Germany may warm by about 1–5°C by the end of the 21st century (from the optimistic RCP 2.6 scenario to the pessimistic RCP 8.5). In the future, significantly amplified precipitation is expected, especially (but not exclusively) in the winter months, with increases potentially as high as 40% by the end of the 21st century. In summer, the duration of dry periods is estimated to roughly double by the end of the century.

Contrary to what is often claimed, no long-term trend of increasing mean wind speed or storms has yet been observed. A storm season today produces neither more violent nor more frequent storms than 100 years ago (Krueger et al., 2019; Krieger et al., 2020; Olonscheck et al., 2023). Future trends in storm activity are unclear from today's perspective. Looking toward the end of the century, the strongest changes in storm activity in northern Germany are expected for the winter months (Feser et al., 2021; Krieger et al., 2022). During this season, storm intensity may increase by up to 10%, and the number of storm days could almost double (Meinke et al., 2018). The sea level in the German Bight has risen by about 15–20 cm within the last 100 years and is not showing signs of unusual acceleration. Depending on future greenhouse gas emissions, the potential sea level rise in the North Sea by the end of the century (2081–2100) is therefore expected to lie within the global range of 30–80 cm. This makes sea level rise the main driver of higher water levels and storm surges (Arns et al., 2017; Jordan et al., 2021; Liu et al., 2022). Projections whether future extreme wind speed will increase or decrease in the German Bight still vary significantly (Quante and Colijn, 2016), but a projected shift in the predominant wind directions might be another additional driver for higher water levels at the end of the century (Sündermann and Pohlmann, 2011).

To deal with these impacts of climate change, a governmental coastal defense plan (General Coastal Protection Plan) has been developed and adjusted over the past decades (MELUND, 2022). It regularly assesses the status of dikes, determines restoration work to be executed, and develops adaptation measures to be taken on the mainland and on the islands. All measures undertaken are based on RCPs 2.6, 4.5, 6.0, and 8.5 from current IPCC (2019) reports and complemented by measurements of water levels and degrees of sedimentation in the North Frisian Wadden Sea carried out by local and regional authorities. Both RCPs and measurements inform local adaptation plans and aim at improving the current state of the art of coastal protection and adaptation measures (Gemeinde Helgoland, 2013; MELUR, 2014). All plans and activities are negotiated with regional actors, administratively supported, politically endorsed as outlined in the Climate Protection Concept North Frisia (Wagner et al., 2011), and promoted by the Climate Alliance North Frisia. On the level of the federal state of Schleswig-Holstein, the General Coastal Protection Plan (MELUND, 2022) is complemented by various sectoral adaptation plans for forest or water management, agriculture and the Strategy Wadden Sea 2100 (MELUR, 2015). On a national level, the Federal Environment Agency promotes climate change adaptation via various programs and funding initiatives, as already outlined in the Climate Change Adaptation Strategy Germany (Bundeskabinett, 2008).

Recent research on the regional and local perception of climate change in North Frisia paints a multi-layered picture. Variations in seasonal weather patterns experienced by locals, changes in the local composition of flora and fauna as well as regional intensification of storms and storm surges are attributed to climate change. Climate change adaptation strategies exist on various scales within society, ranging from individuals and neighborhoods up to parishes. Individual measures taken range from insurance against damage caused by extreme weather events to behavioral adaptation to protect premises or using weather apps to be informed about imminent weather conditions (Döring and Ratter, 2018). On a neighborhood and community level, mitigation strategies such as options for green energy generation are negotiated and jointly implemented (Süsser et al., 2017; Süsser and Kannen, 2017) while telephone chains exist to check if neighbors are safe during serious weather conditions. On the parish level, climate change adaptation in terms of diking and other comprehensive measures are mostly relegated to regional authorities, but advantage is taken of state and national funding programs to, for example, locally finance power supplying devices to secure energy provision in case of larger-scale power failures. Relocation within or moving away from the region are not generally considered an adaptive option because of strong intergenerational ties to local places (Mulligan, 2014; Döring and Ratter, 2018).

Climate change responses

Today, it is mainly the federal states that are responsible for protecting their citizens against the dangers of the sea (Jordan et al., 2019). Concepts of coastal defense are constantly re-evaluated while preventative measures are being developed with the aim of anticipating possible climate-induced storm surges to avoid damage (FAIR, 2020). Planning climate change adaptation in a socially and economically sound way and making the right decisions appears to be tricky for those in charge of coastal protection. Knowing that climate change will affect coastal safety (IPCC, 2019), but uncertain as to how much and when, makes it tough for decision-makers to make technically appropriate and socially acceptable choices. This situation becomes even more difficult due to evolving societal, technical, and ecological requirements. Within the UN decade of ecosystem restoration for instance, adaptive solutions are being called for that frame coastal ecosystems as sensitive entities. As a consequence, tension is growing between the established ways of doing coastal protection and the need to implement nature-based solutions (Jordan and Fröhle, 2022; Kiesel et al., 2023).

Diking has been a visible and effective form of protection in North Frisia. Consequently, citizens have much confidence in the authorities responsible for diking, while there is much less confidence in nature-based solutions (González-Riancho et al., 2017). This has made it easier for those responsible for coastal protection to continue with the diking rationale as the main pathway of climate change adaptation. The concept of the so-called Climate Dike (Reise, 2015; Hofstede, 2019a; Hofstede, 2019b; MELUND, 2022) is an example of this; it widens the dike crest so that the dike can be raised by means of an additional cap to be placed on top. While this clearly responds to estimated sea level rise and the growing intensity of storm surges, there is increasing awareness among practitioners that it represents a one-sided approach to the problems coastal dwellers will be facing. On the one hand, this incremental, path-dependent climate change adaptation measure successfully concentrates on the aspect of protecting lives and livelihoods for another 50–70 years; on the other, it lacks the ability to incorporate possible climatic developments beyond its 70-year design life and to take into account ecological concerns.

Although they have been overshadowed by diking, nature-based solutions exist (Jordan and Fröhle, 2022) and have been applied in the North Frisian Wadden Sea for decades, if not centuries (Jordan et al., 2023). A salt marsh in the dike foreland, for example, can dampen waves and thereby protect the dike foot while also providing a habitat for flora and fauna, thus promoting biodiversity. Experiences with nature-based solutions such as brushwood groins to generate foreland have been taken up by the politically driven Strategy Wadden Sea 2100 (MELUR, 2015), which was adopted by the state government. Here, a climate change adaptation plan was cooperatively developed by authorities and other actors with the dual aim of protecting the Wadden Sea National Park in front of the dike and the livelihoods behind it (Hofstede and Stock, 2018). The concept envisions sediments (naturally occurring or artificially put there via nourishments) to be relocated by the coastal currents, instigating a process of sediment accretion to protect the region against future sea level rise and storm surges. The idea of a naturally growing seabed that prevents natural and cultural landscapes from drowning was appreciated by all participants involved because it reunited the often conflicting parties of nature conservation and coastal protection. The Strategy Wadden Sea 2100, in combination with pilot projects based on or following this strategy, such as the Sandy Coast St. Peter-Ording project, clearly represents a way of transformative climate change adaptation and coastal protection.

Enabling and constraining factors

Diking still represents a technically feasible, socially accepted, and administratively established way of doing coastal protection in North Frisia. Local social trust in the authorities responsible for diking is high; hence the climate dike, with its central focus on the safety of the coastal population, has been developed as the primary climate change adaptation concept. Path dependencies and a medium-term planning horizon of around 50–70 years are enabling factors that support this particular way of coping with the estimated sea-level rise in the region. This, however, is not always seen in a positive light. Nature conservation authorities and environmental NGOs perceive dikes as ecologically disruptive entities in what they regard as a largely natural landscape. The conflicting ideologies between nature conservation and coastal protection disclosed by our interdisciplinary interview study between 2019–2023 (Jordan et al., 2023) clearly represent a constraint for climate change adaptation, which is also evident in the tense and almost non-existent collaboration between both parties. Sectoral thinking and handling of climate change adaptation with almost no attempt to cooperatively explore existing or new ideas currently represents a constraining factor.

Against this background, projects and initiatives such as the Strategy Wadden Sea 2100 represent enabling factors. They are an opportunity to meet outside of the existing cultures of conflict. Open and transparent interaction, acceptance of different ways of knowing, and constant communication about common objectives and achievements among all the parties involved resulted in a cooperatively developed climate change adaptation concept which was adopted by the federal government of Schleswig-Holstein. It currently awaits its broadscale implementation, with first pilot projects being launched already.

Take-home message

Coastal protection, understood as sustainable climate change adaptation, is a socio-technical endeavor. It is structured by social processes, administrative path dependencies, and lock-ins in established approaches that limit the scope of what might, could, or should be done to technically or naturally protect the coast from estimated climate change impacts. Although diking is associated with a low degree of uncertainty, physical feasibility, and established ways of implementation, it is important to develop projects that enable the building of communities of practice where experimenting with alternative or new ways of doing coastal protection can be scientifically assessed, technically tested, and—most importantly—socially experienced and negotiated.

5.10

Small Islands Adaptation in the Maldives

The tropical atoll state of the Maldives lies in the Indian Ocean between the latitudes of 0° and 7°. With an overall area of 923,322 km^2 and only 298 km^2 of land area, the Maldives is represents one of the smallest countries in Asia. At the same time, it is one of the geographically most dispersed countries in the world. Out of 1190 islands, stretched out in a double chain of 26 atolls, 187 are currently inhabited by a population of 521,457 (2021). In 2022, according to World Bank data, the GDP per capita was USD 11,963, ranking the Maldives 71st out of 196 countries (Country Economy, 2022). The Gini index, which measures relative degrees of social inequality, stands at 29.3 (2019) for the Maldives, slightly higher in the capital Male' than in the atolls of the rest of the country. About 100 islands are exclusively used as tourist resorts. As a country, the Maldives is characterized by smallness, remoteness, scarce resources, high population pressure, threats to biodiversity, and high dependence on healthy terrestrial and marine ecosystems (Petzold et al., 2023bs). Environmental resources play a significant role in the state's development, especially in tourism, fisheries, and agriculture, as do international trade links and dependence on international relations.

The Maldivian coralline islands are only 0.5–2.3 m above sea level (Wadey et al., 2017); as such, they are considered particularly vulnerable to the effects of anthropogenic climate change (Magnan et al., 2022; Mycoo et al., 2022; Storlazzi et al., 2018). Coralline islands, coral reefs, and surrounding sand sediments are all morphologically dynamic, driven by the seasonally changing winds, waves, and ocean currents (David and Schlurmann, 2020; Kench, 2012; Kench et al., 2018). It has been shown that natural factors can cause erosion but also accretion of atoll islands, meaning that land areas on atolls can expand despite rising sea levels (Magnan and Duvat, 2020; Masselink et al., 2020; Kench et al., 2018). Magnan and Duvat (2020) calculated that between 2005 and 2015, 41% of the atolls in the Maldives were stable, 0% decreased and 59% increased in size. Functional, ecologically intact coral reefs that surround each atoll are crucial to protect the islands (Ryan et al., 2019): A healthy coral reef provides sand for the islands through biodetritic production and serves as a brake on marine wave energy (Aslam and Kench, 2017). Threats to the reefs originate from global developments (thermal stress, ocean acidification) but also from local activities like pollution, overfishing, and coastal construction activities.

Climate, climatic change, and society in the Maldives

Tropical cyclones rarely directly hit the Maldives, but the seasonally changing monsoon winds regularly lead to damage. The dominant wind systems result in strong swell waves that have varying effects along the length of the state (Wadey et al., 2017). Higher air temperatures lead to more evaporation, while changing rainfall patterns reduce precipitation where it is needed, threatening drinking water supplies. Rising water temperatures, ocean acidification, and marine heat waves lead to coral bleaching, threatening the important island-protecting reefs and their marine biodiversity. Despite these varied impacts of climate change, it is predominantly sea level rise that is at the center of political discussion in the Maldives.

The actual sea level change in the Maldives is difficult to assess as only three tide gauge stations operate along the island chain. Records from 1991–2015 indicate a rise of 3.46 ± 0.25 mm per year for Male' (Wadey et al., 2017) while the northern Indian Ocean sea level rose between 2.3 ± 0.09 mm per year in the period of 1993-2015 (Swapna et al., 2017). Sea level projections for the Maldives islands are extremely inaccurate due to their location in the middle of a vast open sea and the unknown tele-effects of the Himalayas, which makes downscaling of global projections difficult (Cazenave et al., 2018; Palanisamy et al., 2014). Current estimates assume a sea level rise of approximately 7 mm per year, slightly faster than the global average (World Bank Group, 2021b). Sea level rise leads to rising wave heights, while a damaged reef flat leads to an increase in wave power and thus to more erosion.

Numerous scientists consider the expected sea level rise a major threat to low-lying coastal areas and islands (Hoegh-Guldberg et al., 2018; Li et al., 2020; Mycoo et al., 2022; Oppenheimer et al., 2019). Although Gussmann and Hinkel (2021) find it a non-immediate existential threat, it is important to account for the cumulative effects of climate change impacts, such as the frequency of storm surges, accretion, heavy rainfall, and tidal waves, on top of sea level rise. Coastal and marine environments are highly susceptible to global warming, implying that coastal vulnerability needs to be frequently assessed to better understand the actual risks climate change poses to the populations living on the islands and the biodiversity they depend on (Abijith et al., 2023). A key problem is the uncertainty of exactly when, how, and where the rise of sea levels, acting in combination with other climate change effects, will have an impact on islands, as this depends on many factors. Site-specific management of climate change impacts, ecosystem services, and adaptation measures is critical. Coastal adaptation measures, in particular grey or hard coastal protection, are expensive, and financial resources are often limited. Options for action therefore need to be kept open for as long as possible until more is known about local implications of sea level rise to make measures as (cost-)effective as possible (Hinkel et al., 2021; 2023).

Coastal floods caused large-scale destruction in Male' and on 15 other islands in 1987 and 1988 (MHE, 2011). Yet, the key historical event was the 2004 tsunami, in which 83 people were killed and 25 reported missing. 10% of the population were displaced, and about 8000 homes were damaged; the inhabitants of two islands were re-settled (Azfa et al., 2022; Gussmann and Hinkel, 2021; Kothari et al., 2023).

Climate change responses

Between 2013 and 2017, the government spent USD 38.7 million on coastal protection measures–a fraction of the investment that was actually needed (MEE, 2017). Maladaptive practices further exacerbated the problem (David et al., 2021; Kench, 2012; MEE, 2015a): Coastal modifications such as reducing reef widths by claiming new land within the reef flat and building fixed coastal infrastructure on the shorelines is widespread in the Maldives (Hinkel et al., 2023). Standard protection measures have often been poorly implemented, and not all islands in need of protection receive the necessary support. Frustration and disappointment on remote peripheral islands are coupled with a loss of trust in central government (Ratter and Hennig, 2020).

The political aspect of adaptation becomes highly apparent in the Maldivian example. Changes of government have repeatedly led to changes in the understanding of climate change and the strategies adopted. In 2009, former president Nasheed held an underwater cabinet meeting to draw international attention to the archipelago's plight. Sea level rise was clearly seen as the biggest challenge related to climate change, following the dominant narrative that developed countries are responsible for climate change and small islands its victims.

Under President Nasheed (presidency 2008-2012), a plan was proposed to make the Maldives carbon-neutral within a decade (Clark, 2009). The first national climate adaptation program was adopted in 2007 (Abdulla et al., 2007). The National Adaptation Plan of Action was revised in 2012 as well as in 2016 (The Republic of the Maldives, 2020) and then followed by other strategic plans for dealing with climate change. These include the Safer Islands Strategy (MEEW, 2007), which aims to re-settle populations of smaller, more vulnerable islands to larger, protected islands; building codes; Environmental Impact Assessment Regulations; and the Strategic National Action Plan for Disaster Risk Reduction and Climate Change Adaptation 2010–2020 (Gussmann and Hinkel, 2021; Hennig, 2020; Malatesta and Schmidt di Friedberg, 2017). President Nasheed even considered migrating the entire population to Australia, Sri Lanka, or India if sea levels continued to rise. The subsequent government under President Abdulla Yameen recentralized power at the highest levels of government (Robinson, 2015) and shifted its focus toward economic development, neglecting environmental protection (Malatesta and Schmidt di Friedberg, 2017). The current government under Ibrahim Mohamed Solih committed itself back to democratic values and social engagement. However, politics remain volatile, and decisions are often taken based on expected political gains. The presidential election race in 2023 represents the latest critical juncture (Amjad, 2023).

Coping strategies to deal with sea level rise and other climate change impacts are urgently required at different levels. The central government focuses on technical solutions but does so based on political favors instead of prioritizing according to need (ADB, 2015). Large-scale investment projects—financed by China and India—reflect major external geo-strategic interests but cause huge environmental damage (Amjad, 2023).

Different climate change adaptation strategies apply in the capital as the political center, on tourist resort islands, and on islands with a local population.

The capital city of Male', home to 47% of the total population in 2019, was protected from flooding after the 1987 and 1988 high wave events with Japanese aid (JSCE, 2022). This included fortification of the reef edge in the form of a sea wall, revetments, tetrapods, and groynes, as well as rehabilitation of local infrastructure, particularly ports.

New land reclamation combines development goals with protection against erosion and sea level rise (van der Pol et al., 2023); non-binding guidelines state that new land should be created at a level of 1.5–1.8 m above current mean sea level (MEE, 2015b). The largest Maldivian land reclamation project took place in Hulhumale' ("City of Hope") in 1997 and 2015, raising two artificial islands of 400 ha (4.3 km^2) to 1.8–2.0 m above mean sea level. The aim was to alleviate population pressure in the capital and prepare for the resettlement of 240,000 people from other parts of the country (Bisaro et al., 2020). Brown et al. (2023) found that these islands would be safe into the 2090s even under a high emissions scenario and much longer under a low emissions scenario.

Another large infrastructure project, the Greater Male' Connectivity Project of 2021, will promote further urban development, although it requires significant shoreline protection measures (Brown et al., 2023; Gussmann and Hinkel, 2021), indicating that environmental aspects are not taken into consideration.

Tourism islands, catering for international luxury tourism (dell'Agnese, 2021), are mostly managed by private enterprises. Given their larger financial budgets and explicit interest in protecting the pristine environment, resort islands have both a growing interest and the necessary financial means to test new approaches that could help in keeping the islands attractive (Brown et al., 2023; Hosterman and Joel, 2015; MoT, 2015; Ratter et al., 2019; Shakeela and Becken, 2015).

On the islands populated by locals, coastal erosion and flooding have been widespread phenomena in recent decades. Island societies have traditionally protected their settlements against flooding with a slightly higher barrier of dense trees and shrubs (heylhi) around the inner island settlements (Bremner, 2017). This green belt was jointly maintained by the island communities, using the ecosystem services of vegetation to protect against flooding and to contribute to sediment accumulation. With modernization, almost all of these local heylhi have disappeared or are threatened.

Addressing erosion and coastal engineering is now a key responsibility of the Ministry of Environment, Climate Change and Technology. In 2004, 64% of the inhabited islands reported serious erosion problems, and the government expected the problem to worsen due to the impacts of sea level rise (MEE, 2015b). A so-called ministerial red list is used to prepare the annual fiscal budget for erosion protection, with projects funded on the top-ranked islands (Gussmann and Hinkel, 2021). Prioritization is key due to the limited resources, and as detailed surveys cannot be conducted everywhere, pragmatic choices need to be made (Hinkel et al., 2023). Coastal protection in general is characterized by a preference for hard measures, such as revetments or sea walls (Kench, 2012; MHE, 2011). Problems resulting from these measures often result from poor design and construction due to insufficient financial, human, and technical capacity (Kench, 2012; Ratter et al., 2019).

Figure 5.9: Beach of Fuvahmulah, Maldives: Fallen palm trees, erosion, and green belt on the eastern beach of Fuvahmulah, Maldives. Photo: Beate Ratter.

An interdisciplinary study on the southern island of Fuvahmulah demonstrates how inappropriate coastal development can be detrimental not only to the island's coasts but also to the trust and support of the local population toward central government decisions (David et al., 2021; Hennig, 2020). A newly constructed harbor on the southern tip of the island impedes sediment transport; in addition, the breakwater reaches up to the reef edge so that sediment is redirected off the reef and lost to the dynamic sediment system. In consequence, the east coast of the island suffers dramatic coastal erosion (see Figure 5.9). The visible destruction of the beach face is identified by the local community as the most pressing issue on the island. Interestingly, almost a quarter of the population attribute the erosion processes on Fuvahmulah to the construction of the harbor (Ratter et al., 2019). The harbor development resulted in further local skepticism toward central government and especially against its narrative of the Maldives being highly vulnerable to climate change-induced sea level rise. A grant agreement the Ministry of Environment and Energy signed with the Netherlands to finance a coastal protection project on Fuvahmulah's east coast in 2017 left the island council in despair because it has been shown that the planned use of revetments to prevent erosion may actually exacerbate the process in the longer run, leading to a higher risk of erosion along the island's edges (David et al., 2021).

Enabling and constraining factors

Adaptation measures in the Maldives are currently mainly geared toward the development interests of the state and disregard ecological contexts as a prerequisite for sustainable climate adaptation. Objective knowledge related to the biophysical aspects of climate change is often tightly intertwined with subjective opinions related to preferences, adaptation goals, and policy priorities (Hinkel et al., 2023). In addition to sea level rise and other natural factors that determine sediment dynamics, human modification of the shoreline is a crucial factor that can either support or hinder sustainable development.

Coastal adaptation decisions depend on multiple criteria, involving, for example, the safety of coastal residents, coastal infrastructure, and social acceptance (Oppenheimer et al., 2019). Responsibility perception among the island's population plays an important role for the stated willingness to support protective measures (Adloff and Rehdanz, 2024). Trade-offs have been made in focusing on selected islands and also in the continuation of a hard protection strategy for those islands that are already heavily protected, causing a lock-in effect, reinforcing feedback loops, and leaving the Maldives ill-prepared to deal effectively with rising sea levels (Gussmann and Hinkel, 2021). Sea level rise is only marginally integrated in existing sectoral policies, and there is little coherence between climate policy objectives and corresponding measures – and even less compliance with agreed measures. The current static management approaches are counterproductive in the dynamic environment of the Maldivian atolls. Apart from being socially unjust, they affect other societal and ecological goals, for example by reinforcing center-periphery differences and conflicts. Outer atolls have less access to resources, meaning that climate change adaptation remains a more difficult problem for rural, peripheral islands (McNamara et al., 2019).

Take-home message

The stereotype of small, vulnerable islands as victims of sea level rise is too simplistic. Adaptation to the impacts of climate change in the Maldives needs to consider the socio-political framework, anthropogenic pressures on the islands, and locally specific climate change impacts. Generic hard protection measures often reinforce negative feedback loops at the expense of sustainability and biodiversity. While Maldivian atolls have expanded their land area despite regional sea level rise, ecologically intact coral reefs remain crucial as a means of natural protection for the islands. Maladaptation increases unsustainable development even further and risks the habitability of the islands at large.

5.11

Coastal Adaptation in Taiwan

Taiwan is surrounded by the sea and has a total coastline of 1139 km (Yang et al., 2012; Lin et al., 2021). Its total area is 36,197 km^2 (Ministry of Foreign Affairs, 2024). The western coast has comparatively shallow waters with an average depth of 60 m. In contrast, the eastern coast is very steep, with water depths rapidly increasing to several thousand meters. More than half of the coastline is protected by seawalls (Yang et al., 2012). The coast was a restricted area for military purposes until 1987, when the martial law was lifted (Shih, 2017). Since then, there has been rapid development growth in the coastal area. While Taiwan's trade-dependent economy is driven by a competitive manufacturing sector that includes electronics, machinery, petrochemicals, and information and communications technology products, agriculture and fishing are the main economic activities along the coastal region.

Tectonically, Taiwan presents shattered subduction trench lithologies, rapid uplift, regular earthquakes, and intense monsoon and typhoonal rains, which combine to produce rapid erosion rates. This makes Taiwan one of Earth's most geologically active areas. The island's topography includes the flat to gentle plains in the west and the mostly forest-covered mountains in the eastern two-thirds, reaching as high as 3952 m. Two-thirds of Taiwan is mountainous, with only one-third being comparatively flat. Approximately 80% (Lin et al., 2021) of the total population of more than 23 million are living in the flat coastal areas in the western part, which are particularly vulnerable to hydro-meteorological extreme events. These events are caused by high precipitation over the island combined with typhoons and storm surges bringing extremely high waves from the sea (Lin et al., 2021).

Taiwan has a fully democratic system, with the democracy index ranking Taiwan 1st in Asia and 10th globally (EIU, 2023). Politics in Taiwan is characterized by its unique status, and ongoing tensions, with mainland China. Officially known as the Republic of China (ROC), Taiwan considers itself a sovereign state with its own government, military, and constitution. However, China considers Taiwan part of its territory and claims sovereignty over the island. This results in a difficult political situation, with most countries recognizing China rather than Taiwan diplomatically.

Climate, climatic change, and society in Taiwan

The island's climate is subtropical, except for the very southern part, which has a tropical climate. Due to the highly orographic monsoon climate that is dry in winter and wet in summer, the average annual precipitation is about 2200 mm in plain areas and 3800 mm in mountain areas. Typhoons (tropical cyclones) regularly strike the island during the summer season, bringing both extreme meteorological and extreme oceanographic conditions with heavy rainfalls, extremely high wind velocities and, consequently, extremely severe waves conditions. During typhoons, the 24h rainfall can easily reach values of 1000 mm or more (Central Weather Administration; Chien and Kuo, 2011), and significant wave heights of more than 20 m have been observed at the east coast of Taiwan (Doong et al., 2008).

Climate change is already affecting Taiwan, and its impacts are expected to increase in the future. According to Water Resources Agency (2020), the average sea level rise rate near the Tainan area is 5.5 mm per year (water level observations between 1993 and 2012). In addition to the effects of sea level rise, the main consequences of climate change are related to changes in typhoon frequencies and typhoon intensities, as well as general influences on the monsoon-climate. Both factors are expected to have severe impacts on Taiwan. Increased typhoon intensities are causing more precipitation, even torrential rains and floods as well as more extreme wave impacts on the coasts due to higher wind velocities. A shift in monsoon precipitation patterns combined with heat waves is causing droughts. The recorded annual precipitation in Tainan in 2021 was 1001 mm, less than half of the average annual precipitation.

The people of Taiwan are generally familiar with natural disasters such as typhoons, floods, and earthquakes, which has led to a high level of public risk awareness. Typhoon Morakot in 2009 was one of the most catastrophic events in the country's history. Over a period of three days, more than 3000 mm of rainfall was recorded in southern Taiwan, resulting in enormous mudflows, landslides, and severe floods throughout the region. This disaster destroyed the entire village of Xiaolin and resulted in 677 deaths (e.g., Chien and Kuo, 2011). This served as an eye-opening event, encouraging more active thinking and strategy development among government bodies. Since then, government at all levels in Taiwan has shifted its focus of engineering-oriented flood management (see Figure 5.10) to a combination of engineering and non-engineering strategies. These include engaging local communities in capacity building through emergency response and disaster preparedness, as stated in the Disaster Prevention and Protection Plan by the Executive Yuan (2013).

However, while disaster risk perception is generally high, climate risk perception is not as widespread, partly due to lack of information transparency and effective communication (Chou, 2013). Historically, there has been a noticeable lack of experience in collaboration between the government and the public, particularly in public hearings. The process of constructive dialogue, effective communication (both talking and listening), and patience were not consistently practiced, contributing to the disconnect between interested stakeholders. This led to a perception among citizens that most public engagement in Taiwan is superficial, with no real expectations of changes in plans or processes following public comments. This created an environment of distrust and disempowered communities from participating in the process. However, there has been significant improvement in recent years, with more participatory practices being implemented (Wang et al., 2018).

Climate change responses

The first official document about climate change adaptation in Taiwan is the Adaptation Strategy to Climate Change in Taiwan, announced in 2012 by the National Development Council (Executive Yuan, 2012), the leading authority of political decision-making processes. To enhance societal resilience and minimize the impacts of climate change, the guidelines include eight different sectors: disaster, infrastructure, water resources, land use, coast, energy supply and industry, agricultural production and biodiversity, and public health. Each sector is overseen by a designated authority in the central government and is required to develop a sectoral national climate change adaptation action plan. These plans outline general measures to be implemented over the following five years and mandate the publication of a sectoral achievement report every five years. For example, the disaster sector is organized by the National Science and Technology Council, while the water resource sector and the coast sectors are led by the Ministry of Economic Affairs and the Ministry of the Interior, respectively. At the local level, a city or county climate change adaptation action plan is required following the sectoral action plans. For instance, Tainan City published "Tainan City Climate Change Adaptation Project" in 2015, which was updated in 2020 (Tainan City Government, 2020). The 2020 "Tainan City Climate Change Adaptation Project" lists 62 action plans; each is categorized as either short-, mid-, or long-term action. Currently, the third phase of the National Climate Change Adaptation Action Plan is being prepared for 2023-2027.

Climate Change Adaptation in Taiwan addresses a variety of events, including slow-onset and sudden events as well as compound events. These include both climate-induced and non-climate-induced phenomena, such as typhoons, sea level rise, extreme precipitation, heatwaves, droughts, land-use changes, and ecosystem degradation. In 2010, a national platform known as the Taiwan Climate Change Projection Information and Adaptation Knowledge Platform (TCCIP) was launched. It is coordinated by the National Science and Technology Center for Disaster Reduction and aims to build up a climate change dataset, supply projected climate change downscaling data, and provide the climate change scientific data services related to climate change. However, a consensus has not yet been reached on a specific climate scenario for consideration in the action plan, nor is there a fixed time frame for adaptation.

The primary goal of climate change adaptation in Taiwan's coastal areas is to mitigate coastal hazards and ensure the sustainability of marine resources. Most action plans to date have been adapted from existing sectoral plans and strategies. For example, the 2020 "Tainan City Climate Change Adaptation Project" specified the main strategies such as controlling coastal erosion through beach nourishment and enhancing coastal protection. This approach is partly due to the challenges in envisioning futures for climate change adaptation, especially in the absence of a selected climate scenario or an officially endorsed fixed time period (Wang et al., 2023). Additionally, the action plans tend to be more single-sectoral and focus on coping and incremental adaptation, highlighting the need for more collective and transformative efforts as well as increased collaboration across agencies.

It is noteworthy that there have been two important milestones supporting climate change adaptation for coastal areas in Taiwan. The first occurred in February of 2015, when the Coastal Zone Management Act (Executive Yuan, 2017) was implemented. This act enabled the creation of an Integrated Coastal Zone Management Plan, specifying conservation zones and protection zones and assigning responsible agencies to develop and execute these plans. Following this, the Water Resources Agency (WRA) under the Ministry of Economic Affairs announced the Coastal Protection Plan. This plan categorizes the coast's protection level based on the risk level of four types of hazards: storm surge, floods, coastal erosion, and tsunami. In 2020, the WRA also published the first assessment of coastal risks to include climate change impacts, identifying five levels of risk (Water Resources Agency, 2020).

The second milestone occurred in January 2023, when the Climate Change Response Act became law, mandating the implementation of climate change adaptation measures. This act specifies that an adaptation scenario will be established to guide risk assessment and adaptation strategies for the next 20 and 40 years. The strategies in the 2023-2027 National Climate Change Adaptation Action Plan for the coastal sector include (1) establishing appropriate prevention facilities or mechanisms to mitigate coastal disasters, such as sand nourishment or nature-based solutions; (2) protecting marine resources and marine habitats and fostering sustainable ecosystem development; and (3) enhancing monitoring and an early warning system to respond to coastal hazards and change (Executive Yuan, 2023). While these strategies are mostly technical and political, they also include some measures to encourage social cohesion in the context of climate change adaptation. These include public awareness and education, community engagement (involving NGOs and civil society groups), collaborative governance, research and innovation, and international cooperation, as outlined in the Climate Change Adaptation Action Plan. This approach may enhance climate risk communication and perception (Wang et al., 2023). A notable example is the sandbar restoration on the Tainan coast, where the Taijian National Park, the Tzu Chi Foundation, and the Tainan City government collaborated to use soft measures like geotextile tubes and bamboo fences as well as the planting of over 70,000 trees over three years starting in 2021, whilst also recognizing sandbars as natural forms of coastal protection (Tse-Xin Organic Agriculture Foundation, 2021).

Figure 5.10: Tainan, Taiwan: A typical coastal community in Tainan protected by a sea dike with protection level of 50-year storm surge, air-drone photo, Taiwan. Photo: Hsiao-Wen Wang.

Enabling and constraining factors

Over the past forty years, following the lifting of martial law, the need for economic development and disaster prevention has placed a crucial emphasis on safety in Taiwan, particularly influencing social awareness of coastal areas. The dominant strategy for coastal protection has been a hard protection approach, aimed at holding the coastline. This has been achieved primarily through the construction of hard engineering structures such as seawalls, groynes, and armor units along the coastlines (Yang et al., 2012). However, the overuse of coastal regions can lead to coastal erosion and shoreline retreat, threatening the inherent life and property of these areas (Lan and Hsu, 2021). Additionally, there is a strong competition for land between fish farming, renewable energy, and other types of development and nature conservation in coastal areas. This often results in conflicts between the interests of nature conservation and coastal protection, leading to delays in implementing urgent coastal protection measures due to concerns raised by nature conservation advocates.

In general, the main constraining factors in climate change adaptation in Taiwan include fragmented administration, sectoral thinking, and the many layers of bureaucracy. For instance, due to the sectoral routines, the two pillars of the Coastal Management Plan—the Coastal Protection Plan and the Coastal Conservation Plan—, do not seem to have holistic interdisciplinary strategies. Additionally, the need for long-term planning and a lack of knowledge and experience in dealing with uncertainty are other significant factors constraining the adaptation efforts.

However, the national projection information and adaptation knowledge platform TCCIP, which frequently updates data and selected climate change practices and is set to enhance its climate services by supporting the adaptation scenario, is seen as an enabling factor through the integration of diverse ways of knowing. In a recently released report co-published by National Science and Technology Council and the Ministry of Environment (2024), the 2.0°C warming scenario is used for evaluating potential impacts and national adaptation planning. Most of the strategies stated in the Climate Change Adaptation Action Plan are simply adopted from the existing sectoral plans, particularly from the disaster response plan, and are not actively reducing risks and vulnerability by considering future climate conditions. Additionally, other factors, such as the prioritization of the economic potential, the lack of adequate funding support, and a lack of participatory approaches in coastal climate change adaptation, also play a role. Consequently, in coastal areas where the flood potential is high and could be impacted by sea level rise, there are still new developments (e.g., solar panel farms) and new hard protection being built that only meet the current needs. This can lead to unexpected consequences, ultimately increasing vulnerability.

Take-home message

After the lifting of martial law around forty years ago, there has been a strong competition for land between fish farming, renewable energy, and other types of development and nature conservation in Taiwan's coastal areas. Taiwan's frequent experiences with extreme events have generally heightened disaster risk perception, with safety playing a crucial role in influencing social awareness of the coasts. Although climate change adaptation in Taiwan is mainly informed by existing sectoral plans and strategies, the experiences gained from disaster preparedness and emergency response provides opportunities to enhance climate risk perception. This enhancement can enable improved adaptation to climate change by more effectively leveraging synergies with broader work. Site-specific climate scenarios, as required by the Climate Change Response Act, are serving as anticipatory corridors and allow the development of site-specific adaptation strategies tailored to future climate conditions.

5.12

Conclusion and Assessment

The case studies in the previous sections have provided an empirically grounded and systematized assessment of the various conditions of climate change adaptation in urban, rural, and coastal areas. They addressed specific manifestations of the wheres, whens, and hows of place-specific incidents and the emerging problems that need to be tackled by current and future sustainable climate change adaptation. The case studies have also considered the role and importance of diverse ways of knowing in shaping adaptation responses and local practices in the context of climate change (Petzold et al., 2021; Wiener et al., 2023). Despite the limitations stemming from the selection of case studies from around the world, the theoretical frameworks used, and the methods applied, some general convergences and divergences emerged. They can be summarized in the three thematic areas of (1) climate change adaptation and locality, (2) climate change adaptation and the politico-administrative context, and (3) climate change adaptation and the intangible socio-cultural dimension. Rather than separate, these areas should be considered as intersecting if not mutually enmeshed. Based on the empirical and conceptual work, the following sections summarize the insights gained and, where possible, assesses what could be learned from the case studies about the conditions under which sustainable climate change adaptation might be plausible.

Climate change adaptation and locality

This chapter has shown that climate change and adaptation are more than purely evidence-based or rational entities. Adaptation in particular is a genuinely localized and socialized endeavor that is carried out against the backdrop of a unique regional culture. That culture includes local history, place-based contingencies of everyday life, and an existing physical and social environment with its place-specific conditions. Hence, the physicality of climate change merges with an emplaced experience of climate. To paraphrase Booth (2008, p. 299, [addition by authors]): "As we experience place [and climate change] we experience an intertwining of ourselves with that place [and climate change]; an intertwining of memories, both personal and collective, with the physicality of place [and climate change]. This interlacing of place [, climate change] and memory can be said to infuse memory with physicality, place with [social] mentality." This conceptual understanding was encountered in all case studies, leading to possibilities for sustainable climate change adaptation. The aspect of place-based or local perception of climate change is outlined in the greatest detail in the cases of Lower Saxony, Nepal, Namibia, and North Frisia. Here, localized perceptions not only set the scene for adaptation to be perceived as a generally relevant and necessary concept, but also lead to what could, should, and already is being done. In the case of Nepal, certain local adaptation measures such as irrigation procedures clearly evolved out of the specific place-based interaction with climate change. The same holds true for Namibia and Lower Saxony where, although in different cultural and natural contexts, crop rotation is practiced in farming as a response to climate change. In North Frisia, climate change perception is not actively used to adapt to current climate change but forms an important backbone to diking as an existing form of dealing with climate change impacts. In Hamburg, perception and adaptation are separate in that perception does not seem to inform adaptation measures as such.

It is important to note here that local ways of perceiving and adapting to climate change are in fact place-based ways of experiencing and dealing with climate change. These place-based ways of knowing are rarely taken into consideration during so-called stakeholder dialogues, as they often run counter to the established and institutionalized rationale of informing the public based on scientific evidence (for more details on our approach to diverse ways of knowing in a changing climate, see Petzold et al., 2021; Wiener et al., 2023, pp. 22-24; see also Chapter 2). Place-based climate perception and the resulting knowledges, however, are in themselves legitimate social facts and clearly represent an enabler of climate change adaptation. They could contribute to more experiential and localized ways of knowing, in contrast to more abstract and scientific ways, and assist in tailoring adaptation measures to local or regional conditions. At the same time, it is important to acknowledge that the natural environment and its associated local processes set some clear boundary conditions (for assessments of the impact of climate variability and extremes on climate adaptation, see Chapter 4). It therefore matters greatly in terms of sustainable adaptation options and measures whether one lives on a small island in the Maldives or in the middle of a megacity such as São Paulo.

Engaging with and "doing" climate change adaptation is therefore closely linked to social traditions, histories, and local experiences, all of which are deeply embedded in, and in constant interaction with, places. The enabling potential of the place and climate change nexus is, however, constrained by aspects of the politico-administrative system, as explored in the following section.

Climate change and the politico-administrative context

The case studies reveal that strategies of climate change adaptation are often constrained by policies, governance systems, legal regimes, administrative structures, and routines. National, federal, regional, and local adaptation plans represent enabling factors in almost all cases as they officially acknowledge climate change and the need to adapt to it. They can result in politically binding action plans and the release of financial resources to fund adaptation, meaning that community adaptation plans could be developed, such as in Nepal. On the downside, these resources are often laborious to access, as shown in the case of Lower Saxony, where farmers mentioned the bureaucracy involved in obtaining subsidies for changing from extensive to organic or precision agriculture. This indicates that changes in adaptive rationales are tricky to handle because existing political, legal, and administrative structures lack the necessary flexibility to enable new solutions for newly evolving climate challenges.

Comparable aspects can also be seen in the case of Hamburg. Although the city is a German role model for climate change adaptation, practical implementation—as in the Taiwan and Ho Chi Minh City cases—is often constrained by sectoral thinking and the separation of responsibilities for adaptation and mitigation between different administrative bodies, or even between units within the same administration. Furthermore, the mandate of political, administrative or other bodies to issue directives is often unclear, resulting in situations like São Paulo, where municipalities only hold an advisory role and have insufficient political or administrative power. Changes in administrative personnel, unclear institutional responsibilities, unstable political regimes and center-periphery differences—see Taiwan and the Maldives—represent added constraining factors. The various organizational, administrative, and institutional lock-ins at work here clearly lead to a preference for coping strategies and limit incremental or even transformative change in climate change adaptation. They often result in the perpetuation of well-known technical solutions and structural forms of adaptation. This can be seen in the case studies on Ho Chi Minh City, Taiwan, São Paulo, North Frisia, and the Maldives, where such measures are conceived as feasible and fine-tuned to reflect the prevalent administrative and political rationales. Yet they are not really fit to deal with current or future climate change and the goal of sustainable climate change adaptation—with the cases of the Maldives and Ho Chi Minh City also displaying examples of maladaptation and negative trade-offs.

Furthermore, it is often overlooked that from a political point of view adaptation should be conceived as a social and participative process. Ideally, such processes should address social inequalities that should not be framed as a threat to existing policy rationales and administrative practices. On the contrary, participation should be seen as an enabler of sustainable climate change adaptation, as shown in the example of Nepal. This goes hand in hand with acknowledging the potential of diverse ways of knowing in the context of stakeholder dialogues and participation, as alluded to in almost all case studies. The need for genuine, sincere, and trustful involvement of actors in the development and implementation of adaptation measures is important. This goes beyond the raising of awareness, so-called knowledge transfer, or cursory public outreach. Failure to do so can result in structural misalignment of climate change adaptation, as in the case of the Maldives.

Regarding the political and administrative environment of adaptation efforts, many aspects thus need to be considered. They revolve around governance systems, legal regimes, and administrative structures, for example in terms of available action plans, but also less tangible factors such as political stability, bureaucracy, sectoral thinking, staff continuity, and the need to engage in real participation. The implementation gaps detected here are striking, and there is convergence with other gaps identified (see Chapter 6). The political-administrative context can therefore be seen as a key barrier to sustainable climate change adaptation because its charactersitics as outlined above encourage the use of coping strategies.

Climate change adaptation and the intangible socio-cultural dimension

Lastly, the intangible socio-cultural dimension emerged as an important issue in almost all case studies. Strongly intersecting with locality and the respective policy context, its potential has often been downplayed as "only" social and therefore less relevant or impactful. Yet, socio-cultural practices represent an important intangible anchor for the social dimension of adaptation. The long-standing historical experiences and diverging ways of dealing with natural hazards based on diverse ways of knowing clearly represent an enabler. They contain socially established ways of problem-solving, which have become materialized in natural infrastructures such as breakwaters or stalk plantings, as seen in North Frisia. The traditional scrub and tree management for island protection in the Maldives or the division between commercial and household work as in Namibia are further examples for socio-culturally embedded coping strategies. On the other hand, technical infrastructure inevitably leads to path dependencies due to the need to maintain and develop this infrastructure at the level of administration, governance, and civil society, as in the case of North Frisia, where the emblematic dike is as much a socio-cultural as a physical entity. Comparable aspects are also mirrored in the lack of willingness to change farming business habits in Lower Saxony. This can be interpreted as a constraining factor resulting from intergenerational habitus, leading to path dependencies. Such elements represent coping, while incremental efforts as outlined in irrigation strategies as seen in the example of Lower Saxony display a small degree of flexibility.

Besides these social, economic, and political aspects, diverse inequalities represent an important issue that is closely related to the vulnerability of different population groups. Living in specific parts of the city in line with income and the affordability of housing is not only a matter of social status, but also related to the impact of climate change, as can clearly be seen in the unevenly distributed deaths by heat in Ho Chi Minh City or in the fatalities of flooding in São Paulo and Hamburg. Women represent a specifically vulnerable group, as they use space differently, perform work that is often overlooked in male-driven emergency plans, and are not explicitly addressed in climate change communication. For example, communication devices such as adaptation platforms, as shown in the Taiwanese case, do not integrate diverse and gendered ways of knowing. This fosters the non-participation of women and other vulnerable groups, exacerbating inequalities.

Considering all the various aspects mentioned here, the relevance of intangible socio-cultural aspects such as diverse ways of knowing on various levels, social affiliation in connection to vulnerability, and gender issues becomes obvious. Generally, they hold an enabling potential for sustainable climate change adaption that is so far rarely considered, officially addressed, or practically used. In fact, most of the aspects mentioned here are currently overlooked or neglected. The consequence is that considerable potential for climate change adaptation—in particular for facilitating more sustainable adaptation—is, sadly, lost.

Assessment of results and concluding remarks

The plausibility of sustainable climate change adaptation depends not only on the physical conditions of the impact of climate change, but also on the context-specific limits to adaptation as encountered in this chapter. Limits are contingent and can be shifted through innovation. The case studies show that they ultimately depend on prioritization, availability, and allocation of resources, as well as on what is acceptable in a specific socio-political setting. Against the background of growing empirical evidence, it is crucial to acknowledge the risk of maladaptation inherent in technical adaptation efforts, but also the spatial, societal, and political context of successful adaptation. There is a growing tendency to consider disaster risk prevention a form of climate change adaptation, even though successful adaptation measures only prove themselves during the next disaster situation. Even then, there are limits to adaptation that have to be kept in mind. These can be divided into soft and hard limits, the former understood as those for which no further adaptation options are currently available but might exist in the future; and the latter where adaptation options are neither effective today nor conceivable in the future (Thomas et al., 2021). As the case studies have illustrated, innovation can bring unforeseen options; in some circumstances, there are even ways to overcome seemingly insurmountable lock-ins on different levels (see e.g. the case studies North Frisia and Maldives).

Climate Change Adaptation Assessments

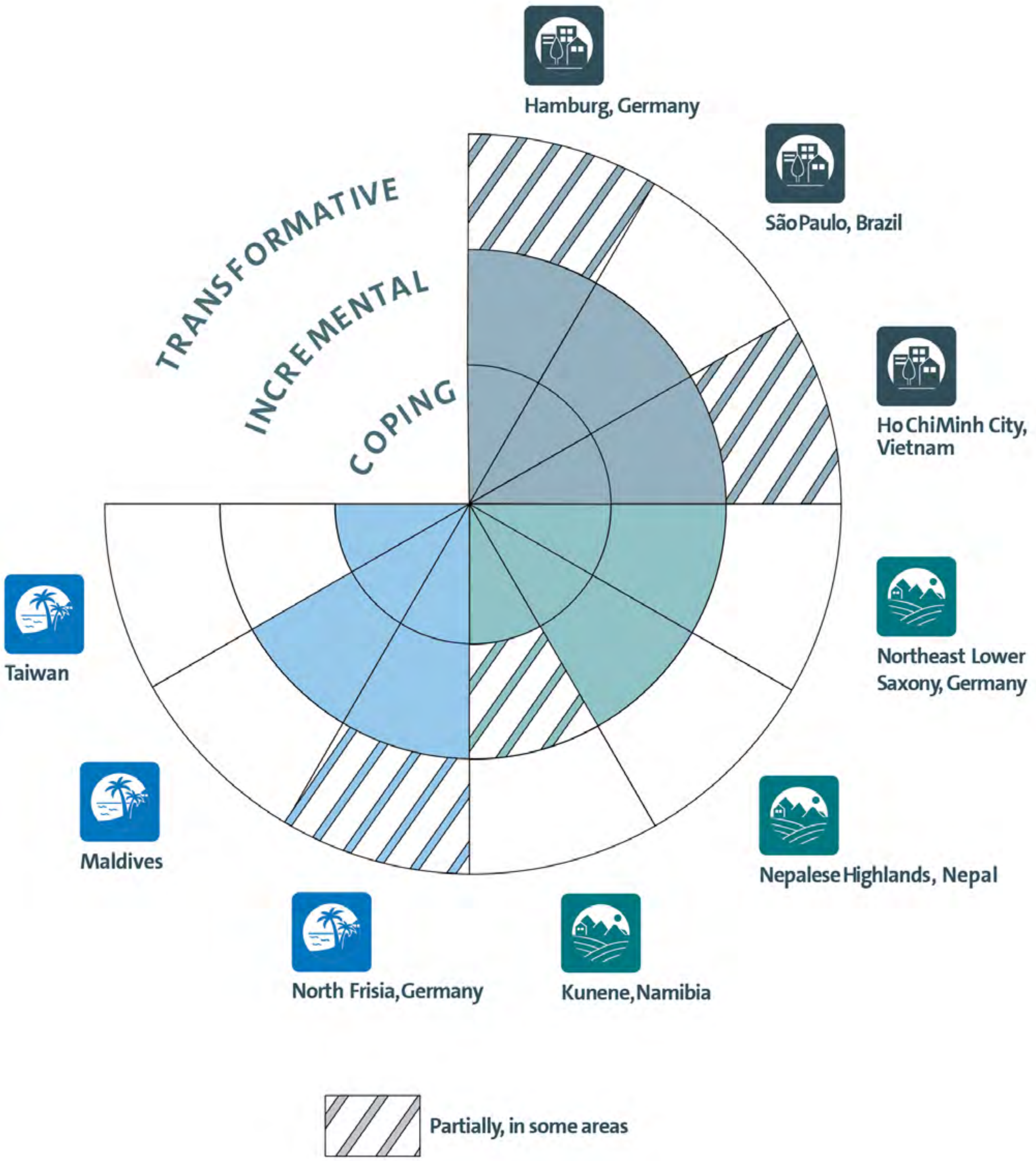


Figure 5.11: Climate change adaptation assessment (please read in clockwise direction and from the center to the periphery) in urban (dark grey), rural (green) and coastal areas (blue) investigated in this chapter. They are divided into the sections of coping, incremental, and transformative. The hatched areas indicate a tendency toward but not fully achieved state, while blanks indicate that such processes were not revealed at all by the analyses in this chapter. Colored areas indicate that, for example, the process of coping is prevalent and well-established.

The limits also concern the degrees of freedom and flexibility as well as the power of political, economic, and social interests to implement adaptation strategies and to decide which form of adaptation is adequate in one's own situation between exposure and vulnerability. The case studies show that the different categories of adaptation responses—(1) coping, (2) incremental adaptation, and (3) transformative adaptation—are not always clearly distinguishable. The vast majority of adaptation responses are trapped in a governance and technical path dependency in that it is predominantly conventional approaches that are used to deal with the challenges of climate change adaptation. Depending on the experienced or anticipated severity of climate change impacts on social and economic systems, these are primarily coping strategies (the Maldives, Taiwan, Namibia, Ho Chi Minh City, and São Paulo) coupled with attempts to slightly adapt incrementally (Lower Saxony, Hamburg, North Frisia, Nepal). Only very few cases aim at full-scale transformation, and then only with regard to singular measures (e.g., water storage capacity in Hamburg, the sponge city; testing of nature-based solutions along the Frisian coast; developing park gardens to capture incoming water in Ho Chi Minh City). In some cases, transformative approaches to climate change adaptation can be detected only in some sectors, while in others it sticks to mostly incremental approaches or exists only as plans, strategies, and declarations of intent. In such cases, it is not possible to uniformly classify existing adaptation as coping, incremental, or transformative as in Hamburg, Ho Chi Minh City, or the Frisian coast (see Figure 5.11). This implies that the sustainability aspect of adaptation strategies is only being insufficiently considered. Indeed, real sustainable pathways could not be detected in the case studies. At the same time, transformation may not always be positive, desirable, and worthwhile either. More conceptual work is needed to critically reflect on the implications of coping, incremental, and transformative adaptation against the backdrop of empirical results over time.

With regard to the plausibility of sustainable climate change adaptation, four main lessons can be drawn from the case studies. Firstly, laws, regulations, and adaptation plans are crucial steps toward sustainable climate adaptation. Overcoming persistent political conflicts, social inequalities, and other structural challenges on various scales are also key here, as they are fundamental obstacles to the implementation of climate adaptation measures, let alone sustainable climate change adaptation strategies. Secondly, goal-setting strategies for climate action are only effective if they establish clear indicators and measurable goals and are developed in a participative, trustful, and mobilizing way. This should not only engage social actors and communities at large, but also support social actors in holding policymakers accountable for any commitments made. Thirdly, local and national governments with their respective political agendas have substantial influence on the implementation of climate adaptation measures (or lack thereof). A lack of clarity with regard to political and administrative responsibilities results in mismatches between adaptive capacities and local climate vulnerabilities. Integrated policies on different scales as well as efforts to strengthen internal relations and adopt a more horizontal way of working are critical to progress toward sustainable climate change adaptation. Finally, there is enormous yet rarely tapped potential for societal mobilization and co-production of knowledge on the barriers and opportunities for sustainable climate change adaptation. This could, for example, draw on historically accumulated experiences in dealing with extreme weather events and climate-related risks and vulnerabilities. Public policies for sustainable climate change adaptation could be informed by this, exploring synergies between the need to adapt to climate change on the ground and socio-economic development as well as human health and well-being.

Against the background of the contextual conditions scrutinized in the case studies, it is clear that political and administrative structures are not currently equipped to deal with the local, political, and social dimensions of climate change adaptation. This applies at the conceptual, social, legal, administrative, and practical level. Only some rare cases show glimpses of the necessary flexibility and openness that allows for diverse ways of knowing to be integrated into participation and place-based implementation of climate change adaption. In North Frisia, one such example is the Strategy Wadden Sea 2100, which is a cautious attempt at bringing together citizens, administrators, and scientists. As it stands, structure and agency confront each other in the context of climate change, primarily leading to the reproduction of a coping rationale that merely reacts to the next disaster or climate related event. The increased accumulation of better data for more scientific knowledge is often seen as a remedy or as a solid evidence base for improved and more suitable sustainable climate change adaptation. However, this is not always the case. Anticipatory planning and dealing with possible and plausible climate futures is still limited, as climate action still largely relies on the rationale of "wait and act" (Aall et al., 2023). A "reflect and act" rationale might be more suitable in view of the results outlined here. What the chapter clearly indicates is that policy and administration have to take much greater account of localities, the politico-administrative systems, and the intangible socio-cultural environments. The different ways of knowing, the potential of societal mobilization inherent in knowing, and the need to redistribute power across the areas explored can contribute to making climate policies more tailored and therefore fit for the future. Only then will sustainable climate change adaptation become plausible.

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6

Integration and Synthesis of Assessments

BOX III Toward an Inclusive and Connected Repertoire of Climate Action

6

Integration and Synthesis of Assessments

Changing social dynamics and physical processes increase the pressure to adapt

The current Outlook consists of three distinct chapters that provide in-depth empirical analyses on social dynamics affecting the plausibility of deep decarbonization by 2050 (Chapter 3), physical processes in the context of regional variability and extremes (Chapter 4), and context conditions for the plausibility of sustainable climate change adaptation (Chapter 5). As in previous editions of the Outlook, Chapter 3 assesses the dynamics of 10 selected social drivers as key processes affecting the prospects of social transformations toward deep decarbonization. The update of the social driver assessments emphasizes that deep decarbonization by 2050 remains not plausible under current conditions. This sobering finding emerges despite heightened social driver dynamics, which are observable in quantitative increases and—to a lesser extent—qualitative shifts in climate action. Overall, there is a proliferation of resources and consequently a qualitative change in the global opportunity structure for climate action (Section 3.1). Nevertheless, there are no fundamental changes in the repertoires of action and ultimately in societal agency toward a low-carbon shift. A key implication of our social plausibility assessment of deep decarbonization by 2050 is that societies worldwide will face increased pressure to adapt to climate change as mitigation efforts lag far behind and greenhouse gas emissions continue to increase.

Chapter 4 assesses the interplay of internal climate variability and extreme events through a selection of examples that illustrate some critical challenges to sustainable climate change adaptation. The chapter provides key insights on (1) the capability of climate models to represent extremes, (2) the attribution of extreme events to human influence, and (3) the probability of compounding extreme events. Understanding the uncertainties and limits of climate models is key for evaluating how well they represent extreme events. This in turn is crucial for predicting future extremes and developing adequate strategies for dealing with uncertainties in adaptation responses. Understanding whether extreme events have—at least in part—been caused by human influence is important for planning and developing adaptation strategies. That said, Chapter 4 also points out that an affected community must respond to an extreme event irrespective of whether it was partly caused by human influence or entirely due to natural causes. The assessments of physical processes further highlight that there is a heightened risk when extremes occur as compound events that may result in disruptions to socio-ecological systems, increasing vulnerability and significantly affecting the adaptive capacity of people and communities.

Against this backdrop, Chapter 5 assesses the plausibility of sustainably adapting to climate change through case studies in nine localities across the globe. The case study assessments show that climate change adaptation is a genuinely localized and socialized endeavor that is affected by politico-administrative dynamics and intangible socio-cultural aspects such as social inequality, gender, and diverse ways of knowing. The overall assessment of case studies delivers insights on diverse adaptation responses categorized as coping, incremental, and transformative adaptation. A key finding in this regard is the prevalence of coping and incremental adaptation responses, highlighting the presence of governance, technical path-dependencies, and lock-ins that could bear the danger of maladaptation in future, changing physical conditions. The analysis of implications underscores the importance of narrowing implementation gaps, for example, through climate action strategies with legally binding, accountable goals, as well as participatory governance and other strategies that incorporate diverse ways of knowing and dealing with natural contingencies and hazards into climate action.

While all assessments deliver key insights on dynamics and contexts that are summarized in more depth in the respective chapters, this chapter develops an integrative assessment that reveals the interconnected nature of the findings. As outlined in the methodology chapter (Chapter 2), this integrative approach, which consists of three building blocks, attempts to answer the overall question of the current Outlook: Under which conditions is sustainable climate change adaptation plausible?

Toward an integrated plausibility analysis

The building blocks of the current Outlook contribute to a better understanding of the plausibility of specific climate futures, understood here not only as projections of future greenhouse gas emissions, but rather as future states of the co-evolution of the physical climate system and society. Climate futures, in this sense, encompass the multi-layered interactions of social and physical processes, which include both mitigation and adaptation scenarios. While the social driver assessments address deep decarbonization by 2050 as a mitigation-specific climate future, the implications of such assessments have important consequences for adaptation responses. That is, the plausibility of deep decarbonization by 2050 affects the plausibility of sustainable climate change adaptation. The adaptive capacity of a region or a community is sometimes constrained and sometimes enabled by context-specific conditions that, in turn, are influenced by current and future global decarbonization pathways and related anthropogenic climate change, especially by regional variability and extremes. The findings of each of the building blocks of the current Outlook edition provide key insights on the interplay of these interlocking elements of plausibility. The overall analysis of the assessments points to two fundamental issues in climate futures research: uncertainty and the relations between global and local scales in physical and social dynamics. In the following, we discuss these important aspects in turn.

Uncertainty in social and physical dynamics

Uncertainty in social and physical dynamics affects the plausibility of sustainable climate change adaptation on three levels. First, in Chapter 3 our sobering conclusion that deep decarbonization by 2050 remains not plausible—even less plausible than in previous assessments—is a finding that narrows down the plausibility range of climate futures scenarios, especially in terms of what we can realistically expect that society will have to adapt to. Whereas in previous Outlook editions our assessment found that two out of 10 social drivers were inhibiting (deep) decarbonization (i.e., corporate responses and consumption trends), the present update adds a third inhibiting social driver, namely fossil-fuel divestment. The dynamics of six other social drivers support decarbonization, but are insufficient for deep decarbonization; one driver is ambivalent (Section 3.12). Uncertainty remains as to how social expectations and anticipatory actions will shape the perceived necessity for future mitigation measures and adaptation strategies to expected effects and impacts of climate change. Furthermore, while achieving a 1.5 °C limit to global warming is currently not plausible, there is a wide range of uncertainties regarding other plausible climate futures beyond that limit that, in turn, hamper anticipatory adaptation responses.

Second, as Chapter 4 highlights, uncertainty is also crucial in assessing regional climate variability and extremes, especially because of the role of chance (or aleatoric uncertainty). Uncertainty is a key element in evaluating the capability of climate models to represent extremes, the attribution of extreme events to human influence, and the probability of compounding extreme events. The attribution of extreme events to anthropogenic climate change or internal climate variability, in particular, raises the question of whether it matters to know what a community is adapting to. Attribution research describes how the likelihood of an extreme event changes with anthropogenic warming, which serves as basic orientation for policy planning and development; conversely, lack of attribution might serve as an excuse for inaction. An additional consideration that goes beyond the scope of our case study assessments is that attribution might become crucial to establish liability and compensation for losses and damages from climate change impacts and risks.

Third, as the case studies in Chapter 5 reveal, climate change adaptation in and of itself is also intrinsically affected by uncertainties in the physical and social worlds, inasmuch as it involves the processes of anticipatory action based on past experiences and future expectations. The overall assessment of the case studies indicates that in addressing or coping with uncertainty, communities often resort to established routines and practices, which can lead to governance and technical path-dependencies. These potential lock-ins constitute limitations to adaptation responses that constrain the plausibility of sustainably adapting to climate change.

Global-local interactions

Global and local dynamics affect the plausibility of sustainable climate change adaptation in two main ways: First, the assessment of social driver dynamics, which focuses on the global opportunity structure for climate action, serves as a backdrop for the case study assessments on sustainable climate change adaptation, which in turn highlight the importance of context-specific conditions and place-based actions. The global dynamics of social drivers point to the dimension of societal agency worldwide that materializes in cumulative greenhouse gas emissions. The plausibility and scenario framework for deep decarbonization, therefore, uses global dynamics as a point of reference for the empirical assessments. The social driver assessments thus focus on trends and dynamics that are observable worldwide and configure a global opportunity structure for climate action. The analysis of the plausibility of sustainable climate change adaptation, in contrast, emphasizes the importance of locality. It manifests itself in regional geohazards and local history, place-based contingencies of everyday life, and more generally the specific conditions of the local physical and social environment. Global dynamics are by no means irrelevant to adaptation; however, an empirically grounded analysis requires a localized approach focusing on the sites where adaptation as a social practice actually takes place. Thus, the question of plausibility adopts a place-based approach that focuses on local manifestations of climate change and different time horizons and therefore requires a local scenario of sustainable climate change adaptation.

As a number of social driver assessments indicate, some decarbonization dynamics reveal an interplay between climate change mitigation and adaptation that is shaped by interactions between global and local scales. UN climate governance sets the framework for international negotiations on adaptation (Section 3.2); transnational cooperation exhibits various initiatives such as city networks on adaptation (Section 3.3); social movements and activism include pre-figurative practices that foster local adaptation (Section 3.5); a number of climate litigation cases worldwide touch on issues of adaptation, although these remain a small portion of climate change cases globally (Section 3.6); corporate responses sometimes include adaptation-related concepts such as organizational risk and organizational resilience (Section 3.7); there is comparatively low media coverage of adaptation issues in selected countries (Section 3.10); and various forms of knowledge production are a core dimension of adaptation responses (Section 3.11). All these prove that the global dynamics of social drivers of decarbonization generate resources and repertoires of climate action that are potentially relevant for local adaptation responses. Further research is needed here to better understand how resources and repertoires of climate change mitigation and adaptation travel across global and local sites of governance. Questions remain, for example, on how global norms and regulations are shaping local adaptive practices—if at all—, or whether financial resources reach localities and enhance the adaptive capacity of communities.

The second way in which global-local dynamics affect the plausibility of sustainable climate change adaptation is in the heightened importance of regional climate information, related to the spatial resolution of global climate models. The assessment of regional climate variability and its impacts on specific localities can be crucial for place-based adaptation responses. The assessments of physical processes in Chapter 4 deliver insights into these dynamics. A key issue that the assessments bring to the fore is that the interplay between anthropogenic climate change and internal climate variability can amplify or attenuate changes in climate extremes on a regional scale. The large-ensemble simulations with increased spatial resolution substantially improve the representation of extreme events; but the required spatial resolution highly depends on the specific location and characteristics of the extreme event. As a result, not all model simulations are suitable for offering high-quality information for adaptation, thus impacting the planning of adaptation strategies to extreme weather events (Section 4.3).

The global and local dimensions of adaption responses (or the lack thereof) are also observable in the potential consequences of compound extreme events that generate impacts on multiple scales or cascades of effects never experienced before. Concurrent extreme heatwaves in the world's crop growing regions, for example, could combine with dry spells to cause crop yield loss, thereby disrupting local food production and posing new challenges to global food security (Section 4.5). Improving our knowledge on the specific global, regional, or local scale(s) on which the consequences and impacts of extreme events will occur is therefore important for the plausibility of sustainable climate change adaptation. These dynamics also empirically highlight the analytical premise of our framework: Social realities and the physical world are inextricably intertwined. While physical processes construct the frames in which social drivers unfold, social dynamics are at the same time shaping the physical environment in countless ways.

Conditions of agency in light of ambition and implementation gaps

In previous assessments, we have identified a growing densification of climate action, for instance in the number of national climate laws and Nationally Determined Contributions, transnational initiatives, attendants to global climate conferences, or climate litigation cases; we also noted an increase in resources within the global opportunity structure for decarbonization and climate justice. At the same time, our assessments of social driver dynamics toward decarbonization and of local case studies on sustainable climate change adaptation also showed persistent gaps in both ambition and implementation. The term *ambition gap* refers to the disparity between given aspirations, such as the goals on mitigation and adaptation set in the Paris Agreement, and the level of commitment, dedication, and planning required to turn these aspirations into reality, which would increase the plausibility of achieving these goals. The term *implementation gap* refers to the difference between the actual realization of mitigation and adaptation measures vis-à-vis proclaimed goals and targets. These goals are, for example, found in projected emissions of different climate scenarios, in Nationally Determined Contributions, and in adaptation plans outlined on different scales of governance.

In our model of change toward achieving the Paris Agreement goals, the building up of social agency and of more (and new) resources for a global opportunity structure is a necessary but not sufficient conditions for closing the existing ambition and implementation gaps. The analysis of social drivers of decarbonization and sustainable climate change adaptation emphasizes that both gaps are the result of various dynamics within and across social drivers and adaptation contexts. Empirical evidence provided in the current Outlook underpin four central and interconnected dimensions that help explain the persistence, or sometimes even widening, of ambition and implementation gaps in the face of increasing levels of climate action: (1) existing power dynamics and inequalities, (2) different ways of understanding, interpreting, and translating climate change-related norms and practices, (3) a lack of political coherence on different scales of climate governance, and (4) climate change mitigation and adaptation as multifaceted and wicked problems.

Power dynamics and inequalities

The current Outlook provides new empirical evidence highlighting how existing power dynamics and social inequalities shape the capacity of societal agents to effectively engage in climate change mitigation and adaptation. The emblematic matter among the social drivers is that the production of fossil-fuel and the consumption of carbon-intensive goods and services remain unevenly distributed and continue to significantly increase both global emissions and revenues for already dominant actors. The vulnerability to the consequences of climate change and the capacity for sustainable climate change adaptation are also shaped by social inequalities and remain unevenly distributed. These inequalities exist *within* local contexts—whether on a city, regional, or state level—as well as *between* these contexts and unfold in different ways. In general, the nine adaptation case studies highlight the larger issue of fundamental asymmetries of adaptive capacity, given the stark inequalities in access to technical means and financial resources. The lack of access to economic, political, and social resources undermines the plausibility of both deep decarbonization and sustainable climate change adaptation. This lack leaves behind certain actors, namely those without the necessary means and conditions to adapt to the consequences of climate change—as seen in the São Paulo case study, where the combination of a high level of social inequalities, the lack of infrastructure, and the consequent unequal levels of risk exposure and vulnerability have led to climate-related fatalities (Section 5.4). Social inequalities also undermine and inhibit dynamics toward deep decarbonization, for instance in the contexts of UN climate governance, climate activism, and fossil-fuel divestment (Sections 3.2, 3.5, and 3.8). Oil-producing states and firms continue to monetize their political power to limit mitigation efforts and increase their income by increasing fossil-fuel investments, having the power to ignore all pressures to divest. Climate activism and social mobilization, in contrast, face severe opposition all around the world. The implementation and ambition gaps thus intersect with power dynamics and inequalities on a spectrum from actively preventing implementation to eroding the grounds for meaningful mitigation and adaptation.

Divergent understandings and contestation of climate change-related norms and practices

Implementation and ambition gaps are also shaped by different ways of understanding, interpreting, engaging with, and translating particular goals, plans, and policies. Their actual meaning often remains contested, especially in light of political and cultural diversity. This ranges from local cases of adaptation strategies suggested by formal state institutions that are shown to fail when based on assumptions that contradict local norms and values (as in the case of pastoralists in Kunene, Namibia, Section 5.8) to global challenges of developing essential resources for decarbonization. The global resources generated by UN climate governance and transnational cooperation (Sections 3.2 and 3.3), for example, can, when incorporated into stable repertoires of climate action, contribute to align expectations and build trust among state and non-state actors or enhance climate-related standard-setting and certification processes. This continuous densification of climate action is an important development since the previous assessment. It indicates new opportunities and potentials for a global low-carbon transformation, as well as new avenues for research on societal climate futures. Nevertheless, empirical findings also highlight that despite the plethora of resources and an increase in dynamics no qualitative transformative shift toward deep decarbonization can be observed. Hence, the implementation gap is also a result of different social dynamics in which political goals, policies, or targets become contested. For example, the social driver assessments and adaptation case studies highlight that implementation is affected by divergent or even contrasting interpretations of particular goals and policies. Implementation may furthermore be impeded by loss of trust in governments or a lack of convinced self-efficacy at the individual level (see the case of the Maldives, Section 5.10, and that of the Nepalese highlands, Section 5.7).

Lack of political coherence on different scales of climate governance

A larger structural dimension that links the contexts of deep decarbonization and sustainable climate change adaptation is the observed lack of political coherence on different scales of climate governance. The overall dynamics of the 10 social drivers not only remain insufficient to attain deep decarbonization by 2050, but also highlight ambivalent and contradicting dynamics within and across drivers. For example, packaged forms of knowledge such as the IPCC assessment reports strongly support the scenario of deep decarbonization by addressing governance problems and policies. Yet, there are various knowledge resources gaining momentum that counter the plausibility of achieving this scenario, as different actors spread mis- and disinformation and establish new forms of climate denialism and delayism (Section 3.11). UN climate governance, transnational cooperation, and climate-related regulation, for example, highlight some positive trends in terms of establishing trust and cooperation through the establishment of standards or policy instruments (Sections 3.2, 3.3, and 3.4). However, there is still little effect on existing structural and institutional context conditions of drivers. The lack of qualitative shifts is indicated by the finding that the actual implementation of policy instruments remains limited due to political and social backlashes, and the change from soft to hard law in climate governance is not in reach. Similarly, the nine case studies on local adaptation also report the lack of political coherence as key constraining conditions to climate change adaptation. Adaptation strategies run through different political and administrative scales, from the local to the national, and display unclear roles and responsibilities of the public sector, frequent changes in regulation, and little coherence or even mismatches between goal setting, planning, and implementation. These different and contextualized ways of managing adaptation result in uncertainties, lack of trust in policy, and administration, as seen in the case of Lower Saxony (Section 5.6) and the Maldives (Section 5.10). Fragmented administration and unstable political dynamics worsen the situation as reported in the case studies of São Paulo and Taiwan (Sections 5.4 and 5.11). Further constraining conditions are limited budgets, no adequate funding support, or a lack of financial capacity at all (Sections 5.4, 5.7, 5.8, and 5.11). Also relevant in the case studies of Hamburg, Lower Saxony, and Taiwan are land or land-use conflicts (Sections 5.4, 5.6, and 5.11). These manifest as a perceived antagonism of housing and economic development on the one hand versus environmental and climate protection on the other.

Climate change mitigation and adaptation as multifaceted and wicked problems

A final point highlighted by the empirical analyses in Chapters 3, 4, and 5 is that the discussed implementation and ambition gaps also result from climate change mitigation and adaptation being a multifaceted and wicked problem. Contradictions and structural constraints with regard to building societal agency become visible in many contexts of climate change adaptation cases, where implementation often remains on a conceptual level and stops short of turning plans into actual practices. Adaptation or prevention action is not only a financial but also a socio-cultural challenge (see e.g. Section 5.9 on North Frisia), and a sense of urgency to act is psychologically linked to an experience rather than a (scientific) prediction. Ambition gaps exist in many cases where a coping rationale, which prefers merely reacting to the next climate-related event or disaster, prevails although transformational approaches would deliver more sustainable solutions. Against this background, a major lack consists in local application of adaptation, anticipatory planning, and dealing with plausible climate futures. The mode of action is currently still more oriented toward acute and pressing Disaster Risk Management approaches than on mid- and long-term adaptation measures. In this sense, the rationale remains one of “predict and act” where a “reflect and act” rationale might be needed. In a similar vein, social drivers of deep decarbonization are constrained by the required long-term measures and rationales, which contrast with short-term interests and goals. This not only manifests itself in the ongoing investments in fossil fuel engagements and corporate responses’ continued contribution to greenhouse gas emissions. There is, moreover, a lack of long-term vision on how to achieve just climate futures. Although a growing focus on just transition programs have resulted in some positive initiatives, such as the just transition partnerships launched within the wider context of UN climate governance, their reach is still limited and may, in many cases, not even prevent the development of new fossil fuel infrastructures.

Additionally, climate action is always embedded in, and intersects with, other dynamics that inhibit required global efforts for climate protection. For example, political and economic rivalries between the US and China, the two major global emitters, often turns climate change into a minor issue although dynamics of rapprochement in the context of climate change are visible. These examples illustrate that acute political crises often stand in the way of the long-term perspective required for both climate change mitigation and adaptation. This turns dealing with climate change into a wicked environmental problem.

Enabling conditions for sustainable climate change adaptation

In this final section, we outline a set of conditions necessary for sustainable climate change adaptation to become plausible. A fundamental and underlying condition for change, as discussed in the integrated plausibility analysis, relates to the interdependencies between mitigation and adaptation scenarios. The plausibility of achieving deep decarbonization by 2050 substantially affects the plausibility of sustainably adapting to climate change, which entails that increasing social dynamics toward a low-carbon shift would facilitate future adaptation responses. However, the specific question of whether an adaptation response will be sustainable or not depends not only on global emissions and the physical boundary conditions of climate change but also on the context-specific limitations to adaptation, which involve a variety of socio-cultural and politico-administrative aspects. These limitations, as the previous section outlines, translate into societal ambition and implementation gaps (see Chapter 5.12).

The overall analysis of the case study assessments clearly highlights the necessity for policymakers and decision-makers at large to consider localities and socio-cultural dimensions when designing and implementing climate adaptation strategies. In general, the existing political and local administrative structures lack conceptual and practical readiness to effectively address the local and place-based dimensions of social and physical context-conditions that are inherent to climate change adaptation responses (or the lack thereof). For example, knowledge production, dissemination, and participation play key roles here. A recurring approach to climate change adaptation policy involves gathering more data to enhance scientific knowledge, commonly perceived as a solution for enhancing and better aligning sustainable climate change adaptation measures. This evidence-based approach, however, often relies on the rationale of "wait and act" where a "reflect and act" rationale would be more fitting in light of the outcomes delineated in this context. Hence, recognizing diverse ways of knowing and related opportunities for social mobilization in these specific policy contexts is imperative to facilitate the co-production of knowledge and policy in a way that addresses extant power dynamics and inequalities.

The prevalence of coping and incremental adaptation responses often reveals governance and technical path-dependencies that maintain insufficient and in part unsustainable adaptive practices and hinder the development of alternative approaches. The case studies highlight the importance of flexibility and openness in politico-administrative approaches to adaptation policy, for example by integrating the diverse ways of knowing of local frontline communities into participative approaches to knowledge production and policy making. The relevance of these conditions lies not only in their potential to generate alternatives and avoid lock-ins, but also in ensuring that climate justice criteria are respected in the processes of transition to resilient societies. Whereas some medium- and large-scale technical interventions in climate change adaptation could be deemed superior in terms of efficiency, climate justice requires an approach that addresses recognition, processual, and distributive criteria.

Finally, sustainable climate change adaptation can only become plausible in a context of societal support for and political action toward structural transformations. This involves addressing social inequalities and asymmetric power dynamics, both of which constitute structural causes of climate change vulnerability and undermine the adaptive capacity and resilience of communities and marginalized groups in society. These challenges point at once to immensely inadequate international adaptation finance and local power dynamics that prevent affected groups from accessing resources that enhance their adaptive capacity and resilience. Such structural transformations are fundamental not only for overcoming current barriers to sustainable climate change adaptation, but also for increasing ambition and closing implementation gaps in climate mitigation while promoting climate justice at different levels of governance.

In sum, the nine case studies underscore the importance of considering context-specific aspects and diverse ways of knowing and dealing with climate-related risks and impacts when assessing, planning, and implementing climate adaptation strategies. In this context, co-producing knowledge, promoting the inclusion of diverse social actors in decision-making processes, and garnering broad societal support for ambitious climate policies and structural transformations is fundamental for sustainable climate change adaptation to become plausible.

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BOX III Toward an Inclusive and Connected Repertoire of Climate Action

Assessing plausible climate futures is a key scientific practice in the highly interdisciplinary field of climate science. In light of the essential task of knowledge production, we see our own role in developing a "responsible assessment". Assessing climate futures in this sense not only reflects underlying assumptions but also takes into account diverse visions of climate futures.

Box 3 illustrates ways to enhance the plausibility of both deep decarbonization and sustainable climate change adaptation. The selection of examples presented here resonates with specific stakeholder groups such as climate activists, carbon managers, and scientists. The examples also underscore the importance of fostering collaborative endeavors and forging synergies. The essence lies in proactively seeking interconnectedness and in leveraging novel resources forged across diverse sectors of society to drive progress in navigating the intricate dynamics of climate change. We reflect on selected principles and their potential implications by diving into the roles of knowledge, funds and power, and preparedness. In so doing, we dare employ a slightly normative tone, in contrast to the usually neutral character of the Outlooks.

Leverage and package diverse knowledges for just climate action: We have shown in this and previous Outlooks that packaged knowledge can create new resources that enable social drivers to turn toward deep decarbonization. Packaged knowledge is understood as various forms of integrated and contextualized knowledge that can be enabling for climate action. The global environmental assessments institutionalized by the Intergovernmental Panel on Climate Change (IPCC) have become the most prominent packaging effort to date. The institutionalized quality of the IPCC reports is reflected in the IPCC's participation in governance procedures and its important role in political and societal debates on climate change. More efforts in collaborating across fields need to be made to produce such packaged knowledge. Scientists in particular need to learn how to translate research results into information that can be used in other fields and that provides evidence for the connection between concrete climate impacts or risks and responsibilities. There is thus a need for formats of knowledge co-production that bring together the producers and users of knowledge across scientific disciplines, policy and advocacy groups, as well as society at large. The inclusion of diverse ways of knowing can help develop more relevant frames of perceiving threats of climate change and addressing injustices and can point to power relations that are constraining the transformation toward deep decarbonization. Diverse ways of knowing need to be included to acknowledge local insights and needs, develop place-specific measures, and—not least—to build political alliances across different scales and interests.

The field of attribution science is another example of packaged knowledge that can create new resources for climate action, for example as a reference point in law suits. While attribution science typically relies on physical climate sciences, more packaged knowledge is required from economics and other social sciences, for instance knowledge on investment risks that addresses the Chief Financial Officers in large corporations. So far, sustainability managers in high-emitting companies have had a hard time to push their company toward low-emission-futures if they lack the support of top-level managers in the fields of finance and asset management.

However, despite knowledge being an important resource, it would be mistaken to expect a linear effect of "better knowledge" in shaping desired climate futures. Knowledge can always be instrumentalized for other purposes, and it can even be completely ignored.

Use political, legal, and financial pressure to phase out fossil fuels: To achieve a more qualitative shift away from fossil-fuel profitability, more and new combinations of political, legal, and financial pressure will be needed to change the power relations, the inequalities, and relations of dependency that keep society locked in fossil-fuel engagements. Of particular relevance is combining public pressure on national governments, the use of legal options against corporate emitters or governments, and organizing as pressure groups to target large institutional investors such as pension funds, insurance companies, and banks. Investments in fossil-fuel engagements appear set to remain profitable for a long time, and this will only change if and when the majority of investors believe that the ambition and implementation gaps will be effectively minimized. Strategic alliances can try and enable this change. Such processes are often rather slow compared to the urgency inherent in the Paris Agreement, but examples from the past have shown that alliances across different fields can be effective in the long term.

One example is the Carbon Disclosure Project, which started in 2000 as a voluntary cooperation between financial experts, NGOs, investors, and representatives of large high-emitting corporations to create a new carbon reporting protocol. Over time, the Carbon Disclosure Project developed into a major tool to identify direct and indirect climate-related risks of corporate strategies and business models. It has changed its form, governance, and coverage, and has now almost global reach. However, turning this and other reporting tools into mandatory standards requires even more legal steps both in national contexts and as part of international agreements. Such reporting tools can contribute to sending a decisive signal to all investors that fossil-fuel engagements will effectively turn into stranded assets soon.

Work across sectors and scales to improve preparedness for the impacts of climate change: It is paramount to recognize the importance of place-specific impacts and interdependencies of climate change as well as place-based knowledge, experiences, and perceptions as highlighted in the case studies in the current Outlook. While sustainable climate change adaptation is embedded in national and global policies, implementation and the development of appropriate solutions takes place at the regional and local scale. Instead of supporting the widespread diffusion of standardized, blueprint technological solutions to climate change adaptation, it is recommended to establish local participatory processes in which existing experiences can be voiced and competing visions negotiated. Implementation is a cross-sectoral challenge that should not stop at traditional jurisdictional boundaries, but instead prepare for interconnections.

Efforts to implement effective sustainable climate change adaptation are facilitated by processes on all scales of governance. On the global scale, political agreement can provide financial resources; it can also create impetus by setting goals for climate change adaptation as part of the UN's climate governance or by supporting the creation of networks and knowledge exchange via transnational cooperation. People in international organizations can work to increase capacities for sustainable climate change adaptation in many different ways. However, it is the national context in which the framework for preparedness is created and where the conditions are set that allow for specific adaptation measures to be implemented. At this level, a genuine interest in improving local situations and creating the necessary spaces for action is crucial. International funds should be used to increase the preparedness of vulnerable groups and not only support the particular interests of the most powerful. Rather than exacerbating commonly experienced center–periphery or national–regional contrasts, such funds should be used to balance them out.

Institutionalizing local adaptation managers on a community level to act as gate-keepers and multipliers can support the practical implementation of climate change adaptation. However, if they are burdened with too many tasks and are only given strategies and political declarations instead of real decision-making power to work with, they will have little room to maneuver. Creating administrative leeway is therefore an important structural measure that can strengthen sustainable climate change adaptation locally. In addition, decision-making based on participation, trust, and mobilization reduces the risks of self-serving and corruption, further improving the conditions for sustainable climate change adaptation in the long run.

Sectoral authorities, goals, plans, and procedures often exist without considering the interdependencies of issues beyond climate change (e.g., nature conservation and biodiversity, sustainability and social justice, sufficiency and circular economy). If regulations and resource allocation in other policy fields do not consider adaptation needs and if responsibilities are distributed among separate authorities, the necessary linkages are often overlooked. The currently fragmented political, legal, and administrative structures lack the necessary flexibility and integration to enable new solutions to be developed for emerging or compounding climate challenges. Systematically checking for mismatches or lack of policy coherence can identify leverage points for improving the administrative context so that effective preparedness can be created and sustainable climate change adaptation achieved.

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7

Implications for Shaping Climate Futures

7

Implications for Shaping Climate Futures

This chapter's goal is to distill practical lessons from our findings. Whether you are an academic researcher, a policymaker, a business leader, or a concerned citizen, the insights shared here are designed to resonate with aspirations for climate futures in which the scenarios of deep decarbonization and sustainable climate change adaptation become more plausible.

There is no one-size-fits-all solution or quick fix to address the challenges posed by climate change. Our research highlights a sobering reality: The required societal transformation is still lacking. Although we have noted a growth of climate actions in many different fields of society, this is not enough for a decisive turning point toward preventing further climate change or for sufficiently adapting to the negative impacts of climate change in a sustainable manner. Numerous obstacles in politics, economy, and culture perpetuate the status quo of high carbon emissions, fueled by entrenched interests, inequalities, and power dynamics (Chapter 6).

Our study offers an empirical analysis. Furthermore, we provide a practical orientation that can help to better understand what supports and what inhibits the effectiveness of climate action. In this chapter we consolidate these implications into a core statement, followed by a set of general principles that we recommend to increase impact of climate action.

Core statement: Realistic assessments set expectations straight and help identify social conditions of effective climate action.

People live in the real world, not in an ideal world. This world is messy. We developed the Social Plausibility Assessment Framework to generate deep, realistic insights into how effective climate action is hindered by multiple strong and connected barriers. While the future remains open to a broad range of possibilities, it is preconditioned by existing circumstances; thus, grounding climate action on realistic expectations can establish a firm foundation for plausible desired climate futures.

To this end, it is crucial to acknowledge that the identified gaps in ambition and implementation are not only a matter of "political will", nor are they merely a technical question or a financial matter. Instead, they come from (1) existing power dynamics and inequalities; from (2) differences in climate change-related norms and practices; from (3) a lack of political coherence on different scales of climate governance; and from (4) climate change mitigation and adaptation being multifaceted and wicked problems. The 10 social-driver assessments give many hints at enabling conditions that could be strengthened, and at constraining conditions that need to be weakened. In particular, the dynamics of three drivers need to change direction: corporate responses, consumption trends, and fossil-fuel divestment.

Most importantly, the profitability of continued fossil-fuel engagements needs to be reduced. This can ultimately only come from binding legal rules and frameworks, provided by national political regulation and UN climate governance. Resources to strengthen the enabling conditions for political decision making can come from knowledge production, media reporting, climate activism, climate litigation, and transnational cooperation.

Starting from a realistic assessment is also crucial for developing local pathways to sustainable climate change adaptation. In nine case studies we identified a number of locally specific conditions in which physical parameters, the politico-administrative context, and socio-cultural dimensions are entangled in messy ways. They create difficult settings for turning from the mode of simply coping with occurring weather events to incremental adjustments or even more to transformative adaptation practices. As with deep decarbonization, climate change adaptation does not simply depend on technical solutions. Quite to the contrary, some technical solutions might lead to maladaptations that prevent sustainable transformation pathways. The case studies have shown that the increase in climate change impacts is pushing current measures and rules to the limits of their effectiveness. Incremental progress on existing paths runs the risk that adaptation will not be sufficient and that certain lock-in situations will lead to even greater risks and damage. Higher climate variability and increasing extreme events call for new approaches, including technological leaps, which can ultimately only be achieved through a transformation of social and governance practices beyond the usual lip services. Finally, our assessments have highlighted that global dynamics severely influence the financial, political, and knowledge capacities that are dedicated to local climate change adaptation.

Building on realistic assessments, we recommend to adopt the following set of general principles:

It is just as important to fight back constraining conditions as it is to strengthen enabling conditions for mitigation and adaptation.

Examples: Building up support for or pressure on policymakers or corporate leaders to adopt more stringent climate targets strengthens enabling conditions of national regulation or corporate responses.

Providing improved regional climate information, for example via higher spatial resolutions of global climate models, or initiating community-led stakeholder dialogs on transformative adaptation practices and involving the public at large can strengthen local capacities for sustainable climate change adaptation and thus contribute to more efficiency.

But going beyond that, engaging in climate litigation against insufficient climate action by corporations or national governments helps weaken constraining conditions, and fighting corruption of political or business elites can strongly reduce a constraining condition for sustainable climate change adaptation.

More climate action is important, but not enough in itself. It is essential to aim for qualitative shifts.

Examples: The assessments have shown many examples of goal-setting activities, both in the sense of emission reduction targets for decarbonization and, at least in some cases, in the sense of measures toward improved adaptation capacity. However, many of these declared goals are vague and non-binding. They are not backed by clear and measurable indicators and a binding obligation to implement these goals.

A translation of vague goals into targets that are monitored and implemented would mark a qualitative shift enabling more effective climate action. Another example would be the shift from non-binding rules and instruments, or what is commonly referred to as "soft law", to legally binding instruments and laws, or "hard law", in climate governance.

Reducing social inequalities can increase the plausibility of climate change mitigation and adaptation.

Examples: The lack of access to economic, political, and social resources undermines the plausibility of both deep decarbonization and sustainable climate change adaptation. Affluent groups contribute, through their very-high-carbon consumption patterns, in a direct way to growing emissions and have greater financial capacity to deal with or sometimes even escape from climate-related impacts. In turn, the vast majority of the world population, and particularly vulnerable communities, who contribute little to global emissions, lack of access to economic, political, and social resources to adapt to climate change, let alone to adopt more sustainable practices.

Minimizing these types of inequalities via policies, regulation, and financial programs can strengthen social cohesion, enable climate action, and even reduce the deadliness of extreme climate events. Reducing inequalities affects the distribution of costs and benefits, rights and duties along the complete spectrum of income and wealth, for example via a reduction of very-high-carbon consumption patterns of affluent groups, via compensating low-income households for disproportionately high climate change-related costs or for climate related lossess and damages, and via improving their access to critical infrastructure.

There is never just one agreed climate goal or one way to achieve that goal. Fair and just negotiation processes can create synergies and generate goals and measures acceptable to all affected parties.

Examples: Forests provide a range of ecosystem services. In addition to habitats for flora and fauna, they provide oxygen, take up CO_2, yield timber as a renewable resource, protect from natural hazards, and offer space for recreation. These various services provide benefits to very different beneficiaries, leading to competing or even conflicting interests. As a consequence, the decision whether forests are managed to optimize mitigation, to contribute to climate adaptation, or to supply merchandizable timber that can then be used for climate-friendly construction can lead to divergent management approaches. These trade-offs must be negotiated and, in the best case, synergies between the interested parties and beneficiaries can be found. Procedures are needed that weigh the physical and socio-economic implications and that create technological and social synergies between climate mitigation, climate adaptation, and other potential goals.

Reinforcing connections between drivers generates new resources for more effective climate action. Such connections are strengthened by new alliances across different fields of society, strategic networks, and trust-building.

Examples: Our assessments include examples of a broad range of resources that are produced in one driver and used in other drivers. In climate litigation, for instance, we see the use of specifically produced attribution knowledge strengthening litigation cases. Likewise, a new type of case uses private standards and state regulations to denounce corporate climate-washing. Climate mobilization highlights the crucial role of climate movements in translating claims-making into implementing steps with regard to adaptation and loss and damage. Strategic alliances and networks across fields are facilitated if actor groups can rely on pre-existing trusting relations.

However, joint forces are not only necessary where new effectiveness is to be achieved, but also where traditionally separate responsibilities reach their limits and cross-sector cooperation is needed. This can become particularly relevant for regions facing different types of climate change impacts and compound events, which are typically dealt with separately in different administrative, sectoral bodies. Sea level rise, torrential rains, and floods coming from the hinterland need cross-sectoral collaboration to handle cascading effects if such—not necessarily extreme—events happen in quick succession or simultaneously and thus become extreme events. Handling such compounded and extreme climate change effects requires openness and trust-building in new connections, the willingness to step out of familiar routines, and the implementation of cooperative, cross-sectoral responsibilities.

The integration of diverse ways of knowing, for instance from local communities or Indigenous Peoples, is crucial for the social meanings of mitigation and adaptation practices and broadens the understanding of climate change impacts.

Examples: Many of our assessments have demonstrated that knowledge is contested or simply ignored, while integrated and contextualized knowledge can be an enabling condition for climate action. The inclusion of diverse ways of knowing is needed to acknowledge local insights and needs, develop place-specific suitable measures, and build political alliances across the Global South–North divide. There is enormous yet rarely tapped potential for societal mobilization and co-production of knowledge on the barriers to and opportunities for sustainable climate change adaptation, in particular, if this knowledge is developed in an equitable and ethical manner. This could, for example, draw on local and Indigenous knowledge in dealing with extreme weather events as well as climate-related risks and vulnerabilities. Public policies for sustainable climate change adaptation could be informed by these, exploring synergies between the need to adapt to climate change on the ground while at the same time fostering socio-economic development, and human health and well-being.

In summary, our assessment findings already provide guidance for those who wish to realize climate futures that are characterized by deep decarbonization and sustainable adaptation to the level of climate change that cannot be avoided. Having said that, we acknowledge that research on what might contribute to this realization of desired climate futures is in its infancy. We are convinced that the Outlook 2024 marks a valuable starting point for this research.

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References

Chapter 1 – Introduction

Copernicus. (2023): Record warm November consolidates 2023 as the warmest year. *Monthly Climate Bulletin*. Last accessed April 22, 2024, available at https://climate.copernicus.eu/record-warm-november-consolidates-2023-warmest-year

Engels, A., Marotzke, J., Gresse, E. G., López-Rivera, A., Pagnone, A., & Wilkens, J. (Eds.). (2023). *Hamburg Climate Futures Outlook: The plausibility of a 1.5°C limit to global warming — social drivers and physical processes*. Hamburg, Germany: Cluster of Excellence Climate, Climatic Change, and Society (CLICCS). doi:10.25592/uhhfdm.11230

Gresse, E. G., Schrum, C., Hanf, F. S., Jantke, K., Pein, J., Hawxwell, T., Hoffmann, P., Bolaños, T. G., Langendijk, G. S., Schneider, U. A., Huang-Lachmann, J.-T., Neuburger, M., Umaña, C. R., Seiffert, R., Wickel, M., Sillmann, J., Scheffran, J., & Held, H. (2023). Toward a Sustainable Adaptation Plausibility Framework. In A. Engels, J. Marotzke, E. G. Gresse, A. López-Rivera, A. Pagnone, & J. Wilkens (Eds.), *Hamburg Climate Futures Outlook: The plausibility of a 1.5° limit to global warming – Social drivers and physical processes* (pp. 54-65). Hamburg, Germany: Cluster of Excellence Climate, Climatic Change, and Society (CLICCS). doi:10.25592/uhhfdm.11230

Juhola, S., & Käyhkö, J. (2023). Maladaptation as a concept and a metric in national adaptation policy-Should we, would we, could we? *PLOS Climate, 2*(5), e0000213. doi:10.1371/journal.pclm.0000213

Stammer, D., Engels, A., Marotzke, J., Gresse, E. G., Hedemann, C., & Petzold, J. (Eds.). (2021). *Hamburg Climate Futures Outlook: Assessing the plausibility of deep decarbonization by 2050*. Hamburg, Germany: Cluster of Excellence Climate, Climatic Change, and Society (CLICCS). doi:10.25592/uhhfdm.9104

Chapter 2 – The Plausibility of Climate Futures: Explaining the methodology

Aykut, S. C., Wiener, A., Engels, A., Gresse, E. G., Hedemann, C., & Petzold, J. (2021). The Social Plausibility Assessment Framework. In D. Stammer, A. Engels, J. Marotzke, E. G. Gresse, C. Hedemann, & J. Petzold (Eds.), *Hamburg Climate Futures Outlook: Assessing the plausibility of deep decarbonization by 2050* (pp. 29-38). Hamburg, Germany: Cluster of Excellence Climate, Climatic Change, and Society (CLICCS).

de Coninck, H., Revi, A., Babiker, M., Bertoldi, P., Buckeridge, M., Cartwright, A., Dong, W., Ford, J., Fuss, S., Hourcade, J.-C., Ley, D., Mechler, R., Newman, P., Revokatova, A., Schultz, S., Steg, L., & Sugiyama, T. (2018). Strengthening and Implementing the Global Response. In V. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, & T. Waterfield (Eds.), *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above preindustrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* (pp. 313-444). Cambridge and New York: Cambridge University Press.

Engels, A., Marotzke, J., Gresse, E. G., López-Rivera, A., Pagnone, A., & Wilkens, J. (Eds.). (2023). *Hamburg Climate Futures Outlook: The plausibility of a 1.5°C limit to global warming — social drivers and physical processes*. Hamburg, Germany: Cluster of Excellence Climate, Climatic Change, and Society (CLICCS). doi:10.25592/uhhfdm.11230

Fedele, G., Donatti, C. I., Harvey, C. A., Hannah, L., & Hole, D. G. (2019). Transformative adaptation to climate change for sustainable social-ecological systems. *Environmental Science & Policy, 101*, 116-125. doi:10.1016/j.envsci.2019.07.001

Gresse, E. G., Schrum, C., Hanf, F. S., Jantke, K., Pein, J., Hawxwell, T., Hoffmann, P., Bolaños, T. G., Langendijk, G. S., Schneider, U. A., Huang-Lachmann, J.-T., Neuburger, M., Umaña, C. R., Seiffert, R., Wickel, M., Sillmann, J., Scheffran, J., & Held, H. (2023). Toward a Sustainable Adaptation Plausibility Framework. In A. Engels, J. Marotzke, E. G. Gresse, A. López-Rivera, A. Pagnone, & J. Wilkens (Eds.), *Hamburg Climate Futures Outlook: The plausibility of a 1.5° limit to gobal warming – Social drivers and physical processes* (pp. 54-65). Hamburg, Germany: Cluster of Excellence Climate, Climatic Change, and Society (CLICCS). doi:10.25592/uhhfdm.11230

Janasik, N. (2021). Plausibility designs, or a probabilistic and predictive take on scenario effectiveness. *Futures*, 127, 102670. doi:10267010.1016/j.futures.2020.102670

Nakashima, D., Krupnik, I., & Rubis, J. T. (Eds.). (2018). *Indigenous knowledge for climate change assessment and adaptation*. Cambridge; Paris: Cambridge University Press and UNESCO.

Petzold, J., Andrews, N., Ford, J. D., Hedemann, C., & Postigo, J. C. (2020). Indigenous knowledge on climate change adaptation: a global evidence map of academic literature. *Environmental Research Letters*, 15(11), 1-17. doi:10.1088/1748-9326/abb330

Petzold, J., Wiener, A., Neuburger, M., Wilkens, J., Datchoua-Tirvaudey, A., Schnegg, M., Notz, D. P., Gresse, E. G., Scheffran, J., Lüdemann, J., Schmitt, T., & Singer, K. (2021). Diverse ways of knowing in a changing climate (Box 3). In D. Stammer, A. Engels, J. Marotzke, E. G. Gresse, C. Hedemann, & J. Petzold (Eds.), *Hamburg Climate Futures Outlook: Assessing the plausibility of deep decarbonization by 2050* (pp. 51). Hamburg, Germany: Cluster of Excellence Climate, Climatic Change, and Society (CLICCS). doi:10.25592/uhhfdm.9104

Stammer, D., Engels, A., Marotzke, J., Gresse, E. G., Hedemann, C., & Petzold, J. (Eds.). (2021). *Hamburg Climate Futures Outlook: Assessing the plausibility of deep decarbonization by 2050*. Hamburg, Germany: Cluster of Excellence Climate, Climatic Change, and Society (CLICCS). doi:10.25592/uhhfdm.9104

Wiener, A., Aykut, S. C., Gresse, E. G., López-Rivera, A., & Wilkens, J. (2023). The Social Plausibility Assessment Framework: from social drivers to the plausibility of deep decarbonization. In A. Engels, J. Marotzke, E. Gresse, A. López-Rivera, A. Pagnone, & J. Wilkens (Eds.), *Hamburg Climate Futures Outlook: The plausibility of a 1.5° limit to global warming – Social drivers and physical processes* (pp. 26-28). Hamburg, Germany: Cluster of Excellence Climate, Climatic Change, and Society (CLICCS). doi:10.25592/uhhfdm.11230

Chapter 3 – The plausibility of achieving deep decarbonization by 2050

Abdulrahman, I. A., Akanbi, S. B., & Oniyide, G. D. (2023). Impact of monetary policy on poverty reduction in Nigeria. *African Journal of Economic Review, 11*(1), 101-119. Last accessed April 22, 2024, available at https://www.ajol.info/index.php/ajer/article/view/240131

Adger, W. N. (2023). Loss and Damage from climate change: legacies from Glasgow and Sharm el-Sheikh. *Scottish Geographical Journal, 139*(1-2), 142-149. doi:10.1080/14702541.2023.2194285

Adrogué, B. C., & Plant, M. (2023). Does SDR Recycling Impair Reserve Management? The Case of the United Kingdom. Center for Global Development, Washington, DC. Last accessed April 22, 2024, available at https://www.cgdev.org/sites/default/files/does-sdr-recycling-impair-reserve-management-case-united-kingdom.pdf

Akbar, A. A. (2023). The Fight Against Cop City. *Dissent, 70*(2), 62-70. doi:10.1353/dss.2023.0011

Akbarian, S. (2023). Gesetz ist Gesetz?: Zur Diskreditierung des „Zivilen Ungehorsams“. Last accessed April 22, 2024, available at https://verfassungsblog.de/gesetz-ist-gesetz/files/1763/gesetz-ist-gesetz.html

Aleluia, J., Tharakan, P., Chikkatur, A. P., Shrimali, G., & Chen, X. (2022). Accelerating a clean energy transition in Southeast Asia: Role of governments and public policy. *Renewable and Sustainable Energy Reviews, 159*, 112226. doi:10.1016/j.rser.2022.112226

Allianz Research Report. (2023). The green industrial revolution: Investment pathways to decarbonize the industrial sector in Europe. Allianz Research, Munich: https://www.allianz.com/content/dam/onemarketing/azcom/Allianz_com/economic-research/publications/specials/en/2023/april/2023-04-05-Industry.pdf

Almiron, N., Moreno, J. A., & Farrell, J. (2023). Climate change contrarian think tanks in Europe: A network analysis. *Public Underst Sci, 32*(3), 268-283. doi:10.1177/09636625221137815

Alperstein, N. (2022). Greenwashing as grassroots or no roots social movement: A multi-platform approach to social media monitoring of hashtag activism. *The Journal of Social Media in Society, 11*(2), 4-28.

Andrews, M., Nesbitt-Larking, P., & Mahendran, K. (2023). Everyday Narratives of Resistance and Reconfigurations of Political Protest after the Pandemic—Editors' Introduction. *Social Sciences, 12*(8), 427. doi:10.3390/socsci12080427

Anisimov, A., Magnan, A. K., Hawke, A., & Fottrell, J. (2023). The global transboundary climate risk report. The Institute for Sustainable Development and International Relations & Adaptation Without Borders. Last accessed April 22, 2024, available at https://adaptationwithoutborders.org/knowledge-base/adaptation-without-borders/the-global-transboundary-climate-risk-report

Aradau, C. (2017). Assembling (Non)Knowledge: Security, Law, and Surveillance in a Digital World. International Political Sociology, 11(4), 327-342. doi:10.1093/ips/olx019

Arestis, P., Ferrari-Filho, F., Resende, M. F. d. C., & Bittes Terra, F. H. (2021). A critical analysis of the Brazilian 'expansionary fiscal austerity': why did it fail to ensure economic growth and structural development? *International Review of Applied Economics, 36*(1), 4-16. doi:10.1080/02692171.2021.1893667

Aronoff, K. (2023). The IRA Is an Invitation to Organizers. *Dissent, 70*(2), 26-29. doi:10.1353/dss.2023.0005.

Arora, P., & Arora, N. K. (2023). COP27: a summit of more misses than hits. *Environmental Sustainability, 6*(1), 99-105. doi:10.1007/s42398-023-00261-0

Ataman, J., & Paddison, L. (2023). French government shuts down a climate group after protests turn violent. CNN. Last accessed April 22, 2024, available at https://edition.cnn.com/2023/06/21/europe/french-government-ban-climate-group-intl/index.html

Aykut, S. C., Foyer, J., & Morena, E. (Eds.). (2017). *Globalizing the climate: COP21 and the climatisation of global debates*. London: Routledge.

Aykut, S. C., D'Amico, E., & Fünfgeld, A. (2023). UN climate governance. In A. Engels, J. Marotzke, E. G. Gresse, A. López-Rivera, A. Pagnone, & J. Wilkens (Eds.), *Hamburg Climate Futures Outlook: The plausibility of a 1.5° limit to gobal warming – Social drivers and physical processes* (pp. 76-82). Hamburg: Cluster of Excellence Climate, Climatic Change, and Society. doi:10.25592/uhhfdm.11230

Aykut, S. C., Pavenstädt, C. N., Datchoua-Tirvaudey, A., D'Amico, E., Braun, M., Karnik Hinks, E., Schenuit, F., Wilkens, J., & Rödder, S. (2022a). Circles of Global Climate Governance: Power, Performance and Contestation at the UN Climate Conference COP26 in Glasgow. *Center for Sustainable Society Research Working Paper Series, Working Paper No. 3* (February 2022), 1-29. doi:10.25592/CSS-WP-004

Aykut, S. C., Schenuit, F., Klenke, J., & D'Amico, E. (2022b). It's a Performance, Not an Orchestra! Rethinking Soft Coordination in Global Climate Governance. *Global Environmental Politics, 22*(4), 173-196. doi:10.1162/glep_a_00675

Aykut, S. C., & Wiener, A. (2023). *Varieties of Climate Agency: Assessing the Societal Dynamics of Global Decarbonization*. (submitted manuscript).

Aykut, S. C., Wiener, A., Engels, A., Gresse, E. G., Hedemann, C., & Petzold, J. (2021). The Social Plausibility Assessment Framework. In D. Stammer, A. Engels, J. Marotzke, E. G. Gresse, C. Hedemann, & J. Petzold (Eds.), *Hamburg Climate Futures Outlook: Assessing the plausibility of deep decarbonization by 2050* (pp. 29-38). Hamburg, Germany: Cluster of Excellence Climate, Climatic Change, and Society (CLICCS). doi:10.25592/uhhfdm.9104

Bäckstrand, K., Kuyper, J. W., Linnér, B.-O., & Lövbrand, E. (2017). Non-state actors in global climate governance: from Copenhagen to Paris and beyond. *Environmental Politics, 26*(4), 561-579. doi:10.1080/09644016.2017.1327485

Baker, V., Ataria, J., Ankeny, R., & Bray, H. (2023). Transdisciplinary science and the importance of Indigenous knowledge. *Integrated Environmental Assessment and Management, 20*(3), 805-816. doi:10.1002/ieam.4847

Bakhtaoui, I., & Shawoo, Z. (2022). Operationalizing finance for loss and damage: from principles to modalities, Stockholm Environment Institute. Last accessed April 22, 2024, available at https://www.sei.org/publications/finance-loss-damage-principles-modalities

Barbhaya, D., Hejjaji, V., Vijayaprakash, A., Rahimian, A., Yamparala, A., Yakkali, S., Muralidharan, A., & Khetan, A. K. (2022). The burden of premature mortality from coal-fired power plants in India is high and inequitable. *Environmental Research Letters*, 17(10), 1-9. doi:10.1088/1748-9326/ac91e3

Basseches, J. A., Bromley-Trujillo, R., Boykoff, M. T., Culhane, T., Hall, G., Healy, N., Hess, D. J., Hsu, D., Krause, R. M., Prechel, H., Roberts, J. T., & Stephens, J. C. (2022). Climate policy conflict in the U.S. states: a critical review and way forward. *Climatic Change, 170*(3-4), 32. doi:10.1007/s10584-022-03319-w

Bauck, W. (2022). Where the Sunrise Movement Goes From Here. Slate. Last accessed April 22, 2024, available at https://slate.com/news-and-politics/2022/11/sunrise-movement-biden-ira-2024.html

Becht, M., Pajuste, A., & Toniolo, A. (2023). Voice Through Divestment. European Corporate Governance Institute, Rochester, NY. Last accessed April 22, 2024, available at https://papers.ssrn.com/abstract=4386469

Beck, S., & Oomen, J. (2021). Imagining the corridor of climate mitigation – What is at stake in IPCC's politics of anticipation? *Environmental Science & Policy, 123*, 169-178. doi:10.1016/j.envsci.2021.05.011

Beckert, J. (2024). *How We Sold Our Future: The Failure to Fight Climate Change*. Cambridge: Polity.

Bednarek, M., Ross, A. S., Boichak, O., Doran, Y., Carr, G., Altmann, E. G., & Alexander, T. J. (2022). Winning the discursive struggle? The impact of a significant environmental crisis event on dominant climate discourses on Twitter. *Discourse, Context & Media, 45*, 100564. doi:10.1016/j.dcm.2021.100564

Behrens, J. (2023). Vietnam's JETP Agreement: Accelerating the Energy Transition in a Just Way? (2023/62). Last accessed April 22, 2024, available at https://www.iseas.edu.sg/articles-commentaries/iseas-perspective/2023-62-vietnams-jetp-agreement-accelerating-the-energy-transition-in-a-just-way-by-julia-behrens/

Belfer, E., Ford, J. D., Maillet, M., Araos, M., & Flynn, M. (2019). Pursuing an Indigenous Platform: Exploring Opportunities and Constraints for Indigenous Participation in the UNFCCC. *Global*

Environmental Politics, 19(1), 12-33. doi:10.1162/glep_a_00489 M4 – Citavi

Bendig, D., Wagner, A., & Lau, K. (2022). Does it pay to be science-based green? The impact of science-based emission-reduction targets on corporate financial performance. *Journal of Industrial Ecology*, 27(1), 125-140. doi:10.1111/jiec.13341

Berger-Schmitz, Z., George, D., Hindal, C., Perkins, R., & Travaille, M. (2023). What explains firms' net zero adoption, strategy and response? *Business Strategy and the Environment, 32*(8), 5583-5601. doi:10.1002/bse.3437

Berglund, O. (2023). Disruptive protest, civil disobedience & direct action. *Politics*, 1-19. doi:10.1177/02633957231176999

Bhardwaj, A. (2022). Styles of decarbonization. *Environmental Politics, 32*(4), 619-641. doi:10.1080/09644016.2022.2113611

Biermann, F., Oomen, J., Gupta, A., Ali, S. H., Conca, K., Hajer, M. A., Kashwan, P., Kotzé, L. J., Leach, M., & Messner, D. (2022). Solar geoengineering: The case for an international non-use agreement. *Wiley Interdisciplinary Reviews: Climate Change, 13*(3), e754. doi:10.1002/wcc.754

Bistline, J., Blanford, G., Brown, M., Burtraw, D., Domeshek, M., Farbes, J., Fawcett, A., Hamilton, A., Jenkins, J., Jones, R., King, B., Kolus, H., Larsen, J., Levin, A., Mahajan, M., Marcy, C., Mayfield, E., McFarland, J., McJeon, H., Orvis, R., Patankar, N., Rennert, K., Roney, C., Roy, N., Schivley, G., Steinberg, D., Victor, N., Wenzel, S., Weyant, J., Wiser, R., Yuan, M., & Zhao, A. (2023). Emissions and energy impacts of the Inflation Reduction Act. *Science, 380*(6652), 1324-1327. doi:10.1126/science.adg3781

Blühdorn, I. (2019). The legitimation crisis of democracy: emancipatory politics, the environmental state and the glass ceiling to socio-ecological transformation. *Environmental Politics, 29*(1), 38-57. doi:10.1080/09644016.2019.1681867

Boecher, M., Zeigermann, U., Berker, L. E., & Jabra, D. (2022). Climate policy expertise in times of populism–knowledge strategies of the AfD regarding Germany’s climate package. *Environmental Politics, 31*(5), 820-840. doi:10.1080/09644016.2022.2090537

Boehm, S., Jeffery, L., Hecke, J., Schumer, C., Jaeger, J., Fyson, C., Levin, K., Nilsson, A., Naimoli, S., Daly, E., Thwaites, J., Lebling, K., Waite, R., Collis, J., Sims, M., Singh, N., Grier, E., Lamb, W., Castellanos, S., Lee, A., Geffray, M.-C., Santo, R., Balehegn, M., Petroni, M., & Masterson, M. (2023). State of Climate Action 2023. World Resources Institute. Last accessed April 22, 2024, available at https://www.wri.org/research/state-climate-action-2023

Boehm, S., Jeffery, L., Levin, K., Hecke, J., Schumer, C., Fyson, C., Majid, A., Jaeger, J., Nilsson, A., Naimoli, S., Thwaites, J., Cassidy, E., Waite, R., Wilson, R., Castellanos, S., Singh, N., Lee, A., & Geiges, A. (2022). State of Climate Action 2022. World Resources Institute. Last accessed April 22, 2024, available at https://www.wri.org/research/state-climate-action-2022

Bordoff, J. (2022). America's Landmark Climate Law. *Finance & Development*.

Borghesi, S., Pahle, M., Perino, G., Quemin, S., & Willner, M. (2023). The Market Stability Reserve in the EU Emissions Trading System: A Critical Review. *Annual Review of Resource Economics, 15*(1), 131-152. doi:10.1146/annurev-resource-111820-030145

Boström, M. (2020). The social life of mass and excess consumption. *Environmental Sociology, 6*(3), 268-278. doi:10.1080/23251042.2020.1755001

Braunreiter, L., van Beek, L., Hajer, M., & van Vuuren, D. (2021). Transformative pathways – Using integrated assessment models more effectively to open up plausible and desirable low-carbon futures. *Energy Research & Social Science, 80*, 102220. doi:10.1016/j.erss.2021.102220

Brüggemann, M., Frech, J., & Schäfer, T. (2022). Transformative Journalisms: How the global ecological crisis is transforming journalism. In A. Hansen & R. Cox (Eds.), *The Routledge Handbook of Environment and Communication* (2 ed.). New York: Routledge.

Brulle, R. J. (2022). Advocating inaction: a historical analysis of the Global Climate Coalition. *Environmental Politics, 32*(2), 185-206. doi:10.1080/09644016.2022.2058815

Brutschin, E., Pianta, S., Tavoni, M., Riahi, K., Bosetti, V., Marangoni, G., & van Ruijven, B. J. (2021). A multidimensional feasibility evaluation of low-carbon scenarios. *Environmental Research Letters, 16*(6), (pp. 1-13). doi:10.1088/1748-9326/abf0ce

Büchs, M., Cass, N., Mullen, C., Lucas, K., & Ivanova, D. (2023). Emissions savings from equitable energy demand reduction. *Nature Energy, 8*(7), 758-769. doi:10.1038/s41560-023-01283-y

Bulkeley, H. (2014). *Transnational climate change governance*: Cambridge: Cambridge University Press.

Bundesverfassungsgericht. (2023). *Urteil des Zweiten Senats vom 15. November 2023 – 2 BvF 1/22 -, Rn. 1-231*.

Burck, J., Uhlich, T., Bals, C., Höhne, N., & Nascimento, L. (2024). Climate Change Performance Index 2024, Germanwatch. Last accessed April 22, 2024, available at https://ccpi.org/download/climate-change-performance-index-2024/

Buzogány, A., & Scherhaufer, P. (2023). The New Climate Movement. In H. Jörgens, C. Knill, & Y. Steinebach (Eds.), *Routledge handbook of environmental policy* (1st edition ed., pp. 358-380). New York: Routledge.

Buzzao, G., & Rizzi, F. (2023). The role of dynamic capabilities for resilience in pursuing business continuity: an empirical study. *Total Quality Management & Business Excellence, 34*(11-12), 1353-1385. doi:10.1080/14783363.2023.2174427

C40. (2022). *Annual Report 2022*. Last accessed April 22, 2024, available at https://www.c40.org/about-c40/#annualreport

Callahan, C. W., & Mankin, J. S. (2022). National attribution of historical climate damages. *Climatic Change, 172*(3-4), 1-19. doi:10.1007/s10584-022-03387-y

Capstick, S., Thierry, A., Cox, E., Berglund, O., Westlake, S., & Steinberger, J. K. (2022). Civil disobedience by scientists helps press for urgent climate action. *Nature Climate Change, 12*(9), 773-774. doi:10.1038/s41558-022-01461-y

Carmona, R., Reed, G., Thorsell, S., Dorough, D. S., MacDonald, J. P., Rai, T. B., & Sanago, G. A. (2023). Analysing engagement with Indigenous Peoples in the Intergovernmental Panel on Climate Change's Sixth Assessment Report. *npj Climate Action, 2*(1), 1-10. doi:10.1038/s44168-023-00048-3

Carrión, A., Ariza-Montobbio, P., & Calero, D. (2022). Territorializing the climate policy agenda in intermediate cities of the Andean Region. *Planning Practice & Research, 38*(6), 796-814. doi:10.1080/02697459.2022.2026036

Casas-Cortés, M. I., Osterweil, M., & Powell, D. E. (2008). Blurring boundaries: Recognizing knowledge-practices in the study of social movements. *Anthropological Quarterly*, 17-58. Last accessed April 22, 2024, available at http://www.jstor.org/stable/30052739

Caswell, D. (2023). AI and Journalism: What's next? *Reuters*. Last accessed April 22, 2024, available at https://reutersinstitute.politics.ox.ac.uk/news/ai-and-journalism-whats-next

Chan, S., Hale, T., Deneault, A., Shrivastava, M., Mbeva, K., Chengo, V., & Atela, J. (2022). Assessing the effectiveness of orchestrated climate action from five years of summits. *Nature Climate Change, 12*(7), 628-633. doi:10.1038/s41558-022-01405-6

Chancel, L., Bothe, P., & Voituriez, T. (2023). Climate Inequality Report 2023. World Inequality Lab Study, Paris. Last accessed April 22, 2024, available at https://wid.world/wp-content/uploads/2023/01/CBV2023-ClimateInequalityReport-3.pdf

Chandrasekhar, A., Dunne, D., Dwyer, O., Evans, S., Gabbatiss, J., Lempriere, M., Patel, A., Tandon, A., & Viglione, G. (2023). COP28: Key outcomes agreed at the UN climate talks in Dubai. Last accessed April 22, 2024, available at https://www.carbonbrief.org/cop28-key-outcomes-agreed-at-the-un-climate-talks-in-dubai/

Charaby, N. (2022). COP27 auf dem Pfad der Ignoranz – Rosa-Luxemburg-Stiftung. *Rosa Luxemburg Stiftung*. Last accessed April 22, 2024, available at https://www.rosalux.de/news/id/49529/cop27-auf-dem-pfad-der-ignoranz

Cherepovitsyna, A., Sheveleva, N., Riadinskaia, A., & Danilin, K. (2023). Decarbonization Measures: A Real Effect or Just a Declaration? An Assessment of Oil and Gas Companies' Progress towards Carbon Neutrality. *Energies, 16*(8), 3575. doi:10.3390/en16083575

Choudry, A. (2020). Reflections on academia, activism, and the politics of knowledge and learning. *The International Journal of Human Rights, 24*(1), 28-45. doi:10.1080/13642987.2019.1630382

Christou, G., Theodorou, E., & Spyrou, S. (2023). 'The slow pandemic': youth's climate activism and the stakes for youth movements under Covid-19. *Children's Geographies, 21*(2), 191-204. doi:10.1080/14733285.2022.2026885

CIEL. (2024). Climate Vulnerable Nations Reject US-led Push for Solar Geoengineering at UNEA-6. Last accessed April 22, 2024, available at https://www.ciel.org/news/ciel-response-to-geoengineering-srm-technology-rejection-unea-6/

Clark, D. (2009). Maldives first to go carbon neutral. *The Guardian*. Last accessed April 22, 2024, available at https://www.theguardian.com/environment/2009/mar/15/maldives-president-nasheed-carbon-neutral

Clark, R., & Zucker, N. (2023). Climate Cascades: IOs and the Prioritization of Climate Action. *American Journal of Political Science*, OnlineFirst, 1-16. doi:https://doi.org/10.1111/ajps.12793

Climate Change Litigation Database. (2019). Milieudefensie et al. v. Royal Dutch Shell plc. – Climate Change Litigation. Last accessed April 22, 2024, available at http://climatecasechart.com/non-us-case/milieudefensie-et-al-v-royal-dutch-shell-plc/

Climate Action Tracker. (2022). Warming Projections Global Update. Last accessed April 22, 2024, available at https://climateactiontracker.org/documents/1094/CAT_2022-11-10_GlobalUpdate_COP27.pdf

Climate Action Tracker. (2023). Costa Rica. Last accessed April 22, 2024, available at https://climateactiontracker.org/countries/costa-rica/

Coen, D., Herman, K., & Pegram, T. (2022). Are corporate climate efforts genuine? An empirical analysis of the climate 'talk–walk' hypothesis. *Business Strategy and the Environment, 31*(7), 3040-3059. doi:10.1002/bse.3063

Cohen, S., Liu, H., Hanna, P., Hopkins, D., Higham, J., & Gössling, S. (2022). The Rich Kids of Instagram: Luxury Travel, Transport Modes, and Desire. *Journal of Travel Research, 61*(7), 1479-1494. doi:10.1177/00472875211037748

Cologna, V., & Oreskes, N. (2022). Don't gloss over social science! a response to: Glavovic et al.(2021)'the tragedy of climate change science'. *Climate and Development, 14*(9), 839-841. doi:10.1080/17565529.2022.2076647

COP27 Presidency (2022b). *Sharm-El-Sheikh Adaptation Agenda*. UNFCCC. Last accessed April 22, 2024, available at https://climatechampions.unfccc.int/wp-content/uploads/2022/12/SeS-Adaptation-Agenda_Complete-Report_COP27-.pdf

COP27 Presidency (2022a). *Sustainable Urban Resilience for the Next Generation (SURGe)*. Last accessed April 22, 2024, available at https://unhabitat.org/cop27-presidency-sustainable-urban-resilience-for-the-next-generation-surge

Correia, D., & Wall, T. (2021). Violent Order: *Essays on the Nature of Police*: Haymarket Books.

Crawford, N. J. W., Michael, K., & Mikulewicz, M. (Eds.). (2023). *Climate justice in the majority world: vulnerability, resistance, and diverse knowledges*. London: Routledge.

Creutzig, F., Niamir, L., Bai, X., Callaghan, M., Cullen, J., Díaz-José, J., Figueroa, M., Grubler, A., Lamb, W. F., Leip, A., Masanet, E., Mata, É., Mattauch, L., Minx, J. C., Mirasgedis, S., Mulugetta, Y., Nugroho, S. B., Pathak, M., Perkins, P., Roy, J., de la Rue du Can, S., Saheb, Y., Some, S., Steg, L., Steinberger, J., & Ürge-Vorsatz, D. (2022). Demand-side solutions to climate change mitigation consistent with high levels of well-being. *Nature Climate Change, 12*(1), 36-46. doi:10.1038/s41558-021-01219-y

Crouzé, R., Godard, L., & Meurs, P. (2023). Learning democracy through activism: the global climate strike movement and Belgian youth's democratic experience in times of environmental emergency. *Social Movement Studies, 23*(1), 56-71. doi:10.1080/14742837.2023.2184792

D'Amico, E., Frisch, T., Scheffran, J., & Zengerling, C. (2023). Transnational Initiatives. In A. Engels, J. Marotzke, E. G. Gresse, A. López-Rivera, A. Pagnone, & J. Wilkens (Eds.), *Hamburg Climate Futures Outlook: The plausibility of a 1.5° limit to gobal warming – Social drivers and physical processes* (pp. 83-90). Hamburg, Germany: Cluster of Excellence Climate, Climatic Change, and Society (CLICCS). doi:10.25592/uhhfdm.11230

Daggett, C. (2018). Petro-masculinity: Fossil Fuels and Authoritarian Desire. *Millennium: Journal of International Studies, 47*(1), 25-44. doi:10.1177/0305829818775817

Dannenberg, A., Lumkowsky, M., Carlton, E. K., & Victor, D. G. (2023). Naming and shaming as a strategy for enforcing the Paris Agreement: The role of political institutions and public concern. *Proceedings of the National Academy of Sciences, 120*(40). doi:10.1073/pnas.2305075120

Davoudi, S., & Machen, R. (2022). Climate imaginaries and the mattering of the medium. *Geoforum, 137*, 203-212. doi:10.1016/j.geoforum.2021.11.003

Day, T., Mooldijk, S., Hans, F., Smit, S., Posada, E., Skribbe, R., Woolands, S., Fearnehough, H., Kuramochi, T., Warnecke, C., Kachi, A., & Höhne, N. (2023). *Corporate Climate Responsibility Monitor 2023: Assessing the transparency and integrity of companies' emission reduction and net-zero targets*. NewClimate Institute. Last accessed April 22, 2024, available at https://newclimate.org/resources/publications/corporate-climate-responsibility-monitor-2023

De la Garza, A. (2023). Why Climate Activism May Look Different in 2023. *Time*. Last accessed April 22, 2024, available at https://time.com/6244805/climate-protest-extinction-rebellion-future/files/1745/climate-protest-extinction-rebellion-future.html

de Moor, J. (2022). Postapocalyptic narratives in climate activism: their place and impact in five European cities. *Environmental Politics, 31*(6), 927-948. doi:10.1080/09644016.2021.1959123

de Moor, J. (2023). Introduction: What Moment for Climate Activism? *South Atlantic Quarterly*, 122(1), 172-180. doi:10.1215/00382876-10242742

de Moor, J., & Marquardt, J. (2023). Deciding whether it's too late: How climate activists coordinate alternative futures in a postapocalyptic present. *Geoforum, 138*, 103666. doi:10.1016/j.geoforum.2022.103666

Debt for Climate. (2023). About Us. *WHY DEBT?* Last accessed April 22, 2024, available at https://www.debtforclimate.org/about-us

Deep Decarbonization Pathways Project. (2015). Pathways to deep decarbonization 2015 report. SDSN – IDDRI, last accessed April 22, 2024, available at http://deepdecarbonization.org/wp-content/uploads/2016/03/DDPP_2015_REPORT.pdf

Della Porta, D. (2022). *Contentious politics in emergency critical junctures: Progressive social movements during the pandemic*. Cambridge: Cambridge University Press.

Dionisio, R., Dombroski, K., & Yates, A. (2023). Testing practices for testing times: Exploring Indigenous-led governance. *Dialogues in Human Geography, 13*(2), 301-305. doi:10.1177/20438206231177079

Dizon, J. P. M., Harper, J., & Kezar, A. (2022). Using Strategies Elites Understand: Divestment as an Approach to Social Change. *Peabody Journal of Education, 97*(5), 584-599. doi:10.1080/0161956x.2022.2125759

Dolphin, G., Pahle, M., Burtraw, D., & Kosch, M. (2023). A net-zero target compels a backward induction approach to climate policy. *Nature Climate Change*, 1-9. doi:10.1038/s41558-023-01798-y

Donger, E. (2022). Children and youth in strategic climate litigation: Advancing rights through legal argument and legal mobilization. *Transnational Environmental Law, 11*(2), 263-289. doi:10.1017/S2047102522000218

Doran, R., Ogunbode, C. A., Böhm, G., & Gregersen, T. (2023). Exposure to and learning from the IPCC special report on 1.5 °C global warming, and public support for climate protests and mitigation policies. *npj Climate Action*, 2(1). doi:10.1038/s44168-023-00042-9

Dubash, N. K. (2023). Rebalance attention from global target setting toward national climate politics and policy. *Science, 382*. doi:10.1126/science.adk7428

Dubuisson-Quellier, S. (2022). How does affluent consumption come to consumers? A research agenda for exploring the foundations and lock-ins of affluent consumption. *Consumption and Society, 1*(1), 31-50. doi:10.1332/uhiw3894

Dwyer, O., Quiroz, Y., & Viglione, G. (2023). Q&A: What the Amazon Summit means for deforestation and climate change. Last accessed April 22, 2024, available at https://www.carbonbrief.org/qa-what-the-amazon-summit-means-for-deforestation-and-climate-change/

Eckes, C. (2023). The Autonomy of the EU Legal Order: The Case of the Energy Charter Treaty. *Amsterdam Centre for European Law and Governance Research Paper*(01). Last accessed April 22, 2024, available at https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4362209

Eckes, C., Main-Klingst, L., & Schaugg, L. (2023). Why a coordinated withdrawal from the Energy Charter Treaty is inevitable. *Euractiv*. Last accessed April 22, 2024, available at https://www.euractiv.com/section/energy/opinion/why-a-coordinated-withdrawal-from-the-energy-charter-treaty-is-inevitable/

Egli, F., Schärer, D., & Steffen, B. (2022). Determinants of fossil fuel divestment in European pension funds. *Ecological Economics, 191*, 107237. doi:10.1016/j.ecolecon.2021.107237

Ekardt, F., Roos, P., Bärenwaldt, M., & Nesselhauf, L. (2023). Energy Charter Treaty: Towards a New Interpretation in the Light of Paris Agreement and Human Rights. *Sustainability, 15*(6), 5006. doi:10.3390/su15065006

Endfossil.finance. (2023). We've only just begun. Last accessed April 22, 2024, available at https://endfossil.finance/media/press-releases/we-have-just-begun

Engels, A., & Marotzke, J. (2023). Assessing the plausibility of climate futures. *Environmental Research Letters, 18*(1). doi:10.1088/1748-9326/acaf90

Engels, A., Marotzke, J., Gresse, E. G., López-Rivera, A., Pagnone, A., & Wilkens, J. (Eds.). (2023). *Hamburg Climate Futures Outlook: The plausibility of a 1.5°C limit to global warming — social drivers and physical processes*. Hamburg, Germany: Cluster of Excellence Climate, Climatic Change, and Society (CLICCS). doi:10.25592/uhhfdm.11230

Epstein, A.-S. (2023). La Directive du 14 décembre 2022 concernant la publication d'informations en matière de durabilité par les entreprises: quels fondements pour quelles critiques ? *Revue Juridique de la Sorbonne – Sorbonne Law Review*(7), 171-183. Last accessed April 22, 2024, available at https://www.economie.gouv.fr/daj/lettre-de-la-daj-la-publication-dinformations-en-matiere-de-durabilite-par-les-entreprises

European Commission. (2023). Commission work programme. Last accessed April 22, 2024, available at https://commission.europa.eu/strategy-documents/commission-work-programme/commission-work-programme-2024_en

European Commission. (2024). Corporate sustainability reporting. Last accessed April 22, 2024, available at https://finance.ec.europa.eu/capital-markets-union-and-financial-markets/

company-reporting-and-auditing/company-reporting/corporate-sustainability-reporting_en#legislation

European Council. (2023a). Fit for 55: how the EU plans to boost renewable energy. Council of the European union. Last accessed April 22, 2024, available at https://www.consilium.europa.eu/en/infographics/fit-for-55-how-the-eu-plans-to-boost-renewable-energy/

European Council. (2023b). The REPowerEU plan explained. Council of the European union, Last accessed April 22, 2024, available at https://www.consilium.europa.eu/en/infographics/repowereu/

Faccioli, M., Law, C., Caine, C. A., Berger, N., Yan, X., Weninger, F., Guell, C., Day, B., Smith, R. D., & Bateman, I. J. (2022). Combined carbon and health taxes outperform single-purpose information or fiscal measures in designing sustainable food policies. *Nature Food, 3*(5), 331-340. doi:10.1038/s43016-022-00482-2

Fakir, S. (2023). South Africa's Just Energy Transition Partnership: A novel approach transforming the international landscape on delivering NDC financial goals at scale. *South African Journal of International Affairs, 30*(2), 297-312. doi:10.1080/10220461.2023.2233006

Fankhauser, S., Smith, S. M., Allen, M., Axelsson, K., Hale, T., Hepburn, C., Kendall, J. M., Khosla, R., Lezaun, J., Mitchell-Larson, E., Obersteiner, M., Rajamani, L., Rickaby, R., Seddon, N., & Wetzer, T. (2022). The meaning of net zero and how to get it right. *Nature Climate Change, 12*(1), 15-21. doi:10.1038/s41558-021-01245-w

Fash, B. C., Vásquez Rivera, B. d. C., & Sojob, M. (2023). Prefiguring buen sobrevivir: Lenca women's (e) utopianism amid climate change. *The Journal of Peasant Studies, 50*(6), 2232-2258. doi:10.1080/03066150.2022.2138353

Fearn, G., & Davoudi, S. (2021). From post-political to authoritarian planning in England, a crisis of legitimacy. *Transactions of the Institute of British Geographers, 47*(2), 347-362. doi:10.1111/tran.12501

Ferns, G., Lambert, A., & Günther, M. (2022). The Analogical Construction of Stigma as a Moral Dualism: The Case of the Fossil Fuel Divestment Movement. *Academy of Management Journal, 65*(4), 1383-1415. doi:10.5465/amj.2018.0615

Fesenfeld, L. P., Schmid, N., Finger, R., Mathys, A., & Schmidt, T. S. (2022). The politics of enabling tipping points for sustainable development. *One Earth, 5*(10), 1100-1108. doi:10.1016/j.oneear.2022.09.004

Firdaus, N., & Mori, A. (2023). Stranded assets and sustainable energy transition: A systematic and critical review of incumbents' response. *Energy for Sustainable Development, 73*, 76-86. doi:10.1016/j.esd.2023.01.014

Fischer, F. (2019). Knowledge politics and post-truth in climate denial: on the social construction of alternative facts. *Critical Policy Studies, 13*(2), 133-152. doi:10.1080/19460171.2019.1602067

Fisher, D. R., & Nasrin, S. (2021). Climate activism and its effects. *Wiley Interdisciplinary Reviews: Climate Change, 12*(1), e683. doi:10.1002/wcc.683

Fisher, D. & Renaghan, Q. (2023). Understanding the growing radical flank of the climate movement as the world burns. Brookings. Last accessed April 22, 2024, available at https://www.brookings.edu/articles/understanding-the-growing-radical-flank-of-the-climate-movement-as-the-world-burns/

Forchtner, B. (2019). Climate change and the far right. *WIREs Climate Change, 10*(5), e604. doi.org/10.1002/wcc.604

Forster, P. M., Smith, C. J., Walsh, T., Lamb, W. F., Lamboll, R., Hauser, M., Ribes, A., Rosen, D., Gillett, N., Palmer, M. D., Rogelj, J., von Schuckmann, K., Seneviratne, S. I., Trewin, B., Zhang, X., Allen, M., Andrew, R., Birt, A., Borger, A., Boyer, T., Broersma, J. A., Cheng, L., Dentener, F., Friedlingstein, P., Gutiérrez, J. M., Gütschow, J., Hall, B., Ishii, M., Jenkins, S., Lan, X., Lee, J.-Y., Morice, C., Kadow, C., Kennedy, J., Killick, R., Minx, J. C., Naik, V., Peters, G. P., Pirani, A., Pongratz, J., Schleussner, C.-F., Szopa, S., Thorne, P., Rohde, R., Rojas Corradi, M., Schumacher, D., Vose, R., Zickfeld, K., Masson-Delmotte, V., & Zhai, P. (2023). Indicators of Global Climate Change 2022: annual update of large-scale indicators of the state of the climate system and human influence. *Earth System Science Data, 15*(6), 2295-2327. doi:10.5194/essd-15-2295-2023

Francis, K., Dongying, S., Dennis, A., Edmund, N. N. K., & Kumah, N. Y. G. (2022). Network governance and renewable energy transition in sub-Saharan Africa: Contextual evidence from Ghana. *Energy for Sustainable Development, 69*, 202-210. doi:10.1016/j.esd.2022.06.009

Fransen, T., Meckling, J., Stünzi, A., Schmidt, T. S., Egli, F., Schmid, N., & Beaton, C. (2023). Taking stock of the implementation gap in climate policy. *Nature Climate Change, 13*(8), 752-755. doi:10.1038/s41558-023-01755-9

Fritz, L., Hansmann, R., Dalimier, B., & Binder, C. R. (2023). Perceived impacts of the *Fridays for Future* climate movement on environmental concern and behaviour in Switzerland.

Sustainability Science, 18(5), 2219-2244. doi:10.1007/s11625-023-01348-7

Fuchs, D., Sahakian, M., Gumbert, T., Di Giulio, A., Maniates, M., Lorek, S., & Graf, A. (2021). *Consumption corridors: Living a good life within sustainable limits*. London: Routledge.

Fünfgeld, A. (2019). Hegemony and Varieties of Contestation: Social Movements and the Struggle over Coal-Based Energy Production in Indonesia. In F. Anderl, C. Daase, N. Deitelhoff, V. Kempf, J. Pfister, & P. Wallmeier (Eds.), *Rule and Resistance Beyond the Nation State: Contestation, Escalation, Exit* (pp. 89-114). London: Rowman & Littlefield.

Gardner, P., Carvalho, T., & Valenstain, M. (2022). Spreading rebellion?: The rise of extinction rebellion chapters across the world. *Environmental Sociology, 8*(4), 424-435. doi:10.1080/23251042.2022.2094995

Geels, F. W., Sovacool, B. K., Schwanen, T., & Sorrell, S. (2017). The Socio-Technical Dynamics of Low-Carbon Transitions. *Joule, 1*(3), 463-479. doi:10.1016/j.joule.2017.09.018

Gewirtzman, J., Natson, S., Richards, J.-A., Hoffmeister, V., Durand, A., Weikmans, R., Huq, S., & Roberts, J. T. (2018). Financing loss and damage: reviewing options under the Warsaw International Mechanism. *Climate Policy, 18*(8), 1076-1086. doi:10.1080/14693062.2018.1450724

Gilio-Whitaker, D. (2019). *As Long as Grass Grows: The Indigenous Fight for Environmental Justice, from Colonization to Standing Rock*. Boston, MA: Beacon Press.

Giuliani, E., Monasterolo, I., & Duranovic, A. (2022). Climate risk, sustainable finance and international business: a research agenda. doi:10.2139/ssrn.4198439

Glasgow Financial Alliance for Net-Zero. (2022). *2022 Progress Report*. Glasgow Financial Alliance for Net-Zero. Last accessed April 22, 2024, available at https://assets.bbhub.io/company/sites/63/2022/10/GFANZ-2022-Progress-Report.pdf

Glavovic, B. C., Dawson, R., Chow, W., Garschagen, M., Haasnoot, M., Singh, C., & Thomas, A. (2022). Cross-Chapter Paper 2: Cities and Settlements by the Sea. In H.-O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, & B. Rama (Eds.), *Climate Change 2022: Impacts, Adaptation and Vulnerability* (pp. 2163-2194). Cambridge, UK and New York, NY, USA: Cambridge University Press.

Glette-Iversen, I., Aven, T., & Flage, R. (2022). The concept of plausibility in a risk analysis context: Review and clarifications of defining ideas and interpretations. *Safety Science, 147*. doi:10.1016/j.ssci.2021.105635

Global Climate Change Litigation. (2022). Milieudefensie et al. v. Royal Dutch Shell plc. Published by: The Sabin Center for Climate Change Law. Last accessed April 22, 2024, available at https://climatecasechart.com/non-us-case/milieudefensie-et-al-v-royal-dutch-shell-plc/

Global Divestment Commitments Database. (2023). Global Fossil Fuel Divestment Commitments Database. Last accessed April 22, 2024, available at https://divestmentdatabase.org/

Global Covenant of Mayors for Climate & Energy. (2022). Energizing City Climate Action: The 2022 Global Covenant of Mayors Impact Report. Global Covenant of Mayors for Climate & Energy (GCOM). Last accessed April 22, 2024, available at https://www.globalcovenantofmayors.org/wp-content/uploads/2022/11/2022-GCoM-Impact-Report.pdf

Global Energy Monitor. (2023). China Poised to Double Wind and Solar Capacity Five Years ahead of 2030 Target. Last accessed April 22, 2024, available at https://globalenergymonitor.org/press-release/china-poised-to-double-wind-and-solar-capacity-five-years-ahead-of-2030-target/

Global Energy Monitor, CREA, E3G, Reclaim Finance, Sierra Club, SFOC, Kiko Network, CAN Europe, Bangladesh Groups, ACJCE, & Chile Sustentable. (2023). Boom and Bust Coal 2023: Tracking the Global Coal Plant Pipeline. Last accessed April 22, 2024, available at https://globalenergymonitor.org/wp-content/uploads/2023/03/Boom-Bust-Coal-2023.pdf

Goodman, J., & Morton, T. (2023). Climate movements in Germany, India, and Australia: dynamics of transition, transformation, and emergency. *Globalizations*, 1-18. doi:10.1080/14747731.2023.2215101

Government of Chile. (2022). A milestone in Chile's environmental history: From today, we have our first Framework Law on Climate Change. *Gob.cl.* Last accessed April 22, 2024, available at https://www.gob.cl/en/news/a-milestone-in-chiles-environmental-history-from-today-we-have-our-first-framework-law-on-climate-change/

Grasso, M., & Heede, R. (2023). Time to pay the piper: Fossil fuel companies' reparations for climate damages. *One Earth, 6*(5), 459-463. doi:10.1016/j.oneear.2023.04.012

Green, J. F. (2017). The strength of weakness: pseudo-clubs in the climate regime. *Climatic Change, 144*(1), 41-52. doi:10.1007/s10584-015-1481-4

Greenpeace Nederland. (2023). The Fossil Fuel Crime File: Proven Crimes and Credible Allegations – Greenpeace Nederland. *Greenpeace Nederland.* Last accessed April 22, 2024, available at https://www.greenpeace.org/nl/klimaatveran dering/56838/the-fossil-fuel-crime-file-proven-crimes-and-credible-allegations/

Gresse, E. G. (2022). *Non-state Actors and Sustainable Development in Brazil: The Diffusion of the 2030 Agenda*. Abingdon, Oxfordshire, UK: Routledge.

Gresse, E. G., Engels, A., & Sander, J. (2021). Social Driver Assessments: Consumption Patterns. In D. Stammer, A. Engels, J. Marotzke, E. G. Gresse, C. Hedemann, & J. Petzold (Eds.), *Hamburg Climate Futures Outlook: Assessing the plausibility of deep decarbonization by 2050* (pp. 101-105). Hamburg , Germany: Cluster of Excellence Climate, Climatic Change, and Society (CLICCS). doi:10.25592/uhhfdm.9104

Gresse, E. G., Engels, A., Struve, S., & Soans, E. (2023a). Social Driver Assessments: Consumption patterns. In A. Engels, J. Marotzke, E. G. Gresse, A. López-Rivera, A. Pagnone, & J. Wilkens (Eds.), *Hamburg Climate Futures Outlook: The plausibility of a 1.5°C limit to global warming – social drivers and physical processes* (pp. 122-128). Hamburg: Cluster of Excellence Climate, Climatic Change, and Society (CLICCS). Hamburg, Germany: Cluster of Excellence Climate, Climatic Change, and Society (CLICCS). doi:10.25592/uhhfdm.11230

Grimm, J., Franzki, H., & Salehi, M. (2023). Neue Radikalität? Protest, Gewalt und ziviler Ungehorsam – Versuche einer Grenzziehung. *Forschungsjournal Soziale Bewegungen, 36*(2), 179-185. doi:10.1515/fjsb-2023-0017

Grimmbacher, J. (2023). Letzte Generation protestiert auf Sylt: Luxusbar in oranger Farbe. *Die Tageszeitung: taz*. Last accessed April 22, 2024, available at https://taz.de/!5939571/ files/1761/!5939571.html

Guenther, L., & Brüggemann, M. (2023). Not here, not now, not me: how distant are climate futures represented in journalistic reporting across four countries? *Journal of Science Communication, 22*(5), A01. doi:10.22323/2.22050201

Guenther, L., Ibrahim, Y., Lüdemann, J., O'Brian, C. I., Pavenstädt, C. N., Sievert, I. J., Brüggemann, M., Rödder, S., & Schnegg, M. (2024). Social Constructions of Climate Futures: Reframing Science's Harmful Impact Frame Across News Media, Social Movements, and Local Communities. *Environmental Communication*, 1-17. doi:10.1080/17524032.2024.2305827

Guenther, L., Meyer, H., Kleinen von Königslöw, K., & Brüggemann, M. (2023). A distant threat? The framing of climate futures across four countries. *Environmental Communication*, 17(7), 775–793. doi: https://doi.org/10.1080/17524032.2023.2253500

Gulliver, R. E., Banks, R., Fielding, K. S., & Louis, W. R. (2023). The Criminalization of Climate Change Protest. *Contention, 11*(1), 24-54. doi:10.3167/cont.2023.110103

Günel, G. (2024) Inside COP28: A Participant's Take on Climate Diplomacy Efforts in Dubai. *Rice University's Baker Institute for Public Policy* (March 2024). doi:10.25613/644G-6408

Guo, X., Liang, C., Umar, M., & Mirza, N. (2022). The impact of fossil fuel divestments and energy transitions on mutual funds performance. *Technological Forecasting and Social Change, 176*, 121429. doi:10.1016/j.techfore.2021.121429

Haines, H. H. (1984). Black Radicalization and the Funding of Civil Rights: 1957-1970. *Social Problems, 32*(1), 31-43. doi:10.2307/800260

Hale, T., Smith, S. M., Black, R., Cullen, K., Fay, B., Lang, J., & Mahmood, S. (2021). Assessing the rapidly-emerging landscape of net zero targets. *Climate Policy, 22*(1), 18-29. doi:10.1080/14693062.2021.2013155

Hameed, I., & Waris, I. (2018). Eco labels and eco conscious consumer behavior: the mediating effect of green trust and environmental concern. *Journal of Management Sciences, 5*(2), 86-105. Last accessed April 22, 2024, available at https://ssrn.com/abstract=3326736

Hansen, N.-J., Toscani, F., & Zhou, J. (2023). *Euro Area Inflation after the Pandemic and Energy Shock: Import Prices, Profits and Wages*. IMF Working Paper No. 2023/131. https://www.imf.org/en/Publications/WP/Issues/2023/06/23/Euro-Area-Inflation-after-the-Pandemic-and-Energy-Shock-Import-Prices-Profits-and-Wages-534837

Hartz, F. (2023). Leaking the IPCC: A question of responsibility? *Wiley Interdisciplinary Reviews: Climate Change, 14*(3). doi:10.1002/wcc.814

Hartzmark, S. M., & Shue, K. (2023). Counterproductive Sustainable Investing: The Impact Elasticity of Brown and Green Firms. In. Rochester, NY: SSRN 4359282. doI: 10.2139/ssrn.4359282

Harvey, F. (2023). Debt relief urgent for poor countries hit by climate shocks, says IMF chief.

The Guardian. Last accessed April 22, 2024, available at https://www.theguardian.com/environment/2023/jun/20/climate-crisis-hit-poor-countries-should-have-debt-relief-says-imf-chief

Hase, V., Mahl, D., Schäfer, M. S., & Keller, T. R. (2021). Climate change in news media across the globe: An automated analysis of issue attention and themes in climate change coverage in 10 countries (2006–2018). *Global Environmental Change, 70*, 102353. doi: 10.1016/j.gloenvcha.2021.102353

Hassan, I., Musa, R. M., Latiff Azmi, M. N., Razali Abdullah, M., & Yusoff, S. Z. (2023). Analysis of climate change disinformation across types, agents and media platforms. *Information Development*, 02666669221148693. doI: 10.1177/02666669221148693

Haßler, J., Wurst, A. K., Jungblut, M., & Schlosser, K. (2023). Influence of the pandemic lockdown on *Fridays for Future*'s hashtag activism. *New Media Soc, 25*(8), 1991-2013. doi:10.1177/14614448211026575

Hayes, G., & MacGregor, S. (2023). Taking Political Time: Thinking Past the Emergency Timescapes of the New Climate Movements. *South Atlantic Quarterly*, 122(1), 181-191. doi:10.1215/00382876-10242756

Hege, E., Okereke, C., Treyer, S., Sokona, Y., Kingiri, A., Keijzer, N., & Denton, F. (2022). Just Energy Transition Partnerships in the Context of Africa-Europe Relations. Reflections from South Africa, Nigeria and Senegal Just energy transitions and partnerships in Africa: A South African case study, A Nigeria case study, A Senegal case study (INIS-FR--23-0123). France

Heikkurinen, P., Clegg, S., Pinnington, A. H., Nicolopoulou, K., & Alcaraz, J. M. (2021). Managing the Anthropocene: Relational Agency and Power to Respect Planetary Boundaries. *Organization & Environment, 34*(2), 267-286. doi:10.1177/1086026619881145

Helberger, N., Van Drunen, M., Vrijenhoek, S., & Möller, J. (2021). Regulation of news recommenders in the Digital Services Act: Empowering David against the very large online Goliath. *Internet Policy Review, 26*.

Held, H., Aykut, S. C., Hedemann, C., Li, C., Marotzke, J., Petzold, J., & Schneider, U. (2021). Plausibility of model-based emissions scenarios. In D. Stammer, A. Engels, J. Marotzke, E. G. Gresse, C. Hedemann, & J. Petzold (Eds.), *Hamburg Climate Futures Outlook: Assessing the Plausibility of Deep Decarbonization by 2050* (pp. 21-28). Hamburg, Germany: Cluster of Excellence Climate, Climatic Change, and Society (CLICCS). doi:10.25592/uhhfdm.9104

Hermwille, L., Lechtenböhmer, S., Åhman, M., van Asselt, H., Bataille, C., Kronshage, S., Tönjes, A., Fischedick, M., Oberthür, S., Garg, A., Hall, C., Jochem, P., Schneider, C., Cui, R., Obergassel, W., Fragkos, P., Sudharmma Vishwanathan, S., & Trollip, H. (2022). A climate club to decarbonize the global steel industry. *Nature Climate Change, 12*(6), 494-496. doi:10.1038/s41558-022-01383-9

Hickel, J., & Slamersak, A. (2022). Existing climate mitigation scenarios perpetuate colonial inequalities. *Lancet Planet Health, 6*(7), e628-e631. doi:10.1016/S2542-5196(22)00092-4

Hirth, S., Kreinin, H., Fuchs, D., Blossey, N., Mamut, P., Philipp, J., Radovan, I., Antal, O., Belousa, I., & Bösch, M. (2023). Barriers and enablers of 1.5° lifestyles: Shallow and deep structural factors shaping the potential for sustainable consumption. *Frontiers in Sustainability, 4. doi:10.3389/frsus.2023.1014662*

Hodgson, C. (2022, 25 September 2022). Two pension funds quit Mark Carney's green alliance. *Financial Times*. Last accessed April 22, 2024, available at https://www.ft.com/content/df321358-c6d1-4dfc-8ab7-4526fab1305b

Holder, F., Mirza, S., Carbone, J., & McKie, R. E. (2023). Climate obstruction and Facebook advertising: how a sample of climate obstruction organizations use social media to disseminate discourses of delay. *Climatic Change, 176*(2), 16. doi: 10.1080/13501763.2021.1918214

Huber, R. A., Maltby, T., Szulecki, K., & Ćetković, S. (2021). Is populism a challenge to European energy and climate policy? Empirical evidence across varieties of populism. *Journal of European Public Policy, 28*(7), 998-1017. doi: 10.1007/s10584-023-03494-4

IEA. (2022). World Energy Outlook 2022, Paris. Last accessed April 22, 2024, available at https://www.iea.org/reports/world-energy-outlook-2022

IEA. (2023a). Europe's energy crisis: What factors drove the record fall in natural gas demand in 2022? IEA, Paris. Last accessed April 22, 2024, available at https://www.iea.org/commentaries/europe-s-energy-crisis-what-factors-drove-the-record-fall-in-natural-gas-demand-in-2022

IEA. (2023b). World Energy Investment 2023. IEA, Paris. Last accessed April 22, 2024, available at https://www.iea.org/reports/world-energy-investment-2023

IEA. (2023c). Fossil Fuels Consumption Subsidies 2022. IEA, Paris. Last accessed April 22, 2024, available at https://www.iea.org/reports/fos sil-fuels-consumption-subsidies-2022

IEA. (2023d). Executive summary – Oil 2023, Paris. Last accessed April 22, 2024, available at https://www.iea.org/reports/oil-2023/execu tive-summary

IEA. (2023e). Electric car sales, 2016-2023. IEA, Paris. Last accessed April 22, 2024, available at https://www.iea.org/data-and-statistics/charts/electric-car-sales-2016-2023

IEA. (2023f). World Energy Outlook 2023. IEA, Paris. Last accessed April 22, 2024, available at https://www.iea.org/reports/world-ener gy-outlook-2023

IEA. (2024). Renewables 2023: Analysis and forecast to 2028. IEA, Paris. Last accessed April 22, 2024, available at https://iea.blob.core.windows.net/assets/96d66a8b-d502-476b-ba94-54ff da84cf72/Renewables_2023.pdf

IPCC. (2018). *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. Cambridge and New York: Cambridge University Press.

IPCC. (2019a). *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. Cambridge and New York: Cambridge University Press.

IPCC. (2019b). *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D.C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. Cambridge and New York: Cambridge University Press.

IPCC. (2022a). *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley]. Cambridge and New York: Cambridge University Press.

IPCC. (2022b). *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge and New York: Cambridge University Press.

IPCC. (2023a). *Climate Change 2023: Synthesis Report. A Report of the Intergovernmental Panel on Climate Change. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Chang*e [Core Writing Team, H. Lee and J. Romero (eds.)]. Geneva, Switzerland: IPCC.

IPCC. (2023b). Summary for Policymakers. In H. Lee & J. Romero (Eds.), *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 1-34). Geneva, Switzerland: IPCC.

IPCC. (2023c). Summary for Policymakers. In P. R. Shukla, J. Skea, A. Reisinger, R. Slade, R. Fradera, M. Pathak, A. Al Khourdajie, M. Belkacemi, R. van Diemen, A. Hasija, G. Lisboa, S. Luz, J. Malley, D. McCollum, S. Some, & P. Vyas (Eds.), *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 3-48). Cambridge and New York: Cambridge University Press.

Iyengar, S. (2023). Human rights and climate wrongs: Mapping the landscape of rights-based climate litigation. *Review of European, Comparative & International Environmental Law, 32*(2), 299-309. doi:10.1111/reel.12498

Jackson, G., N'Guetta, A., De Rosa, S. P., Scown, M., Dorkenoo, K., Chaffin, B., & Boyd, E. (2023). An emerging governmentality of climate change loss and damage. *Progress in Environmental Geography, 2*(1-2), 33-57. doi:10.1177/27539687221148748

Jakob, M., & Steckel, J. C. (Eds.). (2022). *The Political Economy of Coal: Obstacles to Clean Energy Transitions*. London: Routledge.

Jarke-Neuert, J., Perino, G., & Schwickert, H. (2023). Free riding in climate protests. *Nature Climate*

Change, 13(11), 1197-1202. doi:10.1038/s41558-023-01833-y

Jenson, J. (1993). Naming Nations – Making Nationalist Claims in Canadian Public Discourse. *Canadian Review of Sociology and Anthropology-Revue Canadienne De Sociologie Et D Anthropologie, 30*(3), 337-358.Last accessed April 22, 2024, available at https://WOS:A1993MH63000003

Jewell, J., & Cherp, A. (2023). The feasibility of climate action: Bridging the inside and the outside view through feasibility spaces. *WIREs Climate Change, 14*(5), e838. doi: 10.1002/wcc.838

Ji, Z., Lee, N., Frieske, R., Yu, T., Su, D., Xu, Y., Ishii, E., Jin Ye, B., Madotto, A., & Fung, P. (2023). Survey of Hallucination in Natural Language Generation. *ACM Comput. Surv., 55*(12), Article 248. doi:10.1145/3571730

Jordan, A., Huitema, D., Van Asselt, H., & Forster, J. (2018). *Governing climate change: Polycentricity in action?* Cambridge, UK: Cambridge University Press.

Jörgens, H., Knill, C., & Steinebach, Y. (2023). *Routledge Handbook of Environmental Policy*. New York: Routledge.

Kaiser, C. (2022). Rethinking polycentricity: on the North–South imbalances in transnational climate change governance. *International Environmental Agreements: Politics, Law and Economics, 22*(4), 693-713. doi:10.1007/s10784-022-09579-2

Kavya, M., Mikulewicz, M., & Crawford, N. J. W. (2023). Introduction. In N. J. W. Crawford, K. Michael, & M. Mikulewicz (Eds.), *Climate justice in the majority world: vulnerability, resistance, and diverse knowledges* (pp. 1-17). London: Routledge.

Kenny, J. (2023). Disapproval of climate policy dismantlement: A comparative analysis of international public opinion on Donald Trump's withdrawal from the Paris climate change regime. *Journal of Comparative Policy Analysis: Research and Practice*, 1-16.

Kenward, B., & Brick, C. (2023). Large-scale disruptive activism strengthened environmental attitudes in the United Kingdom. *Global Environmental Psychology*, 2. doi:10.5964/gep.11079

Ketu, Y., Miller, T., Rothstein, S., & Lubber, M. (2022). How companies are and are not leading on U.S. climate policy. Ceres Accelerator for Sustainable Capital Markets, U.S. Last accessed April 22, 2024, available at https://assets.ceres.org/sites/default/files/reports/2022-11/RPE%20Report_Nov22.pdf

Keyßer, L. T., & Lenzen, M. (2021). 1.5 °C degrowth scenarios suggest the need for new mitigation pathways. *Nature Communications, 12*(1), 2676. doi:10.1038/s41467-021-22884-9

Khalfan, A. A. N. L., Aguilar, C., Persson, J., Lawson, M., Dabi, N., Jayoussi, S., & Acharya, S.(2023). Climate Equality: A planet for the 99%. Oxfam International, last accessed April 22, 2024, available at https://policy-practice.oxfam.org/resources/climate-equality-a-planet-for-the-99-621551/

Kitschelt, H. P. (1986). Political Opportunity Structures and Political Protest: Anti-Nuclear Movements in Four Democracies. *British Journal of Political Science, 16*(1), (pp. 57-85). doi: 10.1017/S000712340000380X

Kleimann, D., Poitiers, N., Sapir, A., Véron, N., Veugelers, R., & Zettelmeyer, J. (2023). How Europe should answer the PolicyContribution Issue n˚04/23. Last accessed April 22, 2024, available at https://hdl.handle.net/10419/274198

Köpf, M., & Wehner, P. (2022). Protest bei sommerheißen 28 Grad. Last accessed April 22, 2024, available at https://www.sueddeutsche.de/bayern/bayern-g7-elmau-protest-demonstration-garmisch-partenkirchen-1.5609738

Kotzé, L. J., & Knappe, H. (2023). Youth movements, intergenerational justice, and climate litigation in the deep time context of the Anthropocene. *Environmental Research Communications, 5*(2), 025001. doi:10.1088/2515-7620/acaa21

Kountouris, Y., & Williams, E. (2023). Do protests influence environmental attitudes? Evidence from Extinction Rebellion. *Environmental Research Communications, 5*(1), 011003. doi:10.1088/2515-7620/ac9aeb

Kubiciel, M. (2023). Manövrieren an den Grenzen des § 129 StGB. *Verfassungsblog*. doi:10.17176/20230526-231102-0

Kucharavy, D., & De Guio, R. (2011). Application of S-shaped curves. *Procedia Engineering, 9*, 559-572. doi:10.1016/j.proeng.2011.03.142

Kuhl, L., & Shinn, J. (2022). Transformational adaptation and country ownership: competing priorities in international adaptation finance. *Climate Policy, 22*(9-10), 1290-1305. doi: 10.1080/14693062.2022.2104791

Kühne, K., Bartsch, N., Tate, R. D., Higson, J., & Habet, A. (2022). "Carbon Bombs" – Mapping key fossil fuel projects. *Energy Policy, 166*, 112950. doi:10.1016/j.enpol.2022.112950

Kulin, J., Johansson Sevä, I., & Dunlap, R. E. (2021). Nationalist ideology, rightwing populism, and public views about climate change in Europe. *Environmental Politics, 30*(7), 1111-1134. doi: 10.1080/09644016.2021.1898879

Lahsen, M., & Ribot, J. (2022). Politics of attributing extreme events and disasters to climate change. *Wiley Interdisciplinary Reviews: Climate Change, 13*(1), e750. doi: 10.1002/wcc.750

Lamb, W. F., Mattioli, G., Levi, S., Roberts, J. T., Capstick, S., Creutzig, F., Minx, J. C., Müller-Hansen, F., Culhane, T., & Steinberger, J. K. (2020). Discourses of climate delay. *Global Sustainability*, 3, e17. doi: 10.1017/sus.2020.13

Lamboll, R. D., Nicholls, Z. R., Smith, C. J., Kikstra, J. S., Byers, E., & Rogelj, J. (2023). Assessing the size and uncertainty of remaining carbon budgets. *Nature Climate Change*, 1-8. doi: 10.1038/s41558-023-01848-5

Langmack, F.-J., & Brandau, A.-M. (2023). Die „Letzte Generation", die EMRK und das Strafrecht. *Verfassungsblog*. doi:10.17176/20230608-231155-0

Laux, T. (2023). Die gesellschaftliche Einbettung der Klimastreiks. Zur Vermessung der deutschen Klimaschutzbewegungsindustrien. *Berliner Journal für Soziologie, 33*(4), 485-507. doi:10.1007/s11609-023-00508-x

Leal Filho, W., Barbir, J., Gwenzi, J., Ayal, D., Simpson, N. P., Adeleke, L., Tilahun, B., Chirisa, I., Gbedemah, S. F., Nzengya, D. M., Sharifi, A., Theodory, T., & Yaffa, S. (2022). The role of indigenous knowledge in climate change adaptation in Africa. *Environmental Science & Policy, 136*, 250-260. doi:10.1016/j.envsci.2022.06.004

Leal, J. M., & Paterson, M. (2023). Transnational city networks, global political economy, and climate governance: C40 in Mexico and Lima. *Review of International Political Economy, 31*(1), 26-46. doi: 10.1080/09692290.2023.2167849

Lee, J. Y., Jiménez, A., Choi, S.-j., & Choi, Y. H. (2022). Ideological polarization and corporate lobbying activity: The contingent impact of corruption distance. *Journal of Business Research, 141*, 448-461. doi:10.1016/j.jbusres.2021.11.047

Lee, T., Yang, H., & Blok, A. (2020). Does mitigation shape adaptation? The urban climate mitigation-adaptation nexus. *Climate Policy, 20*(3), 341-353. doi:10.1080/14693062.2020.1730152

Leffel, B. (2022). Toward Global Urban Climate Mitigation. *Sociology of Development, 8*(1), 111-137. doi:10.1525/sod.2021.0018

Leffel, B., Derudder, B., Acuto, M., & van der Heijden, J. (2023). Not so polycentric: The stratified structure & national drivers of transnational municipal networks. *Cities, 143*, 104597. doi:10.1016/j.cities.2023.104597 M4

Leipold, S. (2021). Transforming ecological modernization 'from within' or perpetuating it? The circular economy as EU environmental policy narrative. *Environmental Politics, 30*(6), 1045-1067. doi:10.1080/09644016.2020.1868863

Lelo, T. (2023). Fostering Artificial Intelligence to Face Misinformation: Discourses and Practices of Automated Fact-Checking in Brazil. *Journalism & Mass Communication Quarterly*. doi: 10.1177/10776990231207 96

Lenton, T., M, Mckay, D., I Armstrong, Loriani, S., Abrams, J., F, Lade, S., J, Donges, J., F, Buxton, J., E, Milkoreit, M., Powell, T., Smith, S., R., Constantino, S., Zimm, C., Tabara, J. D., Dakos, V., Rocha, J., Kéfi, S., Pereira, L., Boulton, C., A, Bailey, E., Juhola, S., Biggs, R., Bhowmik, A., Fesenfeld, L., & Rockström, J. (2023). *The Global Tipping Points Report 2023*. University of Exeter, Exeter. Last accessed April 22, 2024, available at https://global-tipping-points.org/

Li, M., Trencher, G., & Asuka, J. (2022). The clean energy claims of BP, Chevron, ExxonMobil and Shell: A mismatch between discourse, actions and investments. *PLoS ONE, 17*(2), e0263596. doi: 10.1371/journal.pone.0263596

Linnenluecke, M. K., & Griffiths, A. (2012). Assessing organizational resilience to climate and weather extremes: complexities and methodological pathways. *Climatic Change, 113*(3-4), 933-947. doi:10.1007/s10584-011-0380-6 M4

Lockwood, B., & Lockwood, M. (2022). How Do Right-Wing Populist Parties Influence Climate and Renewable Energy Policies? Evidence from OECD Countries. *Global Environmental Politics, 22*(3), 12-37. doi:10.1162/glep_a_00659

López-Rivera, A. (2023). Diversifying Boundary Organizations: The Making of a Global Platform for Indigenous (and Local) Knowledge in the UNFCCC. *Global Environmental Politics, 23*(4), 52-72. doi:10.1162/glep_a_00706

Lucht, K., & Liebig, S. (2023). Sozial-ökologische Bündnisse als Antwort auf Transformationskonflikte? *PROKLA. Zeitschrift für kritische Sozialwissenschaft, 53*(210), 15-33. doi:10.32387/prokla.v53i210.2037

Lynn, J., & Peeva, N. (2021). Communications in the IPCC's Sixth Assessment Report cycle. *Clim Change, 169*(1-2), 18. doi:10.1007/s10584-021-03233-7

Mai, L., & Elsässer, J. P. (2022). Orchestrating Global Climate Governance Through Data: The UNFCCC Secretariat and the Global Climate Action Platform. *Global Environmental Politics, 22*(4), 151-172. doi:10.1162/glep_a_00667

Markard, J., Wells, P., Yap, X.-S., & van Lente, H. (2023). Unsustainabilities: A study on SUVs and Space Tourism and a research agenda for transition studies. *Energy Research & Social Science, 106*, 103302. doi: 10.1016/j.erss.2023.103302

Marquardt, J. (2023). *Fridays for Future* zwischen ‚follow the science' und ‚system change': Entwicklung einer politischen Bewegung. In J. Pollex & A. Soßdorf (Eds.), *Fridays for Future* (pp. 23-44). Wiesbaden: Springer Fachmedien Wiesbaden. doi: 10.1007/978-3-658-41447-4_2

Marquardt, J., Oliveira, M. C., & Lederer, M. (2022). Same, same but different? How democratically elected right-wing populists shape climate change policymaking. *Environmental Politics, 31*(5), 777-800. doi: 10.1080/09644016.2022.2053423

Marquardt, J., Fünfgeld, A., & Elsässer, J. P. (2023). Institutionalizing climate change mitigation in the Global South: Current trends and future research. *Earth System Governance*, 15. doi:10.1016/j.esg.2022.100163

Marsh, A. (2023, 2023/02/06/). Wall Street's CO2 Agenda Drives Green Bank to Quit Alliance. *Bloomberg.com*. Last accessed April 22, 2024, available at https://www.bloomberg.com/news/articles/2023-02-06/green-banks-are-starting-to-leave-net-zero-industry-group

Martinez-Alier, J., Anguelovski, I., Bond, P., Del Bene, D., Demaria, F., Gerber, J.-F., Greyl, L., Haas, W., Healy, H., & Marín-Burgos, V. (2014). Between activism and science: grassroots concepts for sustainability coined by Environmental Justice Organizations. *Journal of Political Ecology, 21(*1), 19-60. doi: 10.2458/v21i1.21124

Masood, E., Tollefson, J., & Irwin, A. (2022). COP27 climate talks: what succeeded, what failed and what's next. *Nature, 612*(7938), 16-17. doi:10.1038/d41586-022-03807-0

Mbeva, K., Makomere, R., Atela, J., Chengo, V., & Tonui, C. (2023). The Evolving Geopolitics of Climate Change. In *Africa's Right to Development in a Climate-Constrained World* (pp. 85-126). Cham: Springer.

McCammon, H. (2013). Discursive opportunity structure. *The Wiley-Blackwell Encyclopedia of Social and Political Movements*, 1-3. doi: 10.1002/9780470674871.wbespm073.pub2

McCully, P. (2023). Throwing Fuel on the Fire: GFANZ financing of fossil fuel expansion. Last accessed April 22, 2024, available at https://inis.iaea.org/search/search.aspx?orig_q=RN:54020505

McNally, F. (2023). Church of England Pensions Board quits Net-Zero Asset Owner Alliance. Last accessed April 22, 2024, available at https://www.responsible-investor.com/church-of-england-pensions-board-quits-net-zero-asset-owner-alliance/

Medeiros, D., & Badr, H. (2022). Strengthening journalism from the margins: Engaged journalism in Brazil and Egypt. *Digital Journalism, 10*(8), 1342-1362. doi: 10.1080/21670811.2022.2078386

Méjean, A., Guivarch, C., Lefèvre, J., & Hamdi-Cherif, M. (2019). The transition in energy demand sectors to limit global warming to 1.5 C. *Energy Efficiency, 12*, 441-462. doi:10.1007/s12053-018-9682-0

Meyer, H., Pröschel, L., & Brüggemann, M. (2023a). From Disruptive Protests to Disrupted Networks? Analyzing Levels of Polarization in the German Twitter Discourses around "Fridays for Future" and "The Last Generation." *OSF Preprints*. doi: 10.31219/osf.io/nd68z

Meyer, H., Rauxloh, H., Farjam, M., & Brüggemann, M. (2023b). From Disruptive Protests to Discursive Polarization? Comparing German News on Fridays for Future and Letzte Generation. *OSF Preprints*. doi: 10.31219/osf.io/jkaw8

Meyer, H., Peach, A. K., Guenther, L., Kedar, H. E., & Brüggemann, M. (2023c). Between Calls for Action and Narratives of Denial: Climate Change Attention Structures on Twitter. *Media and Communication, 11*(1), 278-292. doi:10.17645/mac.v11i1.6111

Milkoreit, M. (2022). Social tipping points everywhere?—Patterns and risks of overuse. *WIREs Climate Change, 14*(2), e813. doi:10.1002/wcc.813

Monforte, T. M. (2023). The price of protest. *Deusto Journal of Human Rights*(11), 41-71. doi:10.18543/djhr.2774

More in Common. (2023). Wie schaut die deutsche Gesellschaft derzeit auf die Klimabewegung? Last accessed April 22, 2024, available at https://www.moreincommon.de/klimabewegung/

Moreira, D. d. A., Nina, A. L. B., Garrido, C. d. F., & Neves, M. E. S. B. (2023). Rights-based Climate Litigation in Brazil: An Assessment of Constitutional Cases before the Brazilian Supreme Court. *Journal of Human Rights Practice*, huad023. doi: 10.1093/jhuman/huad023

Morgan, S., & Charaby, N. (2023). "We Want the Global North to Pay Its Debt" – Rosa-Luxemburg-Stiftung. *Rosa Luxemburg Stiftung*. Last accessed April 22, 2024, available at https://www.rosalux.de/news/id/50029/der-globale-norden-muss-jetzt-seine-schulden-bezahlen

Mowatt, R. A. (2023). A People's Future of Leisure Studies: Fear City, Cop City and Others Tales, a Call for Police Research. *Leisure Sciences, 45*(3), 497-519. doi: 10.1080/01490400.2023.2183288

MSCI. (2023). *The MSCI Net-Zero Tracker 2023*. Last accessed April 22, 2024, available at https://

www.msci.com/documents/1296102/38217127/NetZero-Tracker-May.pdfY3 – 28.05.2023M4

Muhl, E.-K., Armitage, D., Anderson, K., Boyko, C., Busilacchi, S., Butler, J., Cvitanovic, C., Faulkner, L., Hall, J., Martynuik, G., Paul-Burke, K., Swerdfager, T., Thorpe, H., & van Putten, I. (2023). Transitioning toward "deep" knowledge co-production in coastal and marine systems: examining the interplay among governance, power, and knowledge. *Ecology and Society, 28*(4). doi:10.5751/es-14443-280417

Müller, T. (2023). Fossilindustrie vor Gericht: Petroleum Papers. *Die Tageszeitung: taz*. Last accessed April 22, 2024, available at https://taz.de/!5936699/

Myers, S., & Grant, N. (2023). Combating disinformation wanes at social media giants. *New York Times*, 03-16. Last accessed April 22, 2024, available at https://www.nytimes.com/2023/02/14/technology/disinformation-moderation-social-media.html

Myllyvirta, L. (2023). China's emissions set to fall in 2024 after record growth in clean energy. Last accessed April 22, 2024, available at https://policycommons.net/artifacts/7909459/analysis/8819781/ on 01 Jun 2024. CID: 20.500.12592/s1ksbh.

Net Zero Tracker. (2023). *Net Zero Stocktake 2023: Assessing the status and trends of net zero target setting across countries, sub-national governments and companies*. NewClimate Institute Oxford Net Zero Energy & Climate Intelligence Unit and Data-Driven EnviroLab. Last accessed April 22, 2024, available at https://zerotracker.net/analysis/net-zero-stocktake-2023

NewClimate Institute. (2023). Corporate Climate Responsibility Monitor. Last accessed April 22, 2024, available at https://newclimate.org/resources/publications/corporate-climate-responsibility-monitor-2023

NewClimate Institute, & German Institute of Development and Sustainability. (2022). *Global Climate Action 2022: How have international initiatives delivered, and what more is possible?* Radboud University. Last accessed April 22, 2024, available at https://newclimate.org/resources/publications/global-climate-action-2022

Newman, N. (2023). Journalism, media and technology trends and predictions 2023. Reuters Insitute for the Study of Journalism, UK. Last accessed April 22, 2024, available at https://reutersinstitute.politics.ox.ac.uk/our-research/journalism-media-and-technology-trends-and-predictions-2018

Niyitegeka, H., & Mukayiranga, E. P. (2023). Mapping Loss and Damage Activities: Who is doing what and where and what are the gaps? In: Loss and Damage Collaboration. Last accessed April 22, 2024, available at https://assets-global.website-files.com/605869242b205050a0579e87/63d-2991ce0ee24829c9a5bf4_L%26DC_IIED_MAPPING_L%26D_ACTIVITIES.pdf

Nolan, J. M. (2010). "An inconvenient truth" increases knowledge, concern, and willingness to reduce greenhouse gases. Environment and Behavior, 42(5), 643-658. doi: 10.1177/0013916509357696

Nyambuu, U., & Semmler, W. (2023). *Sustainable Macroeconomics, Climate Risks and Energy Transitions: Dynamic Modeling, Empirics, and Policies*. Cham: Springer International Publishing.

Nyiwul, L., & Iqbal, B. A. (2022). Evidence on Divestment Motives: An Overview. *Global Trade and Customs Journal 17*, 11-12. doi:10.54648/gtcj2022070

O'Brien, K. (2018). Is the 1.5°C target possible? Exploring the three spheres of transformation. *Current Opinion in Environmental Sustainability*, 31, 153-160. doi:10.1016/j.cosust.2018.04.010

OECD. (2021). Statistical Insights: Consumption shifts and inflation measurement during COVID-19. Last accessed April 22, 2024, available at https://www.oecd.org/fr/sdd/prix-ppa/statistical-insights-consumption-shifts-and-inflation-measurement-during-covid-19.htm

Oreskes, N., & Conway, E. M. (2022). From Anti-Government to Anti-Science: Why Conservatives Have Turned Against Science. *Daedalus, 151*(4), 98-123. doi:10.1162/daed_a_01946

Otto, I. M., Donges, J. F., Cremades, R., Bhowmik, A., Hewitt, R. J., Lucht, W., Rockström, J., Allerberger, F., McCaffrey, M., & Doe, S. S. (2020). Social tipping dynamics for stabilizing Earth's climate by 2050. *Proceedings of the National Academy of Sciences, 117*(5), 2354-2365. doi:10.1073/pnas.190057711

Özden, J., & Glover, S. (2022). *Disruptive climate protests in the UK didn't lead to a loss of public support for climate policies*. Social Change Lab M4. Last accessed April 22, 2024, available at https://forum.effectivealtruism.org/posts/YDtsGHmDJMsAWB7Wt/disruptive-climate-protests-in-the-uk-didn-t-lead-to-a-loss

Özden, J., & Glover, S. (2023). What Makes a Protest Movement Succesful? Social Change Lab. Last accessed April 22, 2024, available at https://www.socialchangelab.org/_files/ugd/503ba4_f2b72008b8fd47d087b019a620533236.pdf

Özden, J., & Ostarek, M. (2022). The Radical Flank Effect of Just Stop Oil. Social Change Lab. Last accessed April 22, 2024, available at https://www.socialchangelab.org

Pagnone, A., Gresse, E. G., López-Rivera, A., Wilkens, J., Engels, A., & Marotzke, J. (2023). Plausibility of attaining the Paris Agreement temperature goals. In A. Engels, J. Marotzke, E. G. Gresse, A. López-Rivera, A. Pagnone, & J. Wilkens (Eds.), *Hamburg Climate Futures Outlook: The plausibility of a 1.5°C limit to global warming – social drivers and physical processes* (pp. 33-50). Hamburg, Germany: Cluster of Excellence Climate, Climatic Change, and Society (CLICCS). doi:10.25592/uhhfdm.11230. *Hamburg Climate Futures Outlook: The plausibility of a 1.5°C limit to global warming – social drivers and physical processes* (pp. 33-50). Hamburg, Germany: Cluster of Excellence Climate, Climatic Change, and Society (CLICCS). doi:10.25592/uhhfdm.11230

Pahle, M., Tietjen, O., Osorio, S., Egli, F., Steffen, B., Schmidt, T. S., & Edenhofer, O. (2022). Safeguarding the energy transition against political backlash to carbon markets. *Nature Energy, 7*(3), 290-296. doi: 10.1038/s41560-022-00984-0

Pang, W., Ko, J., Kim, S. J., & Ko, E. (2022). Impact of COVID-19 pandemic upon fashion consumer behavior: focus on mass and luxury products. *Asia Pacific Journal of Marketing and Logistics, 34*(10), 2149-2164. doi: 10.1108/APJML-03-2021-0189

Papin, M., & Beauregard, P. (2023). Can't buy me love: billionaire entrepreneurs' legitimation strategies in transnational climate governance. *Environmental Politics, 33*(1), 70-91. doi:10.1080/09644016.2023.2180909

Parlasca, M. C., & Qaim, M. (2022). Meat consumption and sustainability. *Annual Review of Resource Economics, 14*, 17-41. doi: 10.1146/annurev-resource-111820-032340

Parsons, M. (2023). Governing with care, reciprocity, and relationality: recognising the connectivity of human and more-than-human wellbeing and the process of decolonisation. *Dialogues in Human Geography*. doi: 10.1177/2043820622114481.

Pasimeni, M. R., Valente, D., Zurlini, G., & Petrosillo, I. (2019). The interplay between urban mitigation and adaptation strategies to face climate change in two European countries. *Environmental Science & Policy, 95*, 20-27. doi:10.1016/j.envsci.2019.02.002

Pavenstädt, C., Wilkens, J., Huch, C., Jarke-Neuert, J., Commelin, S., & Mosuela, C. (2023). Climate protest and social movements. In A. Engels, J. Marotzke, E. G. Gresse, A. López-Rivera, A. Pagnone, & J. Wilkens (Eds.), *Hamburg Climate Futures Outlook: The plausibility of a 1.5°C limit to global warming – social drivers and physical processes* (pp. 97-103). Hamburg, Germany: Cluster of Excellence Climate, Climatic Change, and Society (CLICCS). doi:10.25592/uhhfdm.11230

Rödder, S., & Pavenstädt, C. N. (2023). 'Unite behind the Science!' Climate movements' use of scientific evidence in narratives on socio-ecological futures. *Science and Public Policy*, 50(1), 30-41. doi:10.1093/scipol/scac046

Pavenstädt, C. N., & Rödder, S. (2024). Between evidence first and political fight – understanding dynamics of (de-)politicization in US climate movements' future narratives. *Environmental Politics*, 1-22. doi:10.1080/09644016.2024.2324710

Peel, J., Palmer, A., & Markey-Towler, R. (2022). Review of Literature on Impacts of Climate Litigation: Report. Children's Investment Fund Foundation and University of Melbourne, London and Melbourne. Last accessed April 22, 2024, available at https://www.unimelb.edu.au/__data/assets/pdf_file/0008/4238450/Impact-lit-review-report_CIFF_Final_27052022.pdf

Perino, G., Jarke-Neuert, J., Schenuit, F., Wickel, M., & Zengerling, C. (2022). Closing the Implementation Gap: Obstacles in Reaching Net-Zero Pledges in the EU and Germany. *Politics and Governance*, Volume 10, Issue 3, 2022. doi: 10.17645/pag.v10i3.5326

Perino, G., & Schwickert, H. (2023). Animal welfare is a stronger determinant of public support for meat taxation than climate change mitigation in Germany. *Nat Food, 4*(2), 160-169. doi:10.1038/s43016-023-00696-y

Petzold, J., Andrews, N., Ford, J. D., Hedemann, C., & Postigo, J. C. (2020). Indigenous knowledge on climate change adaptation: a global evidence map of academic literature. *Environmental Research Letters, 15*(11), 1-17. doi:10.1088/1748-9326/abb330

Picavet, M. E. B., de Macedo, L. S. V., Bellezoni, R. A., & Puppim de Oliveira, J. A. (2023). How can Transnational Municipal Networks foster local collaborative governance regimes for environmental management? *Environ Manage, 71*(3), 505-522. doi:10.1007/s00267-022-01685-w

Pielke Jr, R., Burgess, M. G., & Ritchie, J. (2022). Plausible 2005–2050 emissions scenarios project between 2 °C and 3 °C of warming by 2100. *Environmental Research Letters, 17*(2). doi:10.1088/1748-9326/ac4ebf

Plakantonaki, S., Kiskira, K., Zacharopoulos, N., Chronis, I., Coelho, F., Togiani, A., Kalkanis, K., & Priniotakis, G. (2023). A Review of Sustainability Standards and Ecolabeling in the

Textile Industry. *Sustainability, 15*(15), 11589. doi: 10.3390/su151511589

Pollex, J., & Soßdorf, A. (2023). *Fridays for Future*. Wiesbaden: Springer Fachmedien Wiesbaden.

Poot, F., & Bauwens, J. (2023). 'Like the Oceans We Rise': News Frames on Youth for Climate. *YOUNG, 31*(2), 107-123. doi:10.1177/110330882211159

Porter, E., & Wood, T. J. (2021). The global effectiveness of fact-checking: Evidence from simultaneous experiments in Argentina, Nigeria, South Africa, and the United Kingdom. *Proc Natl Acad Sci U S A, 118*(37), e2104235118. doi:10.1073/pnas.2104235118

Priyatno, D., Kamilah, A., & Mulyana, A. (2023). Corporate crime in expropriating land rights through intimidation and criminalization. *Cogent Social Sciences, 9*(1). doi:10.1080/23311886.2023.2187739

Pulver, S. (2023). Corporate concessions: Opportunity or liability for climate advocacy groups? *Global Environmental Change, 81*, 102689. doi:10.1016/j.gloenvcha.2023.102689

Qi, J. J., & Dauvergne, P. (2022). China's rising influence on climate governance: Forging a path for the global South. *Global Environmental Change, 73*, 102484. doi:10.1016/j.gloenvcha.2022.102484

Raffety, K., Niyitegeka, H., Ormond-Skeaping, T., & Mukayiranga, E. P. R., Erin. (2022). What happened at COP27 on Loss and Damage and what comes next? Rosa Luxemburg Stiftung, New York.Last accessed April 22, 2024, available at https://uploads-ssl.webflow.com/605869242b205050a0579e87/6388a7def333e344ab-5f98c3_L%26DC_WHAT%20HAPPENED_AT_COP_27_%26_WHAT_NEXT.pdf

Rainforest Action Network, BankTrack, Indigenous Environmental Network, Oil Change International, Reclaim Finance, Sierra Club, et al. (2023). Banking on Climate Chaos. Fossil Fuel Finance Report. Last accessed April 22, 2024, available at https://www.bankingonclimatechaos.org/wp-content/uploads/2023/06/BOCC_2023_06-27.pdf

Read, R. (2023). Extinction Rebellion's future is far less radical than its past. Last accessed April 22, 2024, available at https://www.theguardian.com/commentisfree/2023/nov/08/extinction-rebellion-future-less-radical-unite-positive-action

Reclaim Finance. (2023). Assessment of oil & gas companies' climate strategy. Last accessed April 22, 2024, available at https://reclaimfinance.org/site/en/assessment-of-oil-and-gas-companies-climate-strategy/

Renn, O., Engels, A., Mack, B., Becker, S., & Camier, C. (2022). Will short-term behavior changes during the COVID-19 crisis evolve into low-carbon practices? *GAIA-Ecological Perspectives for Science and Society, 31*(3), 158-166. doi: 10.14512/gaia.31.3.6

Revi, A., Roberts, D., Klaus, I., Bazaz, A., Krishnaswamy, J., Singh, C., Eichel, A., Poonacha Kodira, P., Schultz, S., Adelekan, I., Babiker, M., Bertoldi, P., Cartwright, A., Chow, W., Colenbrander, S., Creutzig, F., Dawson, R., Coninck, H., Kleijne, K., Dhakal, S., Gallardo, L., Garschagen, M., Haasnoot, M., Haldar, S., Hamdi, R., Hashizume, M., Islam, A. K. M. S., Jiang, K., Kılkış, Ş., Klimont, Z., Lemos, M. F., Ley, D., Lwasa, S., McPhearson, T., Niamir, L., Otto, F., Pathak, M., Pelling, M., Pinto, I., Pörtner, H.-O., Pereira, J. P., Raghavan, K., Roy, J., Sara, L. M., Seto, K. C., Simpson, N. P., Solecki, W., Some, S., Sörensson, A. A., Steg, L., Szopa, S., Thomas, A., Trisos, C., & Ürge-Vorsatz, D. (2022). *The Summary for Urban Policymakers of the IPCC's Sixth Assessment Report*: Indian Institute for Human Settlements.

Riahi, K., van Vuuren, D. P., Kriegler, E., Edmonds, J., O'Neill, B. C., Fujimori, S., Bauer, N., Calvin, K., Dellink, R., Fricko, O., Lutz, W., Popp, A., Cuaresma, J. C., Kc, S., Leimbach, M., Jiang, L., Kram, T., Rao, S., Emmerling, J., Ebi, K., Hasegawa, T., Havlik, P., Humpenöder, F., Da Silva, L. A., Smith, S., Stehfest, E., Bosetti, V., Eom, J., Gernaat, D., Masui, T., Rogelj, J., Strefler, J., Drouet, L., Krey, V., Luderer, G., Harmsen, M., Takahashi, K., Baumstark, L., Doelman, J. C., Kainuma, M., Klimont, Z., Marangoni, G., Lotze-Campen, H., Obersteiner, M., Tabeau, A., & Tavoni, M. (2017). The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. *Global Environmental Change, 42*, 153-168. doi:10.1016/j.gloenvcha.2016.05.009

Rippert, U. (2022). Nationwide crackdown on "Last Generation" climate activists in Germany. *World Socialist Web Site*. Last accessed April 22, 2024, available at https://www.wsws.org/en/articles/2022/12/15/hezh-d15.html

Rödder, S., & Pavenstädt, C. N. (2023). 'Unite behind the Science!' Climate movements' use of scientific evidence in narratives on socio-ecological futures. *Science and Public Policy*, 50(1), 30-41. doi:10.1093/scipol/scac046

Rogelj, J., Fransen, T., den Elzen, M. G., Lamboll, R. D., Schumer, C., Kuramochi, T., Hans, F., Mooldijk, S., & Portugal-Pereira, J. (2023). Credibility gap in net-zero climate targets leaves world at high risk. *Science, 380*(6649), 1014-1016. doi: 10.1126/science.adg6248

Romana, H. K., Singh, R. P., Dubey, C. S., & Shukla, D. P. (2022). Analysis of Air and Soil Quality around Thermal Power Plants and Coal Mines of Singrauli Region, India. *International Journal of Environmental Research and Public Health, 19*(18). doi:10.3390/ijerph191811560

Rucht, D. (2023). Die Letze Generation: Eine kritische Zwischenbilanz. *Forschungsjournal Soziale Bewegungen, 36*(2), 186-204. doi:10.1515/fjsb-2023-0018

Ruhnau, O., Stiewe, C., Muessel, J., & Hirth, L. (2023). Natural gas savings in Germany during the 2022 energy crisis. *Nature Energy*, 1-8. doi: 10.1038/s41560-023-01260-5

Sá, J. C., Carvalho, A., Fonseca, L., Santos, G., & Dinis-Carvalho, J. (2023). Science Based Targets and the factors contributing to the sustainable development of an organisation from a Literature review to a conceptual model. *Production Engineering Archives, 29*(3), 241-253. doi: 10.30657/pea.2023.29.28

Sardo, M. C. (2023). Responsibility for climate justice: Political not moral. *European Journal of Political Theory, 22*(1), 26-50. doi:10.1177/1474885120955148

Sassan, C., Mahat, P., Aronczyk, M., & Brulle, R. J. (2023). Energy Citizens "Just Like You"? Public Relations Campaigning by the Climate Change Counter-movement. *Environmental Communication, 17*(7), 794-810. doi: 10.1080/17524032.2023.2255388

Sato, M. G., G. Higham, C. Setzer, J. Venmans, F. (2023). Impacts of climate litigation on firm value. In *Centre for Climate Change Economics and Policy Working Paper 421/Grantham Research Institute on Climate Change and the Environment Working Paper 397*. London: London School of Economics and Political Science. Last accessed April 22, 2024, available at http://eprints.lse.ac.uk/id/eprint/119262

Schalatek, L. (2021). Gebrochene Versprechen: Industriestaaten halten 100 Milliarden Dollar-Klimazusage nicht ein. *Heinrich-Böll-Stiftung*. Last accessed April 22, 2024, available at https://www.boell.de/de/2021/10/26/gebrochene-versprechen-industriestaaten-halten-100-milliarden-dollar-klimazusage-nichtfiles/1817/gebrochene-versprechen-industriestaaten-halten-100-milliarden-dollar-klimazusage-nicht.html

Schalatek, L. (2022). Klimafinanzierung ist das Thema auf der COP27. *Heinrich-Böll-Stiftung*. Last accessed April 22, 2024, available at https://www.boell.de/de/2022/11/02/klimafinanzierung-ist-das-thema-auf-der-cop27

Scheffran, J., Zengerling, C., Lange, A., & D'Amico, E. (2021). Transnational Initiatives. In D. Stammer, A. Engels, J. Marotzke, E. Gresse, C. Hedemann, & J. Petzold (Eds.), *Hamburg Climate Futures Outlook: Assessing the plausibility of deep decarbonization by 2050* (pp. 75-80). Hamburg, Germany: Cluster of Excellence Climate, Climatic Change, and Society (CLICCS). doi:10.25592/uhhfdm.9104

Scheidel, A., Del Bene, D., Liu, J., Navas, G., Mingorria, S., Demaria, F., Avila, S., Roy, B., Ertor, I., Temper, L., & Martinez-Alier, J. (2020). Environmental conflicts and defenders: A global overview. *Glob Environ Change, 63*, 102104. doi:10.1016/j.gloenvcha.2020.102104

Scheuch, E. G., Ortiz, M., Shreedhar, G., & Thomas-Walters, L. (2024). The power of protest in the media: examining portrayals of climate activism in UK news. *Humanities and Social Sciences Communications, 11*(1). doi:10.1057/s41599-024-02688-0

Schifeling, T., & Hoffman, A. J. (2019). Bill McKibben's influence on US climate change discourse: shifting field-level debates through radical flank effects. *Organization & Environment, 32*(3), 213-233. doi: 10.1177/1086026617744278

Schipper, E. L. F., Eriksen, S. E., Fernandez Carril, L. R., Glavovic, B. C., & Shawoo, Z. (2021). Turbulent transformation: abrupt societal disruption and climate resilient development. *Climate and Development, 13*(6), 467-474. doi:10.1080/17565529.2020.1799738

Schneidewind, U., Singer-Brodowski, M., Augenstein, K., & Stelzer, F. (2016). Pledge for a transformative science : a conceptual framework. Wuppertal Institute for Climate, Environment and Energy, Wuppertal. Last accessed April 22, 2024, available at https://nbn-resolving.org/urn:nbn:de:bsz:wup4-opus-64142

Schwartz, J. A., Lendway, P., & Nuri, A. (2023). Fossil fuel divestment and public climate change policy preferences: an experimental test in three countries. *Environmental Politics, 33*(1), 1-24. doi: 10.1080/09644016.2023.2178351

Schwartzkopff, F., & Marsh, A. , (2022, December 7). Vanguard Quits Net-Zero Group, Marking Biggest Defection Yet. *Bloomberg.com*. Last accessed April 22, 2024, available at https://www.bloomberg.com/news/articles/2022-12-07/vanguard-quits-net-zero-alliance-marking-biggest-defection-yet

Science Based Targets initiative. (2024). SBTi Corporate Net-Zero Standard: Version 1.2. Science

Based Targets initiative. Last accessed April 22, 2024, available at https://sciencebasedtargets.org/resources/files/Net-Zero-Standard.pdf

Searchinger, T., James, O., Dumas, P., Kastner, T., & Wirsenius, S. (2022). EU climate plan sacrifices carbon storage and biodiversity for bioenergy. *Nature, 612*(7938), 27-30. doi:10.1038/d41586-022-04133-1

Seddon, N. (2022). Harnessing the potential of nature-based solutions for mitigating and adapting to climate change. *Science, 376*(6600), 1410-1416. doi:10.1126/science.abn9668

Segal, M. (2022). Mark Carney-led GFANZ Drops Requirement for Race to Zero Commitment for Members. *ESG Today*. Last accessed April 22, 2024, available at https://www.esgtoday.com/mark-carney-led-gfanz-drops-requirement-for-race-to-zero-commitment/

Selin, C., & Guimarães Pereira, Â. (2013). Pursuing plausibility. *International Journal of Foresight and Innovation Policy, 9*(2/3/4), 93-109. doi:10.1504/ijfip.2013.058616

Semieniuk, G., Holden, P. B., Mercure, J.-F., Salas, P., Pollitt, H., Jobson, K., Vercoulen, P., Chewpreecha, U., Edwards, N. R., & Viñuales, J. E. (2022). Stranded fossil-fuel assets translate to major losses for investors in advanced economies. *Nature Climate Change, 12*(6), 532-538. doi:10.1038/s41558-022-01356-y

Serhan, Y. (2022). 'Not what you'd expect in a democracy': How Britain is waging war against climate protesters. *Time* Magazine. Last accessed April 22, 2024, available at https://time.com/6241372/uk-public-order-bill-climate-protests/

Setzer, J., & Higham, C. (2023). Global Trends in Climate Change Litigation: 2023 Snapshot. Grantham Research Institute on Climate Change and the Environment and Centre for Climate Change Economics and Policy, London School of Economics and Political Science., London. Last accessed April 22, 2024, available at https://www.lse.ac.uk/granthaminstitute/publication/global-trends-in-climate-change-litigation-2023-snapshot/

Sharma, V. (2023). Big Oil Profits Reached Record High Levels in 2022. *Visual Capitalist*. Last accessed April 22, 2024, available at https://www.visualcapitalist.com/cp/big-oil-profits-reached-record-high-levels-in-2022/

Shove, E., & Walker, G. (2010). Governing transitions in the sustainability of everyday life. *Research Policy, 39*(4), 471-476. doi: 10.1016/j.respol.2010.01.019

Shue, H. (2022). Unseen urgency: Delay as the new denial. *WIREs Climate Change, 14*(1). doi:10.1002/wcc.809

Sobhan, R. (2014). *Vulnerability traps and their effects on human development*. UNDP Human Development Report Office New York. Last accessed April 22, 2024, available at https://hdr.undp.org/content/vulnerability-traps-and-their-effects-human-development

Sokolowski, A., Boldyreva, T., Jenkings-Long, E., Bankole, S., & Twigg, S. (2023). *Are Companies Developing Credible Climate Transition Plans?: Disclosure to key climate transition-focused indicators in CDP's 2022 Climate Change Questionnaire*. Last accessed April 22, 2024, available at https://cdn.cdp.net/cdp-production/cms/reports/documents/000/006/785/original/Climate_transition_plan_report_2022_%2810%29.pdf?1676456406

Sorce, G. (2022). The "Greta Effect": Networked Mobilization and Leader Identification Among Fridays for Future Protesters. *Media and Communication, 10*(2). doi:10.17645/mac.v10i2.5060 M4

Soßdorf, A., & Burgi, V. (2022). "Listen to the science!"—The role of scientific knowledge for the Fridays for Future movement. *Frontiers in Communication, 7*. doi:10.3389/fcomm.2022.983929

Sovacool, B. K., Newell, P., Carley, S., & Fanzo, J. (2022). Equity, technological innovation and sustainable behaviour in a low-carbon future. *Nat Hum Behav, 6*(3), 326-337. doi:10.1038/s41562-021-01257-8

Spaiser, V., Nisbett, N., & Stefan, C. G. (2022). "How dare you?"—The normative challenge posed by Fridays for Future. *PLOS Climate, 1*(10), e0000053. doi:10.1371/journal.pclm.0000053 M4

SRU. (2023). Stellungnahme des SRU zur Verbändebeteiligung KSG-Novelle 2023. Sachverständigenrat für Umweltfragen, Berlin. Last accessed April 22, 2024, available at https://www.umweltrat.de/SharedDocs/Downloads/DE/04_Stellungnahmen/2020_2024/2024_06_stellungnahme_novelle_klimaschutzgesetz.html

Stammer, D., Engels, A., Marotzke, J., Gresse, E. G., Hedemann, C., & Petzold, J. (Eds.). (2021). *Hamburg Climate Futures Outlook: Assessing the plausibility of deep decarbonization by 2050*. Hamburg, Germany: Cluster of Excellence Climate, Climatic Change, and Society (CLICCS). doi:10.25592/uhhfdm.9104

Stehr, N. (2012). Knowledge and non-knowledge. *Science, Technology & Innovation Studies, 8*(1), 3-13. Last accessed April 22, 2024, available at https://www.academia.edu/2328481/

Stehr_Nico_Knowledge_and_non_knowledge_Science_Technology_and_Innovation_Studies_2012

Stokols, E. (2023, February 4). How the climate movement learned to win in Washington – POLITICO. *POLITICO*. Last accessed April 22, 2024, available at https://www.politico.com/news/2023/04/02/climate-politics-change-00088107

Stuart-Smith, R. F., Otto, F. E., Saad, A. I., Lisi, G., Minnerop, P., Lauta, K. C., van Zwieten, K., & Wetzer, T. (2021). Filling the evidentiary gap in climate litigation. *Nature Climate Change, 11*(8), 651-655. doi: 10.1038/s41558-021-01086-7

Suitner, C., Badia, L., Clementel, D., Iacovissi, L., Migliorini, M., Salvador Casara, B. G., Solimini, D., Formanowicz, M., & Erseghe, T. (2023). The rise of #climateaction in the time of the FridaysForFuture movement: A semantic network analysis. *Social Networks, 75*, 170-185. doi:10.1016/j.socnet.2022.06.003

Sultana, F. (2021). Critical climate justice. *The Geographical Journal, 188*(1), 118-124. doi:10.1111/geoj.12417

Sultana, F. (2023). Whose growth in whose planetary boundaries? Decolonising planetary justice in the Anthropocene. Geo: *Geography and Environment, 10*(2), e00128. doi: 10.1002/geo2.128

Sun, L., Fang, S., Iqbal, S., & Bilal, A. R. (2022). Financial stability role on climate risks, and climate change mitigation: Implications for green economic recovery. *Environmental science and pollution research international, 29*(22), 33063-33074. doi:10.1007/s11356-021-17439-w

Sundqvist, G., Gasper, D., St. Clair, A. L., Hermansen, E. A., Yearley, S., Øvstebø Tvedten, I., & Wynne, B. (2018). One world or two? Science–policy interactions in the climate field. *Critical Policy Studies, 12*(4), 448-468. doi: 10.1080/19460171.2017.1374193

Supran, G., Rahmstorf, S., & Oreskes, N. (p.37 2023). Assessing ExxonMobil's global warming projections. *Science, 379*(6628), eabk0063. doi:10.1126/science.abk0063

Task Force on Climate-related Financial Disclosures. (2022). *2022 Status Report*. Task Force on Climate-related Financial Disclosures. Last accessed April 22, 2024, available at https://assets.bbhub.io/company/sites/60/2022/10/2022-TCFD-Status-Report.pdf

Taylor, M. (2021). Environment protest being criminalised around world, say experts. *The Guardian*. Last accessed April 22, 2024, available at https://www.theguardian.com/environment/2021/apr/19/environment-protest-being-criminalised-around-world-say-expertsfiles/1775/environment-protest-being-criminalised-around-world-say-experts.html

Temper, L., Avila, S., Bene, D. D., Gobby, J., Kosoy, N., Billon, P. L., Martinez-Alier, J., Perkins, P., Roy, B., Scheidel, A., & Walter, M. (2020). Movements shaping climate futures: A systematic mapping of protests against fossil fuel and low-carbon energy projects. *Environmental Research Letters, 15*(12), 123004. doi:10.1088/1748-9326/abc197

Teunissen, A., & Chan, S. (2024). Leveraging "Enabling Power" Through Awarding in Global Climate Governance: Catalytic Impacts of UNFCCC's Global Climate Action Award. *Global Environmental Politics, 24*(1), 100-123. doi:10.1162/glep_a_00719

Thierry, A. (2023). "Heading for Extinction": the representation of scientific knowledge in Extinction Rebellion's recruitment talks. *Frontiers in Communication, 8*. doi:10.3389/fcomm.2023.1237700

Thiri, M. A., Villamayor-Tomás, S., Scheidel, A., & Demaria, F. (2022). How social movements contribute to staying within the global carbon budget: Evidence from a qualitative meta-analysis of case studies. *Ecological Economics, 195*, 107356. doi: 10.1016/j.ecolecon.2022.107356

Tilsted, J. P., Palm, E., Bjørn, A., & Lund, J. F. (2023). Corporate climate futures in the making: Why we need research on the politics of Science-Based Targets. *Energy Research & Social Science, 103*, 1-9. doi: 10.1016/j.erss.2023.103229

Toivonen, H. (2022). Themes of climate change agency: a qualitative study on how people construct agency in relation to climate change. *Humanities and Social Sciences Communications, 9*(1). doi:10.1057/s41599-022-01111-w

Tosun, J. (2022). Addressing climate change through climate action. *1*(1), 1-8. doi:10.1007/s44168-022-00003-8

Trust, S., Sanjay, J., Lenton, T., & Oliver, J. (2023). The Emperor's New Climate Scenarios. Limitations and assumptions of commonly used climate-change scenarios in financial services. Institute and Faculty of Actuaries, University of Exeter. Last accessed April 22, 2024, available at https://actuaries.org.uk/media/qeydewmk/the-emperor-s-new-climate-scenarios_ifoa_23.pdf

Tschötschel, R. S., Schumann, N., Roloff, R., & Brüggemann, M. (2022). Der Klimawandel im öffentlich-rechtlichen Fernsehen. Inhaltsanalyse der „Tagesschau" und des Gesamtprogramms von Das Erste, ZDF und WDR 2007 bis 2022. *Media Perspektiven*, 51(12), 574-851.

Uldam, J. (2013). Activism and the online mediation opportunity structure: attempts to impact global climate change policies? *Policy & Internet, 5*(1), 56-75. doi: 10.1002/poi3.22

UN Climate Action. Net Zero Coalition. Last accessed April 22, 2024, available at https://www.un.org/en/climatechange/net-zero-coalition

UNEP. (2023a). Emissions Gap Report 2023: Broken Record – Temperatures hit new highs, yet world fails to cut emissions (again). United Nations Environment Programme, Nairobi. Last accessed April 22, 2024, available at https://www.unep.org/emissions-gap-report-2023

UNEP. (2023b). State of Finance for Nature: The Big Nature Turnaround – Repurposing $7 trillion to combat nature loss. Summary for Decision-makers. United Nations Environment Programme, Nairobi.Last accessed April 22, 2024, available at https://wedocs.unep.org/handle/20.500.11822/44278;jsessionid=3BDCE2CA2965C94EA79AA4CD6EF9BB62

UNEP & International Resource Panel. (2024). Global Resources Outlook 2024. United Nations Environment Programme, Nairobi. Last accessed April 22, 2024, available at https://www.unep.org/resources/Global-Resource-Outlook-2024

UNFCCC. (2022a). NDC Synthesis Report. Last accessed April 22, 2024, available at https://unfccc.int/ndc-synthesis-report-2022

UNFCCC. (2022b). Tacking stock of progress – September 2022: First joint progress report across UN-backed global climate campaigns: Race to Resilience and Race to Zero. Last accessed April 22, 2024, available at https://climatechampions.unfccc.int/wp-content/uploads/2022/09/Race-to-Zero-Race-to-Resilience-Progress-Report.pdf?_gl=1*1ypzrfi*_ga*MTg5OTczMjUzNC4xNjg2MjI5MjE0*_ga_7ZZWT14N79*MTY4ODIyMDY3Mi4xMi4xLjE2ODgyMjA2ODkuMC4wLjA

UNFCCC. (2022c). Report of the Conference of the Parties on its twenty- sixth session, held in Glasgow from 31 October to 13 November 2021. Addendum Part two: Action taken by the Conference of the Parties at its twenty-sixth session. (UN doc FCCC/CP/2021/12/Add.2). Last accessed April 22, 2024, available at https://unfccc.int/documents/460954

UNFCCC. (2023). Global Climate Action Portal (GPAC). Last accessed April 22, 2024, available at https://climateaction.unfccc.int/

UNFCCC Nationally Determined Contributions Registry. Last accessed April 22, 2024, available at https://unfccc.int/NDCREG

UNFCCC FCCC/CP/2022/10/Add.1. (2023). Report of the Conference of the Parties on its twenty-seventh session, held in Sharm el-Sheikh from 6 to 20 November 2022. Addendum. Part two: Action taken by the Conference of the Parties at its twenty-seventh session. Last accessed April 22, 2024, available at https://unfccc.int/documents/626561

UNFCCC FCCC/PA/CMA/2023/L.17. (2023). Outcome of the first global stocktake. Draft decision -/CMA.5. Proposal by the President. Last accessed April 22, 2024, available at https://unfccc.int/documents/636608

Uyeda, R. L. (2022). How criminalizing protests stifles climate justice. Prism. Last accessed April 22, 2024, available at http://prismreports.org/2022/11/08/criminalizing-protests-stifles-climate-justice/files/1784/criminalizing-protests-stifles-climate-justice.html

van Benthem, A. A., Crooks, E., Giglio, S., Schwob, E., & Stroebel, J. (2022). The effect of climate risks on the interactions between financial markets and energy companies. *Nature Energy, 7*(8), 690-697. doi:10.1038/s41560-022-01070-1

van Valkengoed, A. M., Steg, L., & Perlaviciute, G. (2023). The psychological distance of climate change is overestimated. *One Earth, 6*(4), 362-391. doi:10.1016/j.oneear.2023.03.006

Vanhala, L. (2020). Coproducing the Endangered Polar Bear: Science, Climate Change, and Legal Mobilization. *Law & Policy, 42*(2), 105-124. doi:10.1111/lapo.12144

Veland, S., Scoville-Simonds, M., Gram-Hanssen, I., Schorre, A. K., El Khoury, A., Nordbø, M. J., Lynch, A. H., Hochachka, G., & Bjørkan, M. (2018). Narrative matters for sustainability: the transformative role of storytelling in realizing 1.5°C futures. *Current Opinion in Environmental Sustainability, 31*, 41-47. doi:10.1016/j.cosust.2017.12.005 M4 – Citavi

Vieira, L. C., Longo, M., & Mura, M. (2023). From carbon dependence to renewables: The European oil majors' strategies to face climate change. *Business Strategy and the Environment, 32*(4), 1248-1259. doi:10.1002/bse.3185

von Bernstorff, J. (2023). Ist der Umgang mit Klimaprotesten in Deutschland menschenrechtswidrig? Last accessed April 22, 2024, available at https://verfassungsblog.de/ist-der-umgang-mit-klimaprotesten-in-deutschland-menschenrechtswidrig

von Zabern, L., & Tulloch, C. D. (2021). Rebel with a cause: the framing of climate change and intergenerational justice in the German press treatment of the Fridays for Future protests.

Media, Culture & Society, 43(1), 23-47. doi: doi.org/10.1177/0163443720960

Vona, F. (2023). Managing the distributional effects of climate policies: A narrow path to a just transition. *Ecological Economics, 205*, 107689. doi: 10.1016/j.ecolecon.2022.107689

Wahlström, M., & Peterson, A. (2006). Between the state and the market: Expanding the concept of 'political opportunity structure'. *Acta sociologica, 49*(4), 363-377. doi: 10.1177/000169930607167

Waldinger, M., Rainer, H., Ludwig, M., Flückiger, M., Wichert, S., & Fabel, M. (2023). The Power of Youth: The Impact of the" *Fridays for Future*" Climate Movement on Voters, Politicians, and the Media. *PREPRINT (Version 1) available at Research Square*, 1-47. doi:10.21203/rs.3.rs-3199060/v1

Weber, I. M., & Wasner, E. (2023). Sellers' inflation, profits and conflict: why can large firms hike prices in an emergency? *Review of Keynesian Economics, 11*(2), 183-213. doi: 10.4337/roke.2023.02.05

Wehling, P. (2022). Der Umgang mit Ungewissheit und Nichtwissen in der Klimaforschung. In S. Rödder (Ed.), *Schlüsselwerke der sozialwissenschaftlichen Klimaforschung* (pp. 415–424). Bielefeld: transcript. doi: 10.1515/9783839456668-066

Weis, V. (2022). *Criminalization of Activism: Historical, Present and Future Perspectives*: Routledge.

Wentz, J., Merner, D., Franta, B., Lehmen, A., & Frumhoff, P. C. (2023). Research Priorities for Climate Litigation. *Earth's Future, 11*(1), e2022EF002928. doi:10.1029/2022ef002928

White, K., Loughead, R., Linstaedt, J., Rooze, J., & Young, W. (2023). Financing the Transition: Energy Supply Investment and Bank Financing Activity, BloomberNEF. Last accessed April 22, 2024, available at https://assets.bbhub.io/professional/sites/24/BNEF-Bank-Financing-Report-Summary-2023.pdf

Widerberg, O., Boran, I., Chan, S., Deneault, A., Kok, M., Negacz, K., Pattberg, P., & Petersson, M. (2022). Finding synergies and trade-offs when linking biodiversity and climate change through cooperative initiatives. *Global Policy, 14*(1), 157-161. doi:10.1111/1758-5899.13158

Wiedmann, T., Lenzen, M., Keysser, L. T., & Steinberger, J. K. (2020). Scientists' warning on affluence. *Nature Communications, 11*(1), 3107. doi:10.1038/s41467-020-16941-y

Wiener, A. (1998). The Embedded Acquis Communautaire: Transmission Belt and Prism of New Governance. *European Law Journal, 4*(3), 294-315. doi: 10.1111/1468-0386.00054

Wiener, A. (2022). Societal multiplicity for international relations: Engaging societal interaction in building global governance from below. *Cooperation and Conflict, 57*(3), 348-366. doi:10.1177/00108367221098497

Wiener, A., & Aykut, S. C. (2024). Beyond the 'Beyond': Polycentric Climate Governance and the Densification of Global Climate Agency. *Journal of European Public Policy, (submitted manuscript)*.

Wiener, A., Aykut, S. C., Gonçalves Gresse, E. G., López-Rivera, A., & Wilkens, J. (2023). The Social Plausibility Assessment Framework: from social drivers to the plausibility of deep decarbonization. In A. Engels, J. Marotzke, E. G. Gresse, A. López-Rivera, A. Pagnone, & J. Wilkens (Eds.), *Hamburg Climate Futures Outlook: The plausibility of a 1.5°C limit to global warming – social drivers and physical processes* (pp. 26-28). Hamburg, Germany: Cluster of Excellence Climate, Climatic Change, and Society (CLICCS). doi:10.25592/uhhfdm.11230

Wilkens, J., & Datchoua-Tirvaudey, A. R. C. (2022). Researching climate justice: a decolonial approach to global climate governance. *International Affairs, 98*(1), 125-143. doi:10.1093/ia/iiab209

Wilkens, J., Pagnone, A., Gresse, E. G., López-Rivera, A., Engels, A., Marotzke, J., Aykut, S. C., Rödder, S., Sillmann, J., & Wiener, A. (2023). CLICCS Plausibility Assessment Framework. In A. Engels, J. Marotzke, E. G. Gresse, A. López-Rivera, A. Pagnone, & J. Wilkens (Eds.), *Hamburg Climate Futures Outlook: The plausibility of a 1.5°C limit to global warming – social drivers and physical processes* (pp. 20-33). Hamburg, Germany: Cluster of Excellence Climate, Climatic Change, and Society (CLICCS). doi:10.25592/uhhfdm.11230

Wilkes, T., Hübner, A., & Sims, T. (2023, May 26). Insurers flee climate alliance after ESG backlash in the U.S. *Reuters*. Last accessed April 22, 2024, available at https://www.reuters.com/business/allianz-decides-leave-net-zero-insurance-alliance-2023-05-25/

Wilkins, B. (2022). 'Cancel the Debt': Climate Protests Disrupt World Bank Summit. Last accessed April 22, 2024, available at https://www.commondreams.org/news/2022/10/13/cancel-debt-climate-protests-disrupt-world-bank-summit

Wimbadi, R. W., & Djalante, R. (2020). From decarbonization to low carbon development and transition: A systematic literature review of the conceptualization of moving toward net-zero carbon dioxide emission (1995–2019). *Journal of Cleaner Production, 256*, 1-18. doi:10.1016/j.jclepro.2020.120307

Winkelmann, R., Donges, J. F., Smith, E. K., Milkoreit, M., Eder, C., Heitzig, J., Katsanidou, A., Wiedermann, M., Wunderling, N., & Lenton, T. M. (2022). Social tipping processes towards climate action: A conceptual framework. *Ecological Economics, 192*, 107242. doi:10.1016/j.ecolecon.2021.107242

Xaba, N. (2023). Whose just energy transition? A South African perspective. Wiley Interdisciplinary Reviews: *Energy and Environment, 12*(5), e478. doi: doi.org/10.1002/wene.478

Yang, M., Chen, L., Wang, J., Msigwa, G., Osman, A. I., Fawzy, S., Rooney, D. W., & Yap, P.-S. (2023). Circular economy strategies for combating climate change and other environmental issues. *Environmental Chemistry Letters, 21*(1), 55-80. doi: doi.org/10.1007/s10311-022-01499-6

Yates, A., Dombroski, K., & Dionisio, R. (2023). Dialogues for wellbeing in an ecological emergency: Wellbeing-led governance frameworks and transformative Indigenous tools. *Dialogues in Human Geography, 13*(2), 268-287. doi: 10.1177/20438206221102

Yılmaz, M. B., & Baybars, B. (2022). A critical perspective on greenwashing under the roof of corporate environmentalism. *Green Marketing in Emerging Economies: A Communications Perspective*, 119-140. doi: doi.org/10.1007/978-3-030-82572-0_6

Yokessa, M., & Marette, S. (2019). A review of eco-labels and their economic impact. *International Review of Environmental and Resource Economics, 1*3(1-2), 119-163. doi: 10.1561/101.00000107.

Zeit Online (2023). Bundesweite Razzia gegen Letzte Generation. Last accessed April 22, 2024, available at https://www.zeit.de/politik/2023-05/bundesweite-razzia-gegen-letzte-generation

Ziervogel, G., Enqvist, J., Metelerkamp, L., & van Breda, J. (2022). Supporting transformative climate adaptation: community-level capacity building and knowledge co-creation in South Africa. *Climate Policy, 22*(5), 607-622. doi: 10.1080/14693062.2020.1863180

Zilles, J., & Marg, S. (2022). Protest and Polarisation in the Context of Energy Transition and Climate Policy in Germany: Mindsets and Collective Identities. *German Politics, 32*(3), 495-516. doi:10.1080/09644008.2022.2059469

Żuk, P., & Żuk, P. (2022). National energy security or acceleration of transition? Energy policy after the war in Ukraine. *Joule, 6*(4), 709-712. doi:10.1016/j.joule.2022.03.009

Zvobgo, L., Johnston, P., Olagbegi, O. M., Simpson, N. P., & Trisos, C. H. (2023). Role of Indigenous and local knowledge in seasonal forecasts and climate adaptation: A case study of smallholder farmers in Chiredzi, Zimbabwe. *Environmental Science & Policy, 145*, 13-28. doi:10.1016/j.envsci.2023.03.017

Box 1 – The implications of degrowth scenarios for the plausibility of climate futures

Abi Deivanayagam, T., English, S., Hickel, J., Bonifacio, J., Guinto, R. R., Hill, K. X., Huq, M., Issa, R., Mulindwa, H., & Nagginda, H. P. (2023). Envisioning environmental equity: climate change, health, and racial justice. *The Lancet*. doi:10.1016/S0140-6736(23)00919-4

Beck, S., & Oomen, J. (2021). Imagining the corridor of climate mitigation – What is at stake in IPCC's politics of anticipation? *Environmental Science & Policy, 123*, 169-178. doi:10.1016/j.envsci.2021.05.011 M4

Bodirsky, B. L., Chen, D. M.-C., Weindl, I., Soergel, B., Beier, F., Molina Bacca, E. J., Gaupp, F., Popp, A., & Lotze-Campen, H. (2022). Integrating degrowth and efficiency perspectives enables an emission-neutral food system by 2100. *Nature Food*, 3(5), 341-348. doi:10.1038/s43016-022-00500-3

Braunreiter, L., van Beek, L., Hajer, M., & van Vuuren, D. (2021). Transformative pathways – Using integrated assessment models more effectively to open up plausible and desirable low-carbon futures. *Energy Research & Social Science, 80*, 102220. doi:10.1016/j.erss.2021.102220 M4

Cointe, B., & Pottier, A. (2023). Understanding why degrowth is absent from mitigation scenarios. Modelling choices and practices in the IAM community. *Revue de la régulation. Capitalisme, institutions, pouvoirs* (35). doi:10.4000/regulation.23034

Demaria, F., Schneider, F., Sekulova, F., & Martinez-Alier, J. (2013). What is degrowth? From an activist slogan to a social movement. *Environmental Value*s, 22(2), 191-215. doi:10.3197/096327113X13581561725194

Eastwood, L., & Heron, K. (2024). *De Gruyter Handbook of Degrowth*: Walter de Gruyter GmbH & Co KG.

Engels, A., Bassen, A., Busch, T., Commelin, S., Frisch, T., Müller, F., & Neumann, M. (2023). Fossil-fuel divestment. In A. Engels, J. Marotzke, E. G. Gresse, A. López-Rivera, A. Pagnone, & J. Wilkens (Eds.), *Hamburg Climate Futures Outlook: The plausibility of a 1.5° limit to gobal warming – Social drivers and physical processes* (pp. 116-122).

Hamburg, Germany: Cluster of Excellence Climate, Climatic Change, and Society (CLICCS). doi:10.25592/uhhfdm.11230

Fox, N. J. (2023). Green capitalism, climate change and the technological fix: A more-than-human assessment. *The Sociological Review, 71*(5), 1115-1134. doi:10.1177/00380261221121232

Hartl, R. F., Kort, P. M., & Wrzaczek, S. (2023). Reputation or warranty, what is more effective against planned obsolescence? *International Journal of Production Research, 61*(3), 939-954. doi:10.1080/00207543.2021.2020929

Hickel, J. (2020). What does degrowth mean? A few points of clarification. *Globalizations, 18*(7), 1105-1111. doi:10.1080/14747731.2020.1812222

Hickel, J., Brockway, P., Kallis, G., Keyßer, L., Lenzen, M., Slameršak, A., Steinberger, J., & Ürge-Vorsatz, D. (2021). Urgent need for post-growth climate mitigation scenarios. *Nature Energy, 6*(8), 766-768. doi:10.1038/s41560-021-00884-9

IPCC. (2022a). *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge and New York: Cambridge University Press.

IPCC. (2022b). *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley]. Cambridge and New York: Cambridge University Press.

IPCC. (2023). Summary for Policymakers. In H. Lee & J. Romero (Eds.), *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 1-34). Geneva, Switzerland: IPCC.

Joseph, S. R., & Koudur, S. (2023). Development vis-à-vis Degrowth: Stories of Resistance, Struggle, and Survival from the Postcolonial Western Ghats. *Journal of Narrative and Language Studies, 11*(21), 100-117. doi:10.59045/nalans.2023.18

Kallis, G., Kostakis, V., Lange, S., Muraca, B., Paulson, S., & Schmelzer, M. (2018). Research on degrowth. *Annual Review of Environment and Resources*, 43, 291-316. doi:10.1146/annurev-environ-102017-025941

Kallis, G., Mastini, R., & Zografos, C. (2024). Perceptions of degrowth in the European Parliament. *Nature Sustainability*, *7*(1), 64-72. doi:10.1038/s41893-023-01246-x

Kothari, A., Demaria, F., & Acosta, A. (2014). Buen Vivir, degrowth and ecological Swaraj: Alternatives to sustainable development and the green economy. *Development, 57*(3), 362-375. doi:10.1057/dev.2015.24

Oboro, D. E. (2023). Green Economy and the Fear of Degrowth: A Survey of Delta State, Nigeria. *Africa and Asia Journal of Social and Management Sciences, Humanities, Education and Legal Studies*, 4(2), 60-89.

Pielke Jr, R., & Ritchie, J. (2021). Distorting the view of our climate future: The misuse and abuse of climate pathways and scenarios. *Energy Research & Social Science, 72*, 101890. doi:10.1016/j.erss.2020.101890

Rodríguez-Labajos, B., Yánez, I., Bond, P., Greyl, L., Munguti, S., Ojo, G. U., & Overbeek, W. (2019). Not so natural an alliance? Degrowth and environmental justice movements in the global south. *Ecological Economics, 157*, 175-184. doi:10.1016/j.ecolecon.2018.11.007

Salman, A., Choudhary, S. A., & Ali, B. (2023). Redefining Prosperity: Degrowth Economics in the Pakistani Context. *Pakistan Journal of Social Sciences, 43*(4), 555-568. doi:10.5281/zenodo.10421354

Sandberg, M. (2021). Sufficiency transitions: A review of consumption changes for environmental sustainability. *Journal of Cleaner Production, 293*, 126097. doi:10.1016/j.jclepro.2021.126097

Schmelzer, M. (2016). *The hegemony of growth: the OECD and the making of the economic growth paradigm*. Cambridge: Cambridge University Press.

Vezzoni, R. (2023). Green growth for whom, how and why? The REPowerEU Plan and the inconsistencies of European Union energy policy. *Energy Research & Social Science, 101*, 103134. doi:10.1016/j.erss.2023.103134

Vogel, J., & Hickel, J. (2023). Is green growth happening? An empirical analysis of achieved versus Paris-compliant CO_2–GDP decoupling in high-income countries. *The Lancet Planetary Health, 7*(9), 759-769. doi:10.1016/S2542-5196(23)00174-2

Wiedmann, T., Lenzen, M., Keyßer, L. T., & Steinberger, J. K. (2020). Scientists' warning on affluence. *Nature communications, 11*(1), 3107. doi:10.1038/s41467-020-16941-y

Wilson, L. (2023). "Private sufficiency, public luxury": an exploration of consumer clothing circularity. In M. Carrigan, V. Wells & K. Papadas (Eds.) *Research Handbook on Ethical Consumption: Contemporary Research in Responsible and Sustainable Consumer Behaviour* (pp. 312-326). Cheltenham: Edward Elgar Publishing.

Box 2 – The Costs of Military Spending, Wars and the Plausibility of Climate Futures

Barry, B., Fetzek, S., & Emmett, C. (2022). Green Defence: the defence and military implications of climate change for Europe. International Institute for Strategic Studies, Last accessed April 22, 2024, available at https://www.iiss.org/en/research-paper/2022/02/green-defence/

Bundesministeriums der Verteidigung. (2022). Nachhaltigkeitsbericht 2022 des Bundesministeriums der Verteidigung und der Bundeswehr, Berlin. Last accessed April 22, 2024, available at https://www.bmvg.de/resource/blob/5561086/9aac6bb5bc d64e90a0552a3705878987/download-nach haltigkeitsbericht-2022-data.pdf

Crawford, N. C. (2019). Pentagon fuel use, climate change, and the costs of war. Watson Institute, Brown University. Last accessed April 22, 2024, available at https://watson.brown.edu/cost sofwar/files/cow/imce/papers/Pentagon%20 Fuel%20Use%2C%20Climate%20Change%20 and%20the%20Costs%20of%20War%20Re vised%20November%202019%20Crawford.pdf

Crawford, N. C. (2022). *The pentagon, climate change, and war: Charting the rise and fall of US military emissions*. Cambridge, MA: The MIT Press.

Davies, S., Pettersson, T., & Öberg, M. (2023). Organized violence 1989–2022, and the return of conflict between states. *Journal of peace research, 60*(4), 691-708. doi:10.1177/0022343323118516

de Groot, O. J., Bozzoli, C., Alamir, A., & Brück, T. (2022). The global economic burden of violent conflict. *Journal of peace research, 59*(2), 259-276. doi:10.1177/00223433211046823

de Klerk, L., Shlapak, M., Shmurak, A., Mykhalenko, O., Gassan-Zade, O., Kortkuis, A., & Zasiadko, Y. (2023). Climate Damage Caused by Russia's War in Ukraine. Kyiv: Initiative on GHG accounting of war. https://climatefocus.com/wp-content/uploads/2022/11/clim-damage-by-russia-war-12months.pdf.

Depledge, D. (2023). Low-carbon warfare: climate change, net zero and military operations. *International Affairs, 99*(2), 667-685. doi:10.1093/ia/iiad001

Jia, M., Li, F., Zhang, Y., Wu, M., Li, Y., Feng, S., Wang, H., Chen, H., Ju, W., & Lin, J. (2022). The Nord Stream pipeline gas leaks released approximately 220,000 tonnes of methane into the atmosphere. *Environmental Science and Ecotechnology, 12*, 100210. doi:10.1016/j.ese.2022.100210

Lindén, O., Jernelöv, A., & Egerup, J. (2004). The environmental impacts of the Gulf War 1991. International Institute for Applied Systems Analysis, Laxenburg, Austria. Last accessed April 22, 2024, available at https://pure.iiasa.ac.at/id/eprint/7427/1/IR-04-019.pdf

Lopes Da Silva, D. (2023). Military expenditure and arms production. In Stockholm International Peace Research Institute (Ed.), *SIPRI Yearbook 2023*. Oxford: Oxford University Press.

Parkinson, S., & Cottrell, L. (2022). Estimating the Military's Global Greenhouse Gas Emissions. Scientists for Global Responsibility and Environment Observatory, Lancaster: Last accessed April 22, 2024, available at https://ceobs.org/wp-con tent/uploads/2022/11/SGRCEOBS-Estimating_ Global_MIlitary_GHG_Emissions_Nov22_rev.pdf

Rajaeifar, M. A., Belcher, O., Parkinson, S., Neimark, B., Weir, D., Ashworth, K., Larbi, R., & Heidrich, O. (2022). Decarbonize the military—mandate emissions reporting. *Nature, 611*(7934), 29-32. doi:10.1038/d41586-022-03444-7

Sachs, J. D., Lafortune, G., Fuller, G., & Drumm, E. (2023). Sustainable Development Report 2023: Implementing the SDG Stimulus. United States of America. Last accessed April 22, 2024, available at https://policycommons.net/arti facts/4445283/2023-sustainable-develop ment-report/5242513/

Scheffran, J. (2023). Limits to the Anthropocene: geopolitical conflict or cooperative governance? *Frontiers in Political Science, 5*, 1190610. doi:10.3389/fpos.2023.1190610

U. S. Department of Defense. (2023). Department of Defense Plan to Reduce Greenhouse Gas Emissions, Office of the Under Secretary of Defense for Acquisition and Sustainment. United States Department of Defense, Washington, USA. Last accessed April 22, 2024, available at https://media.defense.gov/2023/Jun/16/2003243454/-1/-1/1/2023-DOD-PLAN-TO-REDUCE-GREENHOUSE-GAS-EMISSIONS.PDF

UN Secretary General. (2023). A New Agenda for Peace. Last accessed April 22, 2024, available at https://www.un.org/sites/un2.un.org/files/our-common-agenda-policy-brief-new-agenda-for-peace-en.pdf

Vogler, A. (2023). Tracking Climate Securitization: Framings of Climate Security by Civil and

Defense Ministries. *International Studies Review, 25*(2). doi:10.1093/isr/viad010

World Bank. (2024). Impacts of the Conflict in the Middle East on the Palestinian Economy, February 2024. Washington. Last accessed April 22, 2024, available at https://thedocs.worldbank.org/en/doc/db985000fa4b7237616dbca501d674dc-0280012024/original/PalestinianEconomicNote-Feb2024-Final.pdf

World Bank, Government of Ukraine, European Union, & United Nations. (2023). Ukraine Rapid Damage and Needs Assessment, February 2022 – February 2023. World Bank, Washington, D.C. Last accessed April 22, 2024, available at https://documents1.worldbank.org/curated/en/099184503212328877/pdf/P1801740d1177f03c0ab180057556615497.pdf

Chapter 4 – Regional climate variability and extremes: challenges for adaptation

Amaya, D. J., Jacox, M. G., Fewings, M. R., Saba, V. S., Stuecker, M. F., Rykaczewski, R. R., Ross, A. C., Stock, C. A., Capotondi, A., Petrik, C. M., & Others. (2023). Marine heatwaves need clear definitions so coastal communities can adapt. *Nature, 616*(7955), 29-32. doi:10.1038/d41586-023-00924-2

Arias-Ortiz, A., Serrano, O., Masqué, P., Lavery, P. S., Mueller, U., Kendrick, G. A., Rozaimi, M., Esteban, A., Fourqurean, J. W., Marbà, N., & Others. (2018). A marine heatwave drives massive losses from the world's largest seagrass carbon stocks. *Nature Climate Change*, 8(4), 338-344. doi:10.1038/s41558-018-0096-y

Barkhordarian, A., Nielsen, D. M., & Baehr, J. (2022). Recent marine heatwaves in the North Pacific warming pool can be attributed to rising atmospheric levels of greenhouse gases. *Communications Earth & Environment, 3*(1), 131. doi:10.1038/s43247-022-00461-2

Barkhordarian, A., Nielsen, D. M., Olonscheck, D., & Baehr, J. (2024). Arctic marine heatwaves forced by greenhouse gases and triggered by abrupt sea-ice melt. *Communications Earth & Environment, 5*(1). doi:10.1038/s43247-024-01215-y

Bastos, A., Sippel, S., Frank, D., Mahecha, M. D., Zaehle, S., Zscheischler, J., & Reichstein, M. (2023). A joint framework for studying compound ecoclimatic events. *Nature Reviews Earth & Environment, 4*, 1-18. doi:10.1038/s43017-023-00410-3

Becker, J. N., Grozinger, J., Sarkar, A., Reinhold-Hurek, B., & Eschenbach, A. (2023). Effects of cowpea (*Vigna unguiculata*) inoculation on nodule development and rhizosphere carbon and nitrogen content under simulated drought. *Plant and Soil*. doi:10.1007/s11104-023-06051-1

Bevacqua, E., Suarez-Gutierrez, L., Jézéquel, A., Lehner, F., Vrac, M., Yiou, P., & Zscheischler, J. (2023). Advancing research on compound weather and climate events via large ensemble model simulations. *Nature Communications, 14*(1), 2145. doi:10.1038/s41467-023-37847-5

Bhandari, K., Sharma, K. D., Hanumantha Rao, B., Siddique, K. H. M., Gaur, P., Agrawal, S. K., Nair, R. M., & Nayyar, H. (2017). Temperature sensitivity of food legumes: a physiological insight. *Acta Physiologiae Plantarum, 39*. doi:10.1007/s11738-017-2361-5

Brown, P. T., Ming, Y., Li, W., & Hill, S. A. (2017). Change in the magnitude and mechanisms of global temperature variability with warming. *Nature Climate Change*, 7(10), 743-748. doi:10.1038/nclimate3381

Burger, F. A., Terhaar, J., & Frölicher, T. L. (2022). Compound marine heatwaves and ocean acidity extremes. *Nature communications, 13*(1), 4722. doi:10.1038/s41467-022-32120-7

Christidis, N., Jones, G. S., & Stott, P. A. (2015). Dramatically increasing chance of extremely hot summers since the 2003 European heatwave. *Nature Climate Change*, 5, 46-50. doi:10.1038/nclimate2468

Coll, M., Piroddi, C., Steenbeek, J., Kaschner, K., Ben Rais Lasram, F., Aguzzi, J., Ballesteros, E., Bianchi, C. N., Corbera, J., Dailianis, T., & Others. (2010). The biodiversity of the Mediterranean Sea: estimates, patterns, and threats. *PLoS ONE, 5*(8), e11842. doi:10.1371/journal.pone.0011842

Collins, M., Sutherland, M., Bouwer, L., Cheong, S.-M., Frölicher, T., Jacot Des Combes, H., Koll Roxy, M., Losada, I., McInnes, K., Ratter, B., Rivera-Arriaga, E., Susanto, R. D., Swingedouw, D., & Tibig, L. (2019). Extremes, Abrupt Changes and Managing Risks. In H.-O. Pörtner, D. C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, & N. M. Weyer (Eds.), *The Ocean and Cryosphere in a Changing Climate* (pp. 589-656). Cambridge, UK and New York, NY, USA: Cambridge University Press.

Cornes, R. C., van der Schrier, G., van den Besselaar, E. J. M., & Jones, P. D. (2018). An ensemble version of the E-OBS temperature and precipitation data sets. *Journal of Geophysical Research: Atmospheres, 123*(17), 9391-9409. doi:10.1029/2017JD028200

Davolio, S., Vercellino, M., Miglietta, M. M., Drago Pitura, L., Laviola, S., & Levizzani, V. (2023). The influence of an atmospheric river on a heavy precipitation event over the western Alps. *Weather and Climate Extremes, 39*, 100542. doi:10.1016/j.wace.2022.100542 de Blécourt , M., Gröngröft , A., Baumann, S., & Eschenbach, A. (2019). Losses in soil organic carbon stocks and soil fertility due to deforestation for low-input agriculture in semi-arid southern Africa. *Journal of Arid Environments, 165*, 88-96. doi:10.1016/j.jaridenv.2019.02.006

de Lima, C. Z., Buzan, J. R., Moore, F. C., Baldos, U. L. C., Huber, M., & Hertel, T. W. (2021). Heat stress on agricultural workers exacerbates crop impacts of climate change. *Environmental Research Letters*, 16(4), 044020. doi:10.1088/1748-9326/abeb9f

Deser, C., Lehner, F., Rodgers, K. B., Ault, T., Delworth, T. L., DiNezio, P. N., Fiore, A., Frankignoul, C., Fyfe, J. C., Horton, D. E., Kay, J. E., Knutti, R., Lovenduski, N. S., Marotzke, J., McKinnon, K. A., Minobe, S., Randerson, J., Screen, J. A., Simpson, I. R., & Ting, M. (2020). Insights from Earth system model initial-condition large ensembles and future prospects. *Nature Climate Change*, 10(4), 277-286. doi:10.1038/s41558-020-0731-2

Dodman, D., Hayward, B., Pelling, M., Castan Broto, V., Chow, W., Chu, E., Dawson, R., Khirfan, L., McPhearson, T., Prakash, A., Zheng, Y., & Ziervogel, G. (2022). Cities, Settlements and Key Infrastructure. In D. C. R. H.-O. Pörtner, E. S. P. M. Tignor, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf,, & V. M. S. Löschke, A. Okem, B. Rama (Eds.), *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 907–1040). Cambridge, UK and New York, NY, USA: Cambridge University Press.

Doorenbos, J., & Kassam, A. H. (1979). Yield Response to Water. In FAO (Ed.), *Irrigation and Drainage Paper No. 33*.

Engels, A., Marotzke, J., Gresse, E. G., López-Rivera, A., Pagnone, A., & Wilkens, J. (Eds.). (2023). *Hamburg Climate Futures Outlook: The plausibility of a 1.5°C limit to global warming — social drivers and physical processes*. Hamburg, Germany: Cluster of Excellence Climate, Climatic Change, and Society (CLICCS). doi: doi:10.25592/uhhfdm.9104

Field, C. B., Barros, V., Stocker, T. F., & Dahe, Q. (Eds.). (2012). *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: Special Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press.

Fisher, M. C., Moore, S. K., Jardine, S. L., Watson, J. R., & Samhouri, J. F. (2021). Climate shock effects and mediation in fisheries. *Proceedings of the National Academy of Sciences, 118*(2), e2014379117. doi:10.1073/pnas.2014379117

Fox-Kemper, B., Hewitt, H. T., Xiao, C., Aðalgeirsdóttir, G., Drijfhout, S. S., Edwards, T. L., Golledge, N. R., Hemer, M., Kopp, R. E., Krinner, G., Mix, A., Notz, D., Nowicki, S., Nurhati, I. S., Ruiz, L., Sallée, J.-B., Slangen, A. B. A., & Yu, Y. (2021). Ocean, Cryosphere and Sea Level Change. In V. Masson-Delmotte, P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, & B. Zhou (Eds.), *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 1211–1362). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Franke, J. A., Müller, C., Elliott, J., Ruane, A. C., Jägermeyr, J., Balkovic, J., Ciais, P., Dury, M., Falloon, P. D., Folberth, C., François, L., Hank, T., Hoffmann, M., Izaurralde, R. C., Jacquemin, I., Jones, C., Khabarov, N., Koch, M., Li, M., Liu, W., Olin, S., Phillips, M., Pugh, T. A. M., Reddy, A., Wang, X., Williams, K., Zabel, F., & Moyer, E. J. (2020). The GGCMI Phase 2 experiment: global gridded crop model simulations under uniform changes in CO_2 , temperature, water, and nitrogen levels (protocol version 1.0). *Geoscientific Model Development, 13*, 2315–2336. doi:10.5194/gmd-13-2315-2020

Garrabou, J., Gómez-Gras, D., Ledoux, J.-B., Linares, C., Bensoussan, N., López-Sendino, P., Bazairi, H., Espinosa, F., Ramdani, M., Grimes, S., Benabdi, M., Souissi, J. B., Soufi, E., Khamassi, F., Ghanem, R., Ocaña, O., Ramos-Esplà, A., Izquierdo, A., Anton, I., Rubio-Portillo, E., Barbera, C., Cebrian, E., Marbà, N., Hendriks, I. E., Duarte, C. M., Deudero, S., Díaz, D., Vázquez-Luis, M., Alvarez, E., Hereu, B., Kersting, D. K., Gori, A., Viladrich, N., Sartoretto, S., Pairaud, I., Ruitton, S., Pergent, G., Pergent-Martini, C., Rouanet, E., Teixidó, N., Gattuso, J.-P., Fraschetti, S., Rivetti, I., Azzurro, E., Cerrano, C., Ponti, M., Turicchia, E., Bavestrello, G., Cattaneo-Vietti, R., Bo, M., Bertolino, M., Montefalcone, M., Chimienti, G., Grech, D., Rilov, G., Tuney Kizilkaya, I., Kizilkaya, Z., Eda Topçu, N., Gerovasileiou, V., Sini, M., Bakran-Petricioli, T., Kipson, S., & Harmelin, J. G. (2019). Collaborative database to track mass mortality events in the Mediterranean Sea. *Frontiers in Marine Science, 6*(707), 478167. doi:10.3389/fmars.2019.00707

Garrabou, J., Gomez-Gras, D., Medrano, A., Cerrano, C., Ponti, M., Schlegel, R., Bensoussan, N., Turicchia, E., Sini, M., Gerovasileiou, V., Teixido, N., Mirasole, A., Tamburello, L., Cebrian, E., Rilov, G., Ledoux, J. B., Souissi, J. B., Khamassi, F., Ghanem, R., Benabdi, M., Grimes, S., Ocana, O., Bazairi, H., Hereu, B., Linares, C., Kersting, D. K., la Rovira, G., Ortega, J., Casals, D., Pages-Escola, M., Margarit, N., Capdevila, P., Verdura, J., Ramos, A., Izquierdo, A., Barbera, C., Rubio-Portillo, E., Anton, I., Lopez-Sendino, P., Diaz, D., Vazquez-Luis, M., Duarte, C., Marba, N., Aspillaga, E., Espinosa, F., Grech, D., Guala, I., Azzurro, E., Farina, S., Cristina Gambi, M., Chimienti, G., Montefalcone, M., Azzola, A., Mantas, T. P., Fraschetti, S., Ceccherelli, G., Kipson, S., Bakran-Petricioli, T., Petricioli, D., Jimenez, C., Katsanevakis, S., Kizilkaya, I. T., Kizilkaya, Z., Sartoretto, S., Elodie, R., Ruitton, S., Comeau, S., Gattuso, J. P., & Harmelin, J. G. (2022). Marine heatwaves drive recurrent mass mortalities in the Mediterranean Sea. *Global Change Biology, 28*(19), 5708-5725. doi:10.1111/gcb.16301

Gaupp, F., Hall, J., Hochrainer-Stigler, S., & Dadson, S. (2020). Changing risks of simultaneous global breadbasket failure. *Nature Climate Change, 10*, 54-57. doi:10.1038/s41558-019-0600-z

Grazzini, F., Fragkoulidis, G., Teubler, F., Wirth, V., & Craig, G. C. (2021). Extreme precipitation events over northern Italy. Part II: Dynamical precursors. *Quarterly Journal of the Royal Meteorological Society, 147*(735), 1237-1257. doi:10.1002/qj.3969

Gutjahr, O., Putrasahan, D., Lohmann, K., Jungclaus, J. H., von Storch, J.-S., Brüggemann, N., Haak, H., & Stössel, A. (2019). Max Planck Institute Earth System Model (MPI-ESM1.2) for the High-Resolution Model Intercomparison Project (HighResMIP). *Geoscientific Model Development, 12*(7), 3241-3281. doi:10.5194/gmd-12-3241-2019

Han, W., Zhang, L., Meehl, G. A., Kido, S., Tozuka, T., Li, Y., McPhaden, M. J., Hu, A., Cazenave, A., Rosenbloom, N., & Others. (2022). Sea level extremes and compounding marine heatwaves in coastal Indonesia. *Nature Communications, 13*(1), 6410. doi:10.1038/s41467-022-34003-3

Hawkins, E., Smith, R. S., Gregory, J. M., & Stainforth, D. A. (2016). Irreducible uncertainty in near-term climate projections. *Climate Dynamics, 46*(11), 3807-3819. doi:10.1007/s00382-015-2806-8

Hawkins, E., & Sutton, R. (2009). The Potential to Narrow Uncertainty in Regional Climate Predictions. *Bulletin of the American Meteorological Society, 90*(8), 1095-1108. doi:10.1175/2009BAMS2607.1

Hawkins, E., & Sutton, R. (2011). The potential to narrow uncertainty in projections of regional precipitation change. *Climate Dynamics, 37*(1), 407-418. doi:10.1007/s00382-010-0810-6

Hedemann, C., Mauritsen, T., Jungclaus, J., & Marotzke, J. (2017). The subtle origins of surface-warming hiatuses. *Nature Climate Change*, 7(5), 336-339. doi:10.1038/nclimate3274

Heino, M., Puma, M. J., Ward, P. J., Gerten, D., Heck, V., Siebert, S., & Kummu, M. (2018). Two-thirds of global cropland area impacted by climate oscillations. *Nature Communications, 9*, 1257. doi:10.1038/s41467-017-02071-5

Hobday, A. J., Alexander, L. V., Perkins, S. E., Smale, D. A., Straub, S. C., Oliver, E. C. J., Benthuysen, J. A., Burrows, M. T., Donat, M. G., Feng, M., Holbrook, N. J., Moore, P. J., Scannell, H. A., Sen Gupta, A., & Wernberg, T. (2016). A hierarchical approach to defining marine heatwaves. *Progress in Oceanography, 141*, 227-238. doi:10.1016/j.pocean.2015.12.014

Holbrook, N. J., Sen Gupta, A., Oliver, E. C. J., Hobday, A. J., Benthuysen, J. A., Scannell, H. A., Smale, D. A., & Wernberg, T. (2020). Keeping pace with marine heatwaves. *Nature Reviews Earth & Environment, 1*(9), 482-493. doi:10.1038/s43017-020-0068-4

Ibebuchi, C. C. (2022). Patterns of atmospheric circulation in Western Europe linked to heavy rainfall in Germany: preliminary analysis into the 2021 heavy rainfall episode. *Theoretical and Applied Climatology, 148*(1-2), 269-283. doi:10.1007/s00704-022-03945-5

Iles, C. E., Vautard, R., Strachan, J., Joussaume, S., Eggen, B. R., & Hewitt, C. D. (2020). The benefits of increasing resolution in global and regional climate simulations for European climate extremes. *Geoscientific Model Development, 13*(11), 5583-5607. doi:10.5194/gmd-13-5583-2020

INMET, 2024: Brazilian National Meteorological Institute (Instituto Nacional de Meteorologia), https://portal.inmet.gov.br/

IPCC. (2012). *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change* [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley]. Cambridge and New York: Cambridge University Press.

IPCC SR1.5. (2018). *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D.

Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. Cambridge and New York: Cambridge University Press.

Jägermeyr, J. M., C., Ruane, A. C., Elliott, J., Balkovic, J., Castillo, O., Faye, B., Foster, I., Folberth, C., Franke, J. A., Fuchs, K., Guarin, J. R., Heinke, J., G., H., Iizumi, T., Jain, A. K., Kelly, D., Khabarov, N., Lange, S., Lin, T.-S., Lin, W., Mialyk, O., Minoli, S. M., E.J. Okada, M. Phillips, M. Porter, C. Rabin, S.S: Scheer, C. Schneider, J.M. Schyns, J.F. Skalsky, R. Smerald, A. Stella, T. Stephens, H. Webber, H. Zabel, F:, & Rosenzweig, C. (2021). Climate impacts on global agriculture emerge earlier in new generation of climate and crop models. *Nature Food, 2*, 873–885. doi:10.1038/s43016-021-00400-y

Jain, S., Scaife, A. A., Shepherd, T. G., Deser, C., Dunstone, N., Schmidt, G. A., Trenberth, K. E., & Turkington, T. (2023). Importance of internal variability for climate model assessment. npj *Climate and Atmospheric Science, 6*(1), 1-7. doi:10.1038/s41612-023-00389-0

Kahraman, A., Kendon, E. J., Chan, S. C., & Fowler, H. J. (2021). Quasi-Stationary Intense Rainstorms Spread Across Europe Under Climate Change. *Geophysical Research Letters, 48*(13). doi:10.1029/2020GL092361

Kay, J. E., Deser, C., Phillips, A., Mai, A., Hannay, C., Strand, G., Arblaster, J. M., Bates, S. C., Danabasoglu, G., & Edwards, J. (2015). The Community Earth System Model (CESM) large ensemble project: A community resource for studying climate change in the presence of internal climate variability. *Bulletin of the American Meteorological Society, 96*(8), 1333-1349. doi:10.1175/BAMS-D-13-00255.1

Kendon, E. J., Prein, A. F., Senior, C. A., & Stirling, A. (2021). Challenges and outlook for convection-permitting climate modelling. Philosophical Transactions of the Royal Society A: Mathematical, *Physical and Engineering Sciences, 379*(2195), 20190547. doi:10.1098/rsta.2019.0547

Kharin, V. V., Flato, G. M., Zhang, X., Gillett, N. P., Zwiers, F., & Anderson, K. J. (2018). Risks from Climate Extremes Change Differently from 1.5°C to 2.0°C Depending on Rarity. *Earth's Future, 6*(5), 704-715. doi:10.1002/2018ef000813

Klein Tank, A. M. G., Wijngaard, J. B., Können, G. P., Böhm, R., Demarée, G., Gocheva, A., Mileta, M., Pashiardis, S., Hejkrlik, L., Kern-Hansen, C., Heino, R., Bessemoulin, P., Müller-Westermeier, G., Tzanakou, M., Szalai, S., Pálsdóttir, T., Fitzgerald, D., Rubin, S., Capaldo, M., Maugeri, M., Leitass, A., Bukantis, A., Aberfeld, R., van Engelen, A. F. V., Forland, E., Mietus, M., Coelho, F., Mares, C., Razuvaev, V., Nieplova, E., Cegnar, T., Antonio López, J., Dahlström, B., Moberg, A., Kirchhofer, W., Ceylan, A., Pachaliuk, O., Alexander, L. V., & Petrovic, P. (2002). Daily dataset of 20th-century surface air temperature and precipitation series for the European Climate Assessment: *International Journal of Climatology, 22*(12), 1441-1453. doi:10.1002/joc.773

Kornhuber , K., Coumou , D., Vogel, E., Lesk, C., Donges, J. F., Lehmann, J., & Horton, R. M. (2020). Amplified Rossby waves enhance risk of concurrent heatwaves in major breadbasket regions. *Nature Climate Change, 10*, 48–53. doi:10.1038/s41558-019-0637-z

Kornhuber, K., Lesk, C., Schleussner, C. F., Jägermeyr, J., Pfleiderer, P., & Horton, R. M. (2023). Risks of synchronized low yields are underestimated in climate and crop model projections. Nature Communications, 14(1), 3528. doi:10.1038/s41467-023-38906-7

Kreienkamp, F., Philip, S. Y., Tradowsky, J. S., Kew, S. F., Lorenz, P., Arrighi, J., Belleflamme, A., Bettmann, T., Caluwaerts, S., Chan, S. C., Ciavarella, A., De Cruz, L., De Vries, H., Demuth, Ferrone, A., Fischer, E. M., Fowler, H. J., Goergen, K., Heinrich, D., Henrichs, Y., Lenderink, G., Kaspar, F., Nilson, E., Otto, F. E. L., Ragone, F., Seneviratne, S. I., Singh, R. K., Skålevåg, A., Termonia, P., Thalheimer, L., Van Aalst, M., Van den Bergh, J., Van de Vyver, H., Vannitsem, S., Van Oldenborgh, G. J., Van Schaeybroeck, B., Vautard, R., Vonk, D., & Wanders, N. (2021). Rapid attribution of heavy rainfall events leading to the severe flooding in Western Europe during July 2021. World Weather Attribution, London. Last accessed April 22, 2024, available at https://www.worldweatherattribution.org/wp-content/uploads/Scientific-report-West ern-Europe-floods-2021-attribution.pdf

Lee, J.-Y., Marotzke, J., Bala, G., Cao, L., Corti, S., Dunne, J. P., Engelbrecht, F., Fischer, E., Fyfe, J. C., Jones, C., Maycock, A., Mutemi, J., Ndiaye, O., Panickal, S., & Zhou, T. (2021). Future Global Climate: Scenario-based Projections and Near-term Information. In V. Masson-Delmotte, P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, & B. Zhou (Eds.), *Climate Change 2021 – The Physical Science Basis* (pp. 553-672). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Lehner, F., Hawkins, E., Sutton, R., Pendergrass, A. G., & Moore, F. C. (2023). New Potential to Reduce Uncertainty in Regional Climate Projections by Combining

Physical and Socio-Economic Constraints. *AGU Advances*, 4(4), e2023AV000887. doi:10.1029/2023AV000887

Lehner, F., Deser, C., Maher, N., Marotzke, J., Fischer, E. M., Brunner, L., Knutti, R., & Hawkins, E. (2020). Partitioning climate projection uncertainty with multiple large ensembles and CMIP5/6. *Earth System Dynamics, 11*(2), 491-508. doi:10.5194/esd-11-491-2020

Li, Z., Holbrook, N. J., Zhang, X., Oliver, E. C. J., & Cougnon, E. A. (2020). Remote forcing of Tasman Sea marine heatwaves. *Journal of Climate, 33*(12), 5337-5354. doi:10.1175/JCLI-D-19-0641.1

Lobell, D. B., Schlenker, W., & Costa-Roberts, J. (2011). Climate trends and global crop production since 1980. *Science, 333*, 616–620. doi:10.1126/science.1204531

Lorenz, E. N. (1963). Deterministic Nonperiodic Flow. *Journal of the Atmospheric Sciences, 20*(2), 130-141. doi:10.1175/1520-0469(1963)020<0130:DN-F>2.0.CO;2

Luo, Q. (2011). Temperature thresholds and crop production: a review. *Climatic Change, 109*, 583–598. doi:10.1007/s10584-011-0028-6

Maher, N., Matei, D., Milinski, S., & Marotzke, J. (2018). ENSO Change in Climate Projections: Forced Response or Internal Variability? *Geophysical Research Letters, 45*(20), 11,390-311,398. doi:10.1029/2018GL079764

Maher, N., Milinski, S., & Ludwig, R. (2021). Large ensemble climate model simulations: introduction, overview, and future prospects for utilising multiple types of large ensemble. *Earth System Dynamics, 12*(2), 401-418. doi:10.5194/esd-12-401-2021

Maher, N., Milinski, S., Suarez-Gutierrez, L., Botzet, M., Dobrynin, M., Kornblueh, L., Kröger, J., Takano, Y., Ghosh, R., Hedemann, C., Li, C., Li, H., Manzini, E., Notz, D., Putrasahan, D., Boysen, L., Claussen, M., Ilyina, T., Olonscheck, D., Raddatz, T., Stevens, B., & Marotzke, J. (2019). The Max Planck Institute Grand Ensemble: Enabling the Exploration of Climate System Variability. *Journal of Advances in Modeling Earth Systems, 11*(7), 2050-2069. doi:10.1029/2019MS001639

Marengo, J. A., Alves, L. M., Ambrizzi, T., Young, A., Barreto, N. J. C., & Ramos, A. M. (2020a). Trends in extreme rainfall and hydrogeometeorological disasters in the Metropolitan Area of São Paulo: a review. *Annals of the New York Academy of Sciences, 1472*(1), 5-20. doi:10.1111/nyas.14307

Marengo, J. A., Ambrizzi, T., Alves, L. M., Barreto, N. J. C., Simões Reboita, M., & Ramos, A. M. (2020b). Changing trends in rainfall extremes in the metropolitan area of São Paulo: causes and impacts. *Frontiers in Climate, 2*(3). doi:10.3389/fclim.2020.00003

Marotzke, J. (2019). Quantifying the irreducible uncertainty in near-term climate projections. *WIREs Climate Change, 10*(1), e563. doi:10.1002/wcc.563

Marotzke, J., Hedemann, C., Milinski, S., & Suarez-Gutierrez, L. (2021). Regional temperature trends and their uncertainty. In D. Stammer, A. Engels, J. Marotzke, E. Gresse, C. Hedemann, & J. Petzold (Eds.), *Hamburg Climate Futures Outlook: Assessing the plausibility of deep decarbonization by 2050* (pp. 59). Hamburg, Germany: Cluster of Excellence Climate, Climatic Change, and Society (CLICCS). doi:10.25592/uhhfdm.9104

Marsh, L. E., Baptiste, R., Marsh, D. B., Trinklein, D., & Kremer, R. J. (2006). Temperature Effects on Bradyrhizobium spp. Growth and Symbiotic Effectiveness with Pigeonpea and Cowpea. *Journal of Plant Nutrition, 29*(2), 331-346. doi:10.1080/01904160500476921

Mauritsen, T., Bader, J., Becker, T., Behrens, J., Bittner, M., Brokopf, R., Brovkin, V., Claussen, M., Crueger, T., Esch, M., Fast, I., Fiedler, S., Fläschner, D., Gayler, V., Giorgetta, M., Goll, D. S., Haak, H., Hagemann, S., Hedemann, C., Hohenegger, C., Ilyina, T., Jahns, T., Jimenéz-de-la-Cuesta, D., Jungclaus, J., Kleinen, T., Kloster, S., Kracher, D., Kinne, S., Kleberg, D., Lasslop, G., Kornblueh, L., Marotzke, J., Matei, D., Meraner, K., Mikolajewicz, U., Modali, K., Möbis, B., Müller, W. A., Nabel, J. E. M. S., Nam, C. C. W., Notz, D., Nyawira, S.-S., Paulsen, H., Peters, K., Pincus, R., Pohlmann, H., Pongratz, J., Popp, M., Raddatz, T. J., Rast, S., Redler, R., Reick, C. H., Rohrschneider, T., Schemann, V., Schmidt, H., Schnur, R., Schulzweida, U., Six, K. D., Stein, L., Stemmler, I., Stevens, B., von Storch, J.-S., Tian, F., Voigt, A., Vrese, P., Wieners, K.-H., Wilkenskjeld, S., Winkler, A., & Roeckner, E. (2019). Developments in the MPI-M Earth System Model version 1.2 (MPI-ESM1.2) and Its Response to Increasing CO_2. *Journal of Advances in Modeling Earth Systems, 11*(4), 998-1038. doi:10.1029/2018MS001400

Meehl, G. A., Teng, H., Rosenbloom, N., Hu, A., Tebaldi, C., & Walton, G. (2022). How the Great Plains Dust Bowl drought spread heat extremes around the Northern Hemisphere. *Scientific Reports, 12*(1), 17380. doi:10.1038/s41598-022-22262-5

Mehrabi, Z. (2020). Food system collapse. *Nature Climate Change*, 10(1), 16-17. doi:10.1038/s41558-019-0643-1

Milinski, S., Maher, N., & Olonscheck, D. (2020). How large does a large ensemble need to be? *Earth System Dynamics, 11*(4), 885-901. doi:10.5194/esd-11-885-2020

Molina Bacca, E. J., Stevanović, M., Bodirsky, B. L., Karstens, K., Chen, D. M.-C., Leip, D., Müller, C., Minoli, S., Heinke, J., & Jägermeyr, J. (2023). Uncertainty in land-use adaptation persists despite crop model projections showing lower impacts under high warming. *Communications Earth & Environment, 4*(1), 284. doi:10.1038/s43247-023-00941-z

Müller, W. A., Jungclaus, J. H., Mauritsen, T., Baehr, J., Bittner, M., Budich, R., Bunzel, F., Esch, M., Ghosh, R., Haak, H., Ilyina, T., Kleine, T., Kornblueh, L., Li, H., Modali, K., Notz, D., Pohlmann, H., Roeckner, E., Stemmler, I., Tian, F., & Marotzke, J. (2018). A Higher-resolution Version of the Max Planck Institute Earth System Model (MPI-ESM1.2-HR). *Journal of Advances in Modeling Earth Systems, 10*(7), 1383-1413. doi:10.1029/2017MS001217

Myhre, G., Alterskjær, K., Stjern, C. W., Hodnebrog, Ø., Marelle, L., Samset, B. H., Sillmann, J., Schaller, N., Fischer, E., Schulz, M., & Stohl, A. (2019). Frequency of extreme precipitation increases extensively with event rareness under global warming. *Scientific Reports, 9*(1), 16063. doi:10.1038/s41598-019-52277-4

Olonscheck, D., Rugenstein, M., & Marotzke, J. (2020). Broad Consistency Between Observed and Simulated Trends in Sea Surface Temperature Patterns. *Geophysical Research Letters, 47*(10), e2019GL086773. doi:10.1029/2019GL086773

Olonscheck, D., Schurer, A. P., Lücke, L., & Hegerl, G. C. (2021). Large-scale emergence of regional changes in year-to-year temperature variability by the end of the 21st century. *Nature Communications, 12*(1), 7237. doi:10.1038/s41467-021-27515-x

Olonscheck, D., Suarez-Gutierrez, L., Milinski, S., Beobide-Arsuaga, G., Baehr, J., Fröb, F., Hellmich, L., Ilyina, T., Kadow, C., Krieger, D., Li, H., Marotzke, J., Plésiat, É., Schupfner, M., Wachsmann, F., Wieners, K.-H., & Brune, S. (2023). The new Max Planck Institute Grand Ensemble with CMIP6 forcing and high-frequency model output. Available at https://essopenarchive.org/users/612703/articles/640470-the-new-max-planck-institute-grand-ensemble-with-cmip6-forcing-and-high-frequency-model-output?commit=96403bca5b56fa6a84d539be0f31ff2a3d4fe3ab

Orlov, A., Daloz, A. S., Sillmann, J., Thiery, W., Douzal, C., Lejeune, Q., & Schleussner, C. (2021). Global Economic Responses to Heat Stress Impacts on Worker Productivity in Crop Production. *Economics of Disasters and Climate Change, 5*(3), 367-390. doi:10.1007/s41885-021-00091-6

Patterson, M. (2023). North-West Europe hottest days are warming twice as fast as mean summer days. *Geophysical Research Letters, 50*, e2023GL102757. doi:10.1029/2023GL102757

Pendergrass, A. G., Knutti, R., Lehner, F., Deser, C., & Sanderson, B. M. (2017). Precipitation variability increases in a warmer climate. *Scientific Reports, 7*(1), 17966. doi:10.1038/s41598-017-17966-y

Perry, C. T., & Morgan, K. M. (2017). Bleaching drives collapse in reef carbonate budgets and reef growth potential on southern Maldives reefs. *Scientific reports, 7*(1), 40581. doi:10.1038/srep40581

Petzold, J., Hawxwell, T., Jantke, K., Gresse, E. G., Mirbach, C., Ajibade, I., Bhadwal, S., Bowen, K., Fischer, A. P., Joe, E. T., Kirchhoff, C. J., Mach, K. J., Reckien, D., Segnon, A. C., Singh, C., Ulibarri, N., Campbell, D., Cremin, E., Färber, L., Hegde, G., Jeong, J., Nunbogu, A. M., Pradhan, H. K., Schröder, L. S., Shah, M. A. R., Reese, P., Sultana, F., Tello, C., Xu, J., The Global Adaptation Mapping Initiative Team, & Garschagen, M. (2023). A global assessment of actors and their roles in climate change adaptation. *Nature Climate Change, 13*(11), 1250-1257. doi:10.1038/s41558-023-01824-z

Poschlod, B. (2022). Attributing heavy rainfall event in Berchtesgadener Land to recent climate change–Further rainfall intensification projected for the future. *Weather and Climate Extremes, 38*, 100492. doi:10.1016/j.wace.2022.100492

Provost, M. M., & Botsford, L. W. (2022). How life history determines time scale sensitivity and extinction risk of age-structured populations. *Oikos, 2022*(5), e08909. doi:10.1111/oik.08909

Puma, M. J., Bose, S., Chon, S. Y., & Cook, B. I. (2015). Assessing the evolving fragility of the global food system. *Environmental Research Letters, 10*(2), 024007. doi:10.1088/1748-9326/10/2/024007

Quinn, T., Heath, S., Adger, W. N., Abu, M., Butler, C., Codjoe, S. N. A., Horvath, C., Martinez-Juarez, P., Morrissey, K., Murphy, C., & Smith, R. (2023). Health and wellbeing implications of adaptation to flood risk. A*mbio, 52*(5), 952-962. doi:10.1007/s13280-023-01834-3

Rasche, L., Becker, J. N., Chimwamurombe, P., Eschenbach, A., Gröngröft, A., Jeong, J., Luther-Mosebach, J., Reinhold-Hurek, B., Sarkar, A., & Schneider, U. A. (2023). Exploring the benefits of inoculated cowpeas under different climatic conditions in Namibia. *Scientific Reports, 13*(1), 11761. doi:10.1038/s41598-023-38949-2

Raymond, C., Suarez-Gutierrez, L., Kornhuber, K., Pascolini-Campbell, M., Sillmann, J., & Waliser, D. E. (2022). Increasing spatiotemporal proximity of heat and precipitation extremes in a warming world quantified by a large model ensemble. *Environmental Research Letters, 17*(3), 035005. doi:10.1088/1748-9326/ac5712

Revi, A., Roberts, D., Klaus, I., Bazaz, A., Krishnaswamy, J., Singh, C., Eichel, A., Poonacha Kodira, P., Schultz, S., Adelekan, I., Babiker, M., Bertoldi, P., Cartwright, A., Chow, W., Colenbrander, S., Creutzig, F., Dawson, R., Coninck, H., Kleijne, K., Dhakal, S., Gallardo, L., Garschagen, M., Haasnoot, M., Haldar, S., Hamdi, R., Hashizume, M., Islam, A. K. M. S., Jiang, K., Kılkış, Ş., Klimont, Z., Lemos, M. F., Ley, D., Lwasa, S., McPhearson, T., Niamir, L., Otto, F., Pathak, M., Pelling, M., Pinto, I., Pörtner, H.-O., Pereira, J. P., Raghavan, K., Roy, J., Sara, L. M., Seto, K. C., Simpson, N. P., Solecki, W., Some, S., Sörensson, A. A., Steg, L., Szopa, S., Thomas, A., Trisos, C., & Ürge-Vorsatz, D. (2022). *The Summary for Urban Policymakers of the IPCC's Sixth Assessment Report*: Indian Institute for Human Settlements.

Reynolds, R. W., Smith, T. M., Liu, C., Chelton, D. B., Casey, K. S., & Schlax, M. G. (2007). Daily high-resolution-blended analyses for sea surface temperature. *Journal of Climate, 20*(22), 5473-5496. doi:10.1175/2007JCLI1824.1

Riahi, K., van Vuuren, D. P., Kriegler, E., Edmonds, J., O'Neill, B. C., Fujimori, S., Bauer, N., Calvin, K., Dellink, R., Fricko, O., Lutz, W., Popp, A., Cuaresma, J. C., Kc, S., Leimbach, M., Jiang, L., Kram, T., Rao, S., Emmerling, J., Ebi, K., Hasegawa, T., Havlik, P., Humpenöder, F., Da Silva, L. A., Smith, S., Stehfest, E., Bosetti, V., Eom, J., Gernaat, D., Masui, T., Rogelj, J., Strefler, J., Drouet, L., Krey, V., Luderer, G., Harmsen, M., Takahashi, K., Baumstark, L., Doelman, J. C., Kainuma, M., Klimont, Z., Marangoni, G., Lotze-Campen, H., Obersteiner, M., Tabeau, A., & Tavoni, M. (2017). The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. *Global Environmental Change, 42*, 153-168. doi:10.1016/j.gloenvcha.2016.05.009

Rosenzweig, C., Elliott, J., Deryng, D., Ruane, A. C., Müller, C., Arneth, A., Boote, K. J., Folberth, C., Glotter, M., Khabarov, N., Neumann, K., Piontek, F., Pugh, T. A. M., Schmid, E., Stehfest, E., Yang, H., & Jones, J. W. (2014). Assessing agricultural risks of climate change in the 21st century in a global gridded crop model intercomparison. *Proceedings of the National Academy of Sciences of the United States of America, 111*(9), 3268-3273. doi:10.1073/pnas.1222463110

SASSCAL Weathernet. (2024). Mashare (Station ID: 31195) – Monthly values. Southern African Science Service Centre for Climate Change and Adaptive Land Management (SASSCAL). SASSCAL, Windhoek, Namibia. Last accessed April 22, 2024, available at https://sasscalweathernet.org/weatherstat_monthly_we.php?loggerid_crit=31195&year_crit=2024

Seneviratne, S. I., Corti, T., Davin, E. L., Hirschi, M., Jaeger, E. B., Lehner, I., Orlowsky, B., & Teuling, A. J. (2010). Investigating soil moisture–climate interactions in a changing climate: A review. *Earth-Science Reviews, 99*(3-4), 125-161. doi:10.1016/j.earscirev.2010.02.004

Seneviratne, S. I., Zhang, X., Adnan, M., Badi, W., Dereczynski, C., Di Luca, A., Ghosh, S., Iskandar, I., Kossin, J., Lewis, S., Otto, F., Pinto, I., Satoh, M., Vicente-Serrano, S. M., Wehner, M., & Zhou, B. (2021). Weather and Climate Extreme Events in a Changing Climate. In V. Masson-Delmotte, P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, & B. Zhou (Eds.), *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 1513–1766). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Serrano, O., Arias-Ortiz, A., Duarte, C. M., Kendrick, G. A., & Lavery, P. S. (2021). Impact of marine heatwaves on seagrass ecosystems. In *Ecosystem Collapse and Climate Change* (pp. 345-364): Springer. Doi: doi.org/10.1007/978-3-030-71330-0_13

Shlesinger, T., & van Woesik, R. (2023). Oceanic differences in coral-bleaching responses to marine heatwaves. *Science of The Total Environment, 871*, 162113. doi:10.1016/j.scitotenv.2023.162113

Siebert, S., Webber, H., Zhao, G., & Ewert, F. (2017). Heat stress is overestimated in climate impact studies for irrigated agriculture. *Environmental Research Letters, 12*(5), 054023. doi:10.1088/1748-9326/aa702f

Sillmann, J. (2023). Regional climate change and variability. In A. Engels, J. Marotzke, E. G. Gresse, A. López-Rivera, A. Pagnone, & J. Wilkens (Eds.), *Hamburg Climate Futures Outlook: The plausibility of a 1.5°C limit to global warming – social drivers and physical processes* (pp. 158). Hamburg, Germany: Cluster of Excellence Climate, Climatic Change, and Society (CLICCS). doi:10.25592/uhhfdm.11230

Simon, A., Pires, C., Frölicher, T. L., & Russo, A. (2023). Long-term warming and interannual variability contributions' to marine heatwaves in the

Mediterranean. *Weather and Climate Extremes, 42*, 100619. doi:10.1016/j.wace.2023.100619

Skougaard Kaspersen, P., Høegh Ravn, N., Arnbjerg-Nielsen, K., Madsen, H., & Drews, M. (2017). Comparison of the impacts of urban development and climate change on exposing European cities to pluvial flooding. *Hydrology and Earth System Sciences, 21*, 4131–4147. doi:10.5194/hess-21-4131-2017

Slingo, J., Bates, P., Bauer, P., Belcher, S., Palmer, T., Stephens, G., Stevens, B., Stocker, T., & Teutsch, G. (2022). Ambitious partnership needed for reliable climate prediction. *Nature Climate Change, 12*(6), 499-503. doi:10.1038/s41558-022-01384-8

Smale, D. A., Wernberg, T., Oliver, E. C. J., Thomsen, M., Harvey, B. P., Straub, S. C., Burrows, M. T., Alexander, L. V., Benthuysen, J. A., Donat, M. G., & Others. (2019). Marine heatwaves threaten global biodiversity and the provision of ecosystem services. *Nature Climate Change, 9*(4), 306-312. doi:10.1038/s41558-019-0412-1

Smith, K. E., Burrows, M. T., Hobday, A. J., King, N. G., Moore, P. J., Sen Gupta, A., Thomsen, M. S., Wernberg, T., & Smale, D. A. (2023). Biological impacts of marine heatwaves. *Annual Review of Marine Science, 15*, 119-145. doi:10.1146/annurev-marine-032122-121437

Smith, K. E., Burrows, M. T., Hobday, A. J., Sen Gupta, A., Moore, P. J., Thomsen, M., Wernberg, T., & Smale, D. A. (2021). Socioeconomic impacts of marine heatwaves: Global issues and opportunities. *Science, 374*(6566), eabj3593. doi:10.1126/science.abj3593

Stammer, D., Engels, A., Marotzke, J., Gresse, E. G., Hedemann, C., & Petzold, J. (Eds.). (2021). *Hamburg Climate Futures Outlook: Assessing the plausibility of deep decarbonization by 2050*. Hamburg, Germany: Cluster of Excellence Climate, Climatic Change, and Society (CLICCS). doi:10.25592/uhhfdm.9104

Stevens, B., Satoh, M., Auger, L., Biercamp, J., Bretherton, C. S., Chen, X., Düben, P., Judt, F., Khairoutdinov, M., Klocke, D., Kodama, C., Kornblueh, L., Lin, S.-J., Neumann, P., Putman, W. M., Röber, N., Shibuya, R., Vanniere, B., Vidale, P. L., Wedi, N., & Zhou, L. (2019). DYAMOND: the DYnamics of the Atmospheric general circulation Modeled On Non-hydrostatic Domains. *Progress in Earth and Planetary Science, 6*(1), 61. doi:10.1186/s40645-019-0304-z

Stojanov, R., Duží, B., Kelman, I., Němec, D., & Procházka, D. (2017). Local perceptions of climate change impacts and migration patterns in Malé, Maldives. *The Geographical Journal, 183*(4), 370-385. doi:10.1111/geoj.12177

Suárez-Gutiérrez, L., Li, C., Müller, W. A., & Marotzke, J. (2018). Internal variability in European summer temperatures at 1.5 °C and 2 °C of global warming. *Environmental Research Letters, 13*, 064026. doi:10.1088/1748-9326/aaba58

Suárez-Gutiérrez, L., Milinski, S., & Maher, N. (2021). Exploiting large ensembles for a better yet simpler climate model evaluation. *Climate Dynamics, 57*(9), 2557-2580. doi:10.1007/s00382-021-05821-w

Suárez-Gutiérrez, L., Müller, W. A., Li, C., & Marotzke, J. (2020). Hotspots of extreme heat under global warming. *Climate Dynamics, 55*(3-4), 429-447. doi:10.1007/s00382-020-05263-w

Suárez-Gutiérrez, L., Müller, W. A., & Marotzke, J. (2023). Extreme heat and drought typical of an end-of-century climate could occur over Europe soon and repeatedly. *Communications Earth & Environment, 4*(1), 415. doi:10.1038/s43247-023-01075-y

Sully, S., Burkepile, D. E., Donovan, M. K., Hodgson, G., & Van Woesik, R. (2019). A global analysis of coral bleaching over the past two decades. *Nature communications, 10*(1), 1264. doi:10.1038/s41467-019-09238-2

Teixeira, E. I., Fischer, G., van Velthuizen, H., Walter, C., & Ewert, F. (2013). Global hot-spots of heat stress on agricultural crops due to climate change. *Agricultural and Forest Meteorology, 170*, 206-215. doi:10.1016/j.agrformet.2011.09.002

Thackeray, C. W., Hall, A., Norris, J., & Chen, D. (2022). Constraining the increased frequency of global precipitation extremes under warming. *Nature Climate Change, 12*(5), 441-448. doi:10.1038/s41558-022-01329-1

Tradowsky, J. S., Philip, S. Y., Kreienkamp, F., Kew, S. F., Lorenz, P., Arrighi, J., Bettmann, T., Caluwaerts, S., Chan, S. C., & De Cruz, L. (2023). Attribution of the heavy rainfall events leading to severe flooding in Western Europe during July 2021. *Climatic Change, 176*(7), 90. doi:10.1007/s10584-023-03502-7

Trainer, V. L., Moore, S. K., Hallegraeff, G., Kudela, R. M., Clement, A., Mardones, J. I., & Cochlan, W. P. (2020). Pelagic harmful algal blooms and climate change: Lessons from nature's experiments with extremes. *Harmful algae, 91*, 101591. doi:10.1016/j.hal.2019.03.009

Trenberth, K. E., & Shea, D. J. (2005). Relationships between precipitation and surface temperature. *Geophysical Research Letters, 32*(14). doi:10.1029/2005GL022760

Vanlauwe, B., Hungria, M., Kanampiu, F., & Giller, K. E. (2019). The role of legumes in the sustainable intensification of African smallholder agriculture: Lessons learnt and challenges for the future. *Agriculture, Ecosystems & Environment, 284*, 106583. doi:10.1016/j.agee.2019.106583

Wall, P. C., Thierfelder, C., Ngwira, A., Govaerts, B., Nyagumbo, I., & F., B. (2013). Conservation agriculture in Eastern and Southern Africa. In Jat, R. A., Sahrawat, K. L., & Kassam, A. H. (Eds.), *Conservation agriculture: global prospects and challenges* (pp. 263-292).

Wehner, M. F., Reed, K. A., Li, F., Prabhat, Bacmeister, J., Chen, C. T., Paciorek, C., Gleckler, P. J., Sperber, K. R., Collins, W. D., Gettelman, A., & Jablonowski, C. (2014). The effect of horizontal resolution on simulation quality in the Community Atmospheric Model, CAM5.1. *Journal of Advances in Modeling Earth Systems, 6*(4), 980-997. doi:10.1002/2013ms000276

Wernberg, T. (2021). Marine heatwave drives collapse of kelp forests in Western Australia. In Canadell, J. G., & Jackson, R. B. (Eds.), *Ecosystem collapse and climate change* (pp. 325-343). Cham: Springer.

Wills, R. C. J., Dong, Y., Proistosecu, C., Armour, K. C., & Battisti, D. S. (2022). Systematic Climate Model Biases in the Large-Scale Patterns of Recent Sea-Surface Temperature and Sea-Level Pressure Change. *Geophysical Research Letters, 49*(17), e2022GL100011. doi:10.1029/2022GL100011

World Meteorological Organization. (2021). State of Climate Services: Water. WMO, Geneva. Last accessed April 22, 2024, available at https://library.wmo.int/idurl/4/57630

Würtz, M. (2010). *Mediterranean pelagic habitat: oceanographic and biological processes, an overview:* ICUN.

Zscheischler, J., Sillmann, J., & Alexander, L. (2022). Introduction to the special issue: Compound weather and climate events. *Weather and Climate Extremes, 35*, 100381. doi:10.1016/j.wace.2021.100381

Zscheischler, J., Westra, S., Hurk, B., Seneviratne, S., Ward, P., Pitman, A., AghaKouchak, A., Bresch, D., Leonard, M., Wahl, T., & Zhang, X. (2018). Future climate risk from compound events. *Nature Climate Change, 8*. doi:10.1038/s41558-018-0156-3

Chapter 5 – Sustainable Climate Change Adaptation: Insights and Reflections from the Field

Aall, C., Meyer-Habighorst, C., Gram-Hanssen, I., Korsbrekke, M. H., & Hovelsrud, G. (2023). “I’m Fixing a Hole Where the Rain Gets in, and Stops My Mind from Wandering”: Approaching Sustainable Climate Change Adaptations. *Weather, Climate, and Society, 15*(2), 349-364. doi:10.1175/WCAS-D-22-0113.1

Abdulla, A., Adam, M. S., Moosa, L., Moosa, S., Naseer, A., Saeed, S., & Shaig, A. (2007). National Adaptation Programme of Action (NAPA). Republic of Maldives. Ministry of Environment,, Energy and Water,, Malé: https://unfccc.int/resource/docs/napa/mdv01.pdf

Abijith, D., Saravanan, S., & Sundar, P. K. S. (2023). Coastal vulnerability assessment for the coast of Tamil Nadu, India—a geospatial approach. *Environmental Science and Pollution Research, 30*, 1-19. doi:10.1007/s11356-023-27686-8

ADB. (2010). Ho Chi Minh City Adaptation to Climate Change: Summary Report, January 2010. Manila.

ADB. (2015). Maldives. Overcoming The Challenges Of A Small Island State: Country Diagnostic Study. Asian Development Bank,, Manila: https://www.adb.org/sites/default/files/publication/172704/maldives-overcoming-challenges-small-island-state.pdf

Adger, W. N., Brown, K., Nelson, D. R., Berkes, F., Eakin, H., Folke, C., Galvin, K., Gunderson, L., Goulden, M., & O'Brien, K. (2011). Resilience implications of policy responses to climate change. *Wiley Interdisciplinary Reviews: Climate Change, 2*(5), 757-766. doi:10.1002/wcc.133

Adger, W. N., & Jordan, A. (2009). Sustainability: exploring the processes and outcomes of governance. In W. N. Adger & A. Jordan (Eds.), *Governing Sustainability* (pp. 3-31). Cambridge: Cambridge University Press.

Adloff, S., & Rehdanz, K. (2024). Responsibility attribution and community support of coastal adaptation to climate change: Evidence from a choice experiment in the Maldives. *Journal of choice modelling, 50*, 100468. doi:10.1016/j.jocm.2024.100468

Amjad, H. (2023). Hanging in the balance: Maldives Presidential race & big-ticket infrastructure. *Observer Research Foundation (ORF)*. Retrieved from https://www.orfonline.org/expert-speak/hanging-in-the-balance/

An, B. (2021). Solutions towards Climate Change Adaptation in Ho Chi Minh City. *Environment and Tourism in Vietnam Magazine*. Retrieved from https://moitruongdulich.vn/index.php/item/15911

Anh, H. H. (2023). *Sustainable sand management in the Mekong Delta, Vietnam*. Paper presented at the Presentation during the Workshop "Climate Change", April 2023, German Vietnamese Science Day, Da Nang, Vietnam.

Armani, G., de Lima, N. G., Garcia, M., & Carvalho, J. (2022). Regional climate projections for the State of São Paulo, Brazil, in the 2020–2050 period. 43, E773. doi:10.14295/derb.v43.773

Arns, A., Dangendorf, S., Jensen, J., Talke, S., Bender, J., & Pattiaratchi, C. (2017). Sea-level rise induced amplification of coastal protection design heights. *Scientific reports, 7*(1), 40171. doi:10.1038/srep40171

Aslam, M., & Kench, P. S. (2017). Reef island dynamics and mechanisms of change in Huvadhoo Atoll, Republic of Maldives, Indian Ocean. *Anthropocene, 18*, 57-68. doi:10.1016/j.ancene.2017.05.003

Azfa, A., Jackson, G., Westoby, R., McNamara, K. E., McMichael, C., & Farbotko, C. (2022). 'We didn't want to leave our island': stories of involuntary resettlement from Gaadhoo Island, Maldives. *Territory, Politics, Governance, 10*(2), 159-179. doi:10.1080/21622671.2020.1768139

Back, A. G., Di Giulio, G. M., & Malheiros, T. F. (2022). Challenges for sustainable urban transformation in São Paulo: visions, interests and demands under debate. *Revista Brasileira de Estudos Urbanos e Regionais, 24*(1). doi:10.22296/2317-1529.rbeur.202225pt

Back, A. G., Marques Di Giulio, G., & Fabrício Malheiros, T. (2021). São Paulo's strategic master plan and the challenges of sustainable urban transformation. *Sustainability in Debate, 12*(3). doi:10.18472/SustDeb.v12n1.2021.40197

Barbi, F., & de Macedo, L. V. (2019). Transnational municipal networks and cities in climate governance. In J. van der Heijden, H. Bulkeley, & C. Certomà, *Urban climate politics: agency and empowerment*, 59-79. doi:10.1017/9781108632157.004

Barnett, J., & O'Neill, S. J. (2013). Minimising the risk of maladaptation: a framework for analysis. *Climate adaptation futures*, 87-93. doi:10.1002/9781118529577.ch7

Barnett, J., & O'Neill, S. J. (2010). Maladaptation. *Global Environmental Change, 20*(2), 211-213. doi:10.1016/j.gloenvcha.2009.11.004

Bayerisches Staatsministerium für Ernährung Landwirtschaft und Forsten. (2023). Baumarten für den Klimawandel – Leitlinien der Bayerischen Forstverwaltung. München: https://www.awg.bayern.de/mam/cms02/asp/dateien/baumartenwahl_klimawald_zukunft_barrierefrei.pdf

Bechtel, B., & Schmidt, K. J. (2011). Floristic mapping data as a proxy for the mean urban heat island. *Climate Research, 49*(1), 45-58. doi:10.3354/cr01009

Behre, K. (2008). *Landschaftsgeschichte Norddeutschlands. Umwelt und Siedlung von der Steinzeit bis zur Gegenwart*. Neumünster: Wachholtz.

Berkhout, F., & Dow, K. (2023). Limits to adaptation: Building an integrated research agenda. *Wiley Interdisciplinary Reviews: Climate Change, 14*(3). doi:10.1002/wcc.817

Berrang-Ford, L., Siders, A. R., Lesnikowski, A., Fischer, A. P., Callaghan, M. W., Haddaway, N. R., Mach, K. J., Araos, M., Shah, M. A. R., Wannewitz, M., Doshi, D., Leiter, T., Matavel, C., Musah-Surugu, J. I., Wong-Parodi, G., Antwi-Agyei, P., Ajibade, I., Chauhan, N., Kakenmaster, W., Grady, C., Chalastani, V. I., Jagannathan, K., Galappaththi, E. K., Sitati, A., Scarpa, G., Totin, E., Davis, K., Hamilton, N. C., Kirchhoff, C. J., Kumar, P., Pentz, B., Simpson, N. P., Theokritoff, E., Deryng, D., Reckien, D., Zavaleta-Cortijo, C., Ulibarri, N., Segnon, A. C., Khavhagali, V., Shang, Y., Zvobgo, L., Zommers, Z., Xu, J., Williams, P. A., Canosa, I. V., van Maanen, N., van Bavel, B., van Aalst, M., Turek-Hankins, L. L., Trivedi, H., Trisos, C. H., Thomas, A., Thakur, S., Templeman, S., Stringer, L. C., Sotnik, G., Sjostrom, K. D., Singh, C., Siña, M. Z., Shukla, R., Sardans, J., Salubi, E. A., Safaee Chalkasra, L. S., Ruiz-Díaz, R., Richards, C., Pokharel, P., Petzold, J., Penuelas, J., Pelaez Avila, J., Murillo, J. B. P., Ouni, S., Niemann, J., Nielsen, M., New, M., Nayna Schwerdtle, P., Nagle Alverio, G., Mullin, C. A., Mullenite, J., Mosurska, A., Morecroft, M. D., Minx, J. C., Maskell, G., Nunbogu, A. M., Magnan, A. K., Lwasa, S., Lukas-Sithole, M., Lissner, T., Lilford, O., Koller, S. F., Jurjonas, M., Joe, E. T., Huynh, L. T. M., Hill, A., Hernandez, R. R., Hegde, G., Hawxwell, T., Harper, S., Harden, A., Haasnoot, M., Gilmore, E. A., Gichuki, L., Gatt, A., Garschagen, M., Ford, J. D., Forbes, A., Farrell, A. D., Enquist, C. A. F., Elliott, S., Duncan, E., Coughlan de Perez, E., Coggins, S., Chen, T., Campbell, D., Browne, K. E., Bowen, K. J., Biesbroek, R., Bhatt, I. D., Bezner Kerr, R., Barr, S. L., Baker, E., Austin, S. E., Arotoma-Rojas, I., Anderson, C., Ajaz, W., Agrawal, T., & Abu, T. Z. (2021). A systematic global stocktake of evidence on human adaptation to climate change. *Nature Climate Change*, 11(11), 989-1000. doi:10.1038/s41558-021-01170-y

Bisaro, A., de Bel, M., Hinkel, J., Kok, S., & Bouwer, L. M. (2020). Leveraging public adaptation finance through urban land reclamation: cases from Germany, the Netherlands and the Maldives. *Climatic Change, 160*(4), 671-689. doi:10.1007/s10584-019-02507-5

BMEL. (2022). Trockenheit und Dürre im Jahr 2018. Last accessed July 14, 2023, available at https://www.bmel.de/DE/themen/wald/wald-in-deutschland/wald-trockenheit-klimawandel.html

BMEL. (2023). Massive Schäden – Einsatz für die Wälder. Last accessed July 14, 2023, available at https://www.bmel.de/DE/themen/wald/wald-in-deutschland/wald-trockenheit-klimawandel.html

Böhner, J., & Hasson, S. (2023). Modelling climate change over high Asia – Options, scopes, limitations and projections. *GeoÖko, in press*.

Booth, K. (2008). Risdon Vale: Place, memory, and suburban experience. *Ethics Place and Environment, 11*(3), 299-311. doi:10.1080/13668790802559700

Bouwer, L. M. (2022). *The Roles of Climate Risk Dynamics and Adaptation Limits in Adaptation Assessment*. Paper presented at the Climate Adaptation Modelling, Cham.

Brandt, K. (1992). Besiedlungsgeschichte der Nord- und Ostseeküste bis zum Beginn des Deichbaus. In J. a. R. Kramer, H. (Ed.), *Historischer Küstenschutz. Deichbau, Inselschutz und Binnenentwässerung an Nord- und Ostsee* (pp. 17-37). Stuttgart: Verlag Konrad Wittwer.

Brazil. (2009). Lei 12.187 de 29 de dezembro de 2009. Institui a Política Nacional sobre Mudança do Clima – PNMC e dá outras providências. Brasília, DF, Brazil. Last accessed April 22, 2024, available at http://www.planalto.gov.br/ccivil_03/_ato2007-2010/2009/lei/l12187.htm.

Bremner, L. (2017). Observations on the Concept of the Aquapelago Occasioned by Researching the Maldives. *Shima: The International Journal of Research into Island Cultures, 11*(1), 18-29. doi:10.21463/shima.11.1.05

Brown, P. T., Ming, Y., Li, W., & Hill, S. A. (2017). Change in the magnitude and mechanisms of global temperature variability with warming. *Nature Climate Change*, 7(10), 743-748. doi:10.1038/nclimate3381

Brown, S., Nicholls, R. J., Bloodworth, A., Bragg, O., Clauss, A., Field, S., Gibbons, L., Pladaitė, M., Szuplewski, M., Watling, J., Shareef, A., & Khaleel, Z. (2023). Pathways to sustain atolls under rising sea levels through land claim and island raising. *Environmental Research: Climate, 2*(1), 015005. doi:10.1088/2752-5295/acb4b3

BSW. (2021). *Wohnungsbauprogramm des Senats – Vertrag für Hamburg*. Behörde für Stadtentwicklung und Wohnen (BSW) Retrieved from https://www.hamburg.de/bsw/vertrag-fuer-hamburg/

Bundeskabinett. (2008). Deutsche Anpassungsstrategie an den Klimawandel. Berlin: https://www.bmuv.de/download/deutsche-anpassungsstrategie-an-den-klimawandel

Bürgerschaft der FHH. (2014). *Mitteilung des Senats an die Bürgerschaft. Einzelplan 6 Behörde für Stadtentwicklung und Umwelt Gründachstrategie für Hamburg – Zielsetzung, Inhalt und Umsetzung*. Hamburg: Bürgerschaft der Freien und Hansestadt Hamburg (FHH) Retrieved from https://www.hamburg.de/contentblob/4334618/2510ee3f7968bb09e58bf2f49837b133/data/d-drucksache-gruendachstrategie.pdf

Burschel, P., & Huss, J. (2003). *Grundriss des Waldbaus*. Suttgart: Ulmer.

BVerfG. (2021). Order of the First Senate of 24 March 2021 – 1 BvR 2656/18 -, paras. 1-270.

C40 Cities Climate Leadership Group. (2016). Climate Change Adaption in Delta Cities. https://www.c40.org/wp-content/uploads/2022/02/C40-Good-Practice-Guide-Climate-Change-Adaptation-in-Delta-Cities.pdf

Calderon, A. J. (2022). *Medidas de adaptação de mudanças climáticas à luz da justiça climática: um estudo de caso da megacidade de São Paulo*. Universidade Católica de São Paulo, Retrieved from https://repositorio.pucsp.br/jspui/handle/handle/29618

Callaghan, M. W., Minx, J. C., & Forster, P. M. (2020). A topography of climate change research. *Nature Climate Change, 10*(2), 118-123. doi:10.1038/s41558-019-0684-5

CARE. (2015) Practitioner brief 1: Adaptation planning with communities. In. Nairobi, Kenya: CARE International.

Carlos, A. F. A. (2004). São Paulo: do capital industrial ao capital financeiro. In *Geografias de São Paulo: a metrópole do século xxi* (pp. 51-83).

Cazenave, A., Palanisamy, H., & Ablain, M. (2018). Contemporary sea level changes from satellite altimetry: What have we learned? What are the new challenges? *Advances in Space Research, 62*(7), 1639-1653. doi:10.1016/j.asr.2018.07.017

Central Weather Administration. Last accessed April 22, 2024, available at https://www.cwa.gov.tw/eng/

Chaudhary, P., & Aryal, K. (2009). Global warming in Nepal: Challenges and policy imperatives. *Journal of Forest and Livelihood, 8*(1), 5-14. Retrieved from https://www.researchgate.net/publication/312469261_Global_Warming_in_Nepal_Challenges_and_Policy_Imperatives_Design_and_Layout_Corrected_proof_in_press_Global_Warming_in_Nepal_Challenges_and_Policy_Imperatives

Chien, F.-C., & Kuo, H.-C. (2011). On the extreme rainfall of Typhoon Morakot (2009). *Journal of Geophysical Research: Atmospheres, 116*(D5). doi:10.1029/2010JD015092

Chou, K. T. (2013). The public perception of climate change in Taiwan and its paradigm shift. *Energy Policy, 61*, 1252–1260. doi:10.1016/j.enpol.2013.06.016

Clark, D. (2009). Maldives first to go carbon neutral. *The Guardian*. Retrieved from https://www.theguardian.com/environment/2009/mar/15/maldives-presidentnasheed-carbon-neutral

Country Economy. (2022). Maldives GDP – Gross Domestic.Product. Last accessed April 22, 2024, available at https://countryeconomy.com/gdp/maldivas

D'Almeida Martins, R., & da Costa Ferreira, L. (2011). Climate change action at the city level: tales from two megacities in Brazil. *Management of Environmental Quality: An International Journal*, 22(3), 344-357. doi:10.1108/14777831111122914

Dannenberg, P., & Follmann, A. (2023). Landwirtschaft und ländliche Räume. In E. Kulke (Ed.), *Wirtschaftsgeographie Deutschlands* (pp. 103-136). Berlin, Heidelberg: Springer Berlin Heidelberg.

Darjee, K. B., Neupane, P. R., & Köhl, M. (2022). Do Local Perceptions of Climate Variability and Changes Correspond to Observed Climate Changes? A Comparative Study from Nepal as One of the Most Climate-Vulnerable Countries. *Weather, Climate, and Society, 14*(1), 205-222. doi:10.1175/WCAS-D-21-0081.1

Darjee, K. B., Neupane, P. R., & Köhl, M. (2023). Proactive adaptation responses by vulnerable communities to climate change impacts. *Sustainability, 15*(14), 10952. doi:10.3390/su151410952

David, C. G., Hennig, A., Ratter, B. M. W., Roeber, V., Zahid, & Schlurmann, T. (2021). Considering socio-political framings when analyzing coastal climate change effects can prevent maldevelopment on small islands. *Nature Communications, 12*(1), 5882. doi:10.1038/s41467-021-26082-5

David, C. G., & Schlurmann, T. (2020). Hydrodynamic Drivers and Morphological Responses on Small Coral Islands — The Thoondu Spit on Fuvahmulah, the Maldives. *Frontiers in Marine Science, 7*, 885. doi:10.3389/fmars.2020.538675

de Guttry, C., & Ratter, B. (2022). Expiry date of a disaster: Memory anchoring and the storm surge 1962 in Hamburg, Germany. *International Journal of Disaster Risk Reduction, 70*, 102719. doi:10.1016/j.ijdrr.2021.102719

dell'Agnese, E. (2021). Greening the resort, de-bordering the enclave. In S. Malatesta, M. S. d. Friedberg, S. Zubair, D. Bowen, & M. Mohamed (Eds.), *Atolls of the Maldives – Nissology and Geography* (pp. 132-154). Lanham, Maryland, United States: Rowman & Littlefield International.

Di Giulio, G. M., Bedran-Martins, A. M., da Penha Vasconcellos, M., & Ribeiro, W. C. (2017). Climate change, risks and adaptation in the megacity of São Paulo, Brazil. *Sustainability in Debate, 8*(2), 75-87. doi:10.18472/SustDeb.v8n2.2017.19868

Di Giulio, G. M., Bedran-Martins, A. M. B., Vasconcellos, M. d. P., Ribeiro, W. C., & Lemos, M. C. (2018). Mainstreaming climate adaptation in the megacity of São Paulo, Brazil. *Cities, 72*, 237-244. doi:10.1016/j.cities.2017.09.001

Di Giulio, G. M., Torres, R. R., Lapola, D. M., Bedran-Martins, A. M., da Penha Vasconcellos, M., Braga, D. R., Fuck, M. P., Juk, Y., Nogueira, V., & Penna, A. C. (2019). Bridging the gap between will and action on climate change adaptation in large cities in Brazil. *Regional Environmental Change, 19*, 2491-2502. doi:10.1007/s10113-019-01570-z

Doong, D.-J., Kao, C. C., Liu, P. C., & Chen, H. S. (2008). *An Observed Extreme Large Wave*. Paper presented at the Taiwan-Polish Joint Seminar on Coastal Protection 2008, Tainan, Taiwan.

Döring, M., & Ratter, B. M. W. (2015). 'Heimat' as a boundary object? Exploring the potentialities of a boundary object to instigate productive science-stakeholder interaction in North Frisia (Germany). *Environmental Science & Policy, 54*, 448-455. doi:10.1016/j.envsci.2015.08.009

Döring, M., & Ratter, B. M. W. (2018). The regional framing of Climate Change: Towards a place-based perspective on regional climate change perception in North Frisia. *Journal of Coastal Conservation, 16*, 131-143. doi:10.1007/s11852-016-0478-0

Döring, M., & Ratter, B. M. W. (2021). "I show you my coast..." – a relational study of coastscapes in the North Frisian Wadden Sea. *Maritime Studies, 20*, 317-327. doi:10.1007/s40152-021-00239-w

Dos Santos, S. A. (2011). The metamorphosis of black movement activists into black organic intellectuals. *Latin American Perspectives, 38*(3), 124-135. doi:10.1177/0094582X103936

Driessen, P. P. J., Hegger, D. L. T., Kundzewicz, Z. W., Van Rijswick, H. F. M. W., Crabbé, A., Larrue, C., Matczak, P., Pettersson, M., Priest, S., & Suykens, C. (2018). Governance strategies for improving flood resilience in the face of climate change. *Water, 10*(11), 1595. doi:10.3390/w10111595

DWD. (2021). Klimareport Hamburg. Deutscher Wetterdienst (DWD), Offenbach am Main, Deutschland: https://www.dwd.de/DE/leistungen/klimareports/klimareport_hh_2021_download.html

Eckert, R., & Waibel, M. (2009). Climate Change and Challenges for the Urban Development of Ho Chi Minh City / Vietnam. *Pacific News, 31*, 18-20. Retrieved from http://www.pacific-geographies.org/wp-content/uploads/sites/2/2017/06/pn31_waibel_eckert.pdf

Eckstein, D., Künzel, V., & Schäfer, L. (2021). Global Climate Risk Index 2021: Who Suffers Most from Extreme Weather Events? Weather-related loss events in 2019 and 2000-2019. Germanwatch, Bonn, Germany: https://www.germanwatch.org/sites/default/files/Global%20Climate%20Risk%20Index%202021_2.pdf

EEA. (2019). Environmental justice, environmental hazards and the vulnerable in European society (briefing). European Environment Agency (EEA), https://www.eea.europa.eu/publications/unequal-exposure-and-unequal-impacts/environmental-justice-environmental-hazards-and/view

EIU. (2023). Democracy Index 2022: Frontline democracy and the battle for Ukraine. Economist Intelligence Unit, https://www.eiu.com/n/wp-content/uploads/2023/02/Democracy-Index-2022_FV2.pdf?li_fat_id=f1fbad7e-a282-4b9e-9f8f-6a6d5a9fe6b8

Engelbrecht, F., Adegoke, J., Bopape, M.-J., Naidoo, M., Garland, R., Thatcher, M., McGregor, J., Katzfey, J., Werner, M., & Ichoku, C. (2015). Projections of rapidly rising surface temperatures over Africa under low mitigation. *Environmental Research Letters, 10*(8), 085004. doi:10.1088/1748-9326/10/8/085004

Engels, A., Marotzke, J., Gresse, E. G., López-Rivera, A., Pagnone, A., & Wilkens, J. (Eds.). (2023). *Hamburg Climate Futures Outlook: The plausibility of a 1.5°C limit to global warming – social drivers and physical processes*. Hamburg, Germany: Cluster of Excellence Climate, Climatic Change, and Society (CLICCS). doi:10.25592/uhhfdm.11230

Executive Yuan. (2012). *Adaptation Strategy to Climate Change in Taiwan* [in Chinese]. Executive Yuan,

Executive Yuan. (2013). *Disaster Prevention and Protection Plan [in Chinese]*. (ISBN 9789860379228). New Taipei City, Taiwan: Executive Yuan

Executive Yuan. (2017). *Integrated Coastal Zone Management Plan [in Chinese]*. Executive Yuan,

Executive Yuan. (2023). *National Climate Change Adaptation Action Plan*. Executive Yuan, Retrieved from https://english.ey.gov.tw/News3/9E5540D592A5FECD/fff51eaf-f1e9-4ca4-999e-7bc98f47c28a

FAIR. (2020). Adaptive Asset Management for Flood Protection: FAIR end report. European Regional Development Fund, European Union: https://northsearegion.eu/media/13662/fair_end_report-03-06-2020.pdf

FAO. (2015). *Mapping the vulnerability of mountain peoples to food insecurity*. Rome: Food and Agriculture Organization of the United Nations.

Fedele, G., Donatti, C. I., Harvey, C. A., Hannah, L., & Hole, D. G. (2019). Transformative adaptation to climate change for sustainable social-ecological systems. *Environmental Science & Policy, 101*, 116-125. doi:10.1016/j.envsci.2019.07.001

Federal Ministry for the Environment Nature Conservation Building and Nuclear Safety. (2016). Climate Action Plan 2050: Principles and goals of the German government's climate policy. Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB), Berlin: https://www.bmuv.de/fileadmin/Daten_BMU/Pools/Broschueren/klimaschutzplan_2050_en_bf.pdf

Feindt, P. H., Krämer, C., Früh-Müller, A., Heißenhuber, A., Pahl-Wostl, C., Purnhagen, K. P., Thomas, F., van Bers, C., & Wolters, V. (2019). *Ein neuer Gesellschaftsvertrag für eine nachhaltige Landwirtschaft: Wege zu einer integrativen Politik für den Agrarsektor*: Springer Berlin Heidelberg.

Fellmer, M. (2014). *Bürgerschaftliches Engagement und Sturmfluten: Ausprägungen und Einflussfaktoren am Beispiel des Flussgebiets der Tideelbe*: Rohn.

Feola, G. (2015). Societal Transformation in Response to Global Environmental Change: A Review of Emerging Concepts. *AMBIO A Journal of the Human Environment, 44*, 376-390. doi:10.1007/s13280-014-0582-z

Feser, F., Krueger, O., Woth, K., & van Garderen, L. (2021). North Atlantic winter storm activity in modern reanalyses and pressure-based observations. *Journal of Climate, 34*(7), 2411-2428. doi:10.1175/JCLI-D-20-0529.1

Fischer, N. (Ed.) (2021). *Zwischen Wattenmeer und Marschenland. Deiche und Deichforschung an der Nordseeküste*. Stade: Landschaftsverband Stade.

Francisconi, L. (2004). Trabalho e Indústria em São Paulo. In A. F. A. Carlos (Ed.), *Geografias de São Paulo: Representação e Crise da Metrópole*.

Garschagen, M., & Romero-Lankao, P. (2015). Exploring the relationships between urbanization trends and climate change vulnerability. *Climatic Change, 133*, 37-52. doi:10.1007/s10584-013-0812-6

Gemeinde Helgoland. (2013). Klimaschutzkonzept Helgoland, Integriertes kommunales Klimaschutzkonzept für die Gemeinde Helgoland. Gemeinde Helgoland, Helgoland: https://www.helgoland.de/rathaus/leben-auf-helgoland/nachhaltigkeit/

General Statistics Office of Vietnam (2023). Statistical Yearbook of 2022. Statistical Publishing House, Hanoi. Last accessed February 21, 2024, available at https://www.gso.gov.vn/wp-content/uploads/2023/06/Sach-Nien-giam-TK-2022-update-21.7_file-nen-Water.pdf

Geyer, J., Kreft, S., Jeltsch, F., & Ibisch, P. L. (2017). Assessing climate change-robustness of protected area management plans—The case of Germany. *PLoS ONE, 12*(10), e0185972. doi:10.1371/journal.pone.0185972

Glavovic, B. C., Dawson, R., Chow, W., Garschagen, M., Haasnoot, M., Singh, C., & Thomas, A. (2022). Cross-Chapter Paper 2: Cities and Settlements by the Sea. In H.-O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, & B. Rama (Eds.), *Climate Change 2022: Impacts, Adaptation and Vulnerability* (pp. 2163-2194). Cambridge, UK and New York, NY, USA: Cambridge University Press.

Gomiero, T., Pimentel, D., & Paoletti, M. G. (2011). Environmental impact of different agricultural management practices: conventional vs. organic agriculture. *Critical reviews in plant sciences, 30*(1-2), 95-124. doi:10.1080/07352689.2011.554355

GoN. (2019). *Climate Change Policy 2019*. Singhdurbar Kathmandu, Nepal: Government of Nepal, Ministry of Forest and Environment (MoFE)

González-Riancho, P., Gerkensmeier, B., & Ratter, B. (2017). Storm surge resilience and the Sendai Framework. Risk perception, intention to prepare and enhanced collaboration along the German North Sea coast. *Ocean & Coastal Management, 141*, 118-131. doi:10.1016/j.ocecoaman.2017.03.006

Gresse, E. G. (2022). *Non-state Actors and Sustainable Development in Brazil: The Diffusion of the 2030 Agenda*. Abingdon, Oxfordshire, UK: Routledge.

Gresse, E. G., Schrum, C., Hanf, F. S., Jantke, K., Pein, J., Hawxwell, T., Hoffmann, P., Bolaños, T. G., Langendijk, G. S., Schneider, U. A., Huang-Lachmann, J.-T., Neuburger, M., Umaña, C. R., Seiffert, R., Wickel, M., Sillmann, J., Scheffran, J., & Held, H. (2023). Toward a Sustainable Adaptation Plausibility Framework. In A. Engels, J. Marotzke, E. G. Gresse, A. López-Rivera, A. Pagnone, & J. Wilkens (Eds.), *Hamburg Climate Futures Outlook: The plausibility of a 1.5° limit to gobal warming – Social drivers and physical processes* (pp. 54-65). Hamburg, Germany: Cluster of Excellence Climate, Climatic Change, and Society (CLICCS). doi:10.25592/uhhfdm.11230

Grossmann, I. (2008). Perspectives for Hamburg as a port city in the context of a changing global environment. *Geoforum, 39*(6), 2062-2072. doi:10.1016/j.geoforum.2008.04.011

Grunwald, S., & Böhner, J. (2022). Geographical information systems (GIS) and soils. In *Reference Module in Earth Systems and Environmental Sciences*: Elsevier.

GSO – General Statistics Office. (2023). Statistical Yearbook of Vietnam 2022. General Statistics Office (GSO), https://www.gso.gov.vn/en/data-and-statistics/2023/06/statistical-yearbook-of-2022/

Gussmann, G., & Hinkel, J. (2021). A framework for assessing the potential effectiveness of adaptation policies: Coastal risks and sea-level rise in the Maldives. *Environmental Science & Policy, 115*, 35-42. doi:10.1016/j.envsci.2020.09.028

Hagedoorn, L. C., Bubeck, P., Hudson, P., & Brander, L. M. (2021). Preferences of vulnerable social groups for ecosystem-based adaption to flood risk in Central Vietnam. *World Development, 148*, 105650. doi:10.1016/j.worlddev.2021.105650

Hanf, F. S., Ament, F., Boettcher, M., Burgemiester, F., Gaslikova, L., & Hoffmann, H. (2024, under review). Towards a socio-ecological system understanding of urban flood risk under climate change: Barriers to adaptation in cities.

Haunschild, R., Bornmann, L., & Marx, W. (2016). Climate Change Research in View of Bibliometrics. *PLoS ONE, 11*(7). doi:10.1371/journal.pone.0160393

HCMC Department of Planning and Architecture. (2016). *Communication and Guidelines for Climate Change Adaption in Ho Chi Minh City*. Retrieved from https://qhkt.hochiminhcity.gov.vn/do-thi-xanh/

tuyen-truyen-huong-dan-ve-thich-ung-voi-bien-doi-khi-hau-1128.html

HCMC Party Committee. (2022). The Development of Phu Xuan Wetland Park in Ho Chi Minh city. Last accessed July 12, 2023, available at https://www.hcmcpv.org.vn/tin-tuc/khanh-thanh-cong-trinh-xay-dung-cong-vien-phu-xuan-phuc-vu-nhan-dan

HCMC People Committee. (2021a). Decision No 3273 on the issuance of the Climate Change Adaptation Action Plan for the period 2021-2030, vision to 2050 in Ho Chi Minh city.

HCMC People Committee. (2021b). Planning for Climate Change Adaptation, Ho Chi Minh City, Vietnam. Last accessed June 24, 2023, available at https://plo.vn/tphcm-len-ke-hoach-ung-pho-voi-bien-doi-khi-hau-post656022.html

Heger, A., Becker, J. N., Vásconez Navas, L. K., & Eschenbach, A. (2021). Factors controlling soil organic carbon stocks in hardwood floodplain forests of the lower middle Elbe River. *Geoderma, 404*, 115389. doi:10.1016/j.geoderma.2021.115389

Hennig, A. (2020). *Enablers and Barriers to Local Adaptive Capacity – A Case Study on Coastal Governance in the Maldives*. (Dissertation). Universität Hamburg, Hamburg. Retrieved from https://ediss.sub.uni-hamburg.de/handle/ediss/9416

Hinkel, J., Feyen, L., Hemer, M., Le Cozannet, G., Lincke, D., Marcos, M., Mentaschi, L., Merkens, J. L., de Moel, H., Muis, S., Nicholls, R. J., Vafeidis, A. T., van de Wal, R. S. W., Vousdoukas, M. I., Wahl, T., Ward, P. J., & Wolff, C. (2021). Uncertainty and bias in global to regional scale assessments of current and future coastal flood risk. *Earth's Future, 9*(n/a), e2020EF001882. doi:10.1029/2020EF001882

Hinkel, J., Garcin, M., Gussmann, G., Amores, A., Barbier, C., Bisaro, A., Le Cozannet, G., Duvat, V., Imad, M., Khaleel, Z., Marcos, M., Pedreros, R., Shareef, A., & Waheed, A. (2023). Co-creating a coastal climate service to prioritise investments in erosion prevention and sea-level rise adaptation in the Maldives. [CLISER-D-22-00125R2]. *Climate Services, 31*, 100401. doi:10.1016/j.cliser.2023.100401

HmbGVBl. (2002). *Verordnung zum Schutz vor Sturmfluten im Gebiet der HafenCity (Flutschutzverordnung-HafenCity) – Vom 18. Juni 2002*. Retrieved from https://www.landesrecht-hamburg.de/bsha/document/jlr-FlSchuVHArahmen

Hoegh-Guldberg, O., Jacob, D., Taylor, M., Bindi, M., Brown, S., Camilloni, I., Diedhiou, A., Djalante, R., Ebi, K. L., Engelbrecht, F., Guiot, J., Hijioka, Y., Mehrotra, S., Payne, A., Seneviratne, S. I., Thomas, A., Warren, R., & Zhou, G. (2018). Impacts of 1.5°C of global warming on natural and human systems. In V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, A. Maycock, M. Tignor, & T. Waterfield (Eds.), *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* (pp. 175-312). Cambridge, New York: Cambridge University Press, Cambridge, UK and New York, NY, U.

Hoegh-Guldberg, O., Jacob, D., Taylor, M., Guillén Bolaños, T., Bindi, M., Brown, S., Camilloni, I. A., Diedhiou, A., Djalante, R., & Ebi, K. (2019). The human imperative of stabilizing global climate change at 1.5°C. *Science, 365*(6459). doi:10.1126/science.aaw6974

Hofstede, J. (2019a). Küstenschutz in Schleswig-Holstein: ein Überblick über die Strategien und Maßnahmen. *Die Küste, 87*. doi:10.18171/1.087103

Hofstede, J. (2019b). On the feasibility of managed retreat in the Wadden Sea of Schleswig-Holstein. Journal of Coastal Conservation, 23, 1069-1079. doi:10.1007/s11852-019-00714-x

Hofstede, J., & Stock, M. (2018). Climate Change adaptation in the Schleswig-Holstein sector of the Wadden Sea: An integrated state governmental strategy. *Journal of Coastal Conservation 22*, 22. doi:10.1007/s11852-016-0433-0

Högberg, P., Lundmark, T., & Kauppi, P. E. (2023). Smart forest management boosts both carbon storage and bioenergy. *Nature, 613*(7944), 437. doi:10.1038/d41586-023-00097-y

Holden, M. (2019). Bringing the Neighbourhood Into Urban Infill Development in the Interest of Well-Being. *International Journal of Community Well-Being, 1*, 137-155. doi:10.1007/s42413-018-0010-4

Holzhausen, J., & Grecksch, K. (2021). Historic narratives, myths and human behavior in times of climate change: A review from northern Europe's coastlands. *Wiley Interdisciplinary Reviews: Climate Change, 12*(5), e723. doi:10.1002/wcc.723

Hong, K. T., & Downes, N. K. (2023). Narratives of Women's Resilience to Flood Risks in Ho Chi Minh City, Vietnam. *Environment and Urbanization ASIA, 14*, 90-103. doi:10.1177/09754253231168693

Hosterman, H., & Joel, S. (2015). Economic costs and benefits of climate change impacts and adaptation to the Maldives tourism industry: increasing climate change resilience of Maldives through adaptation in the tourism Sector: Tourism Adaptation Project (TAP). In: Ministry of Tourism, Maldives.

HSE and BUE. (2015). *RISA Strukturplan Regenwasser 2030. Ergebnisbericht des Projektes RISA – RegenInfraStrukturAnpassung*. Hamburg Retrieved from https://www.risa-hamburg.de/downloads.html

Hulme, M. (2009). *Why we disagree about climate change: Understanding controversy, inaction and opportunity*: Cambridge University Press.

Hulme, M. (2021). *Climate Change* (1 ed.). London: Routledge.

Hunter, N. B., North, M. A., Roberts, D. C., & Slotow, R. (2020). A systematic map of responses to climate impacts in urban Africa. *Environmental Research Letters, 15*(10). doi:10.1088/1748-9326/ab9d00

HW. (2023). The RISA-Project – RainInfraStructureAdaption. Last accessed February 19, 2024, available at https://www.risa-hamburg.de/english.html

IAG-USP. (2023). *Estação Meteorológica do IAG-USP: Seção Técnica de Serviços Meteorológicos*. Retrieved from: http://estacao.iag.usp.br/seasons/index.php

IBGE. (2010). Localidades 2010. Last accessed June 12, 2024, available at https://www.ibge.gov.br/geociencias/organizacao-do-territorio/estrutura-territorial/27385-localidades.html

IBGE. (2022). População. Last accessed April 22, 2024, available at https://cidades.ibge.gov.br/brasil/sp/sao-paulo/panorama

IBGE. (2023). PIB dos municípios mostra que economia do país continuou a se desconcentrar em 2021. Last accessed March 6, 2024, available at https://agenciadenoticias.ibge.gov.br/agencia-noticias/2012-agencia-de-noticias/noticias/38683-pib-dos-municipios-mostra-que-economia-do-pais-continuou-a-se-desconcentrar-em-2021

IKM. (2023). Metropolregion Hamburg. Last accessed April 22, 2024, available at https://deutsche-metropolregionen.org/metropolregion/hamburg/

INMET. (2022). *Normais Climatológicas do Brasil*. Retrieved from: https://portal.inmet.gov.br/normais

IPCC. (2001). *Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change* [McCarthy, J.J., O.F. Canziani, N.A. Leary, D.J. Dokken, and K.S. White (eds.)]. Cambridge and New York: Cambridge University Press.

IPCC. (2013). Summary for Policymakers. In T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, & P. M. Midgley (Eds.), *Climate Change 2013: The Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 1-30). Cambridge and New York: Cambridge University Press.

IPCC. (2018). *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*. [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. Cambridge and New York: Cambridge University Press.

IPCC. (2019). *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*. [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. Cambridge and New York: Cambridge University Press.

IPCC. (2022). *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge and New York: Cambridge University Press.

Ishii, M., & Mori, N. (2020). d4PDF: large-ensemble and high-resolution climate simulations for global warming risk assessment. *Progress in Earth and Planetary Science, 7*(1), 58. doi:10.1186/s40645-020-00367-7

Jacobi, P. R., Torres, P., & Gresse, E. G. (2019). Governing Shallow Waters: SDG 6 and Water

Security in São Paulo. UNESCO i-WSSM, Daejeon: https://unesco-iwssm.org/board/select?bbsNo=0000000064&nttSn=35

Jacobi, P. R., & Trani, E. (2019). Planejando o futuro hoje: ODS 13, adaptação e mudanças climáticas em São Paulo. Last accessed April 22, 2024, available at https://repositorio.fgv.br/items/e9707cf2-d857-4003-8927-ed48b22ec813

Jantke, K., Hartmann, M. J., Rasche, L., Blanz, B., & Schneider, U. A. (2020). Agricultural Greenhouse Gas Emissions: Knowledge and Positions of German Farmers. *Land, 9*(5), 130. doi:10.3390/land9050130

Jordan, C., Visscher, J., & Schlurmann, T. (2021). Projected responses of tidal dynamics in the North Sea to sea-level rise and morphological changes in the Wadden Sea. *Frontiers in Marine Science, 8*, 685758. doi:10.3389/fmars.2021.685758

Jordan, P., Döring, M., Fröhle, P., & Ratter, B. M. W. (2023). Exploring past and present dynamics of coastal protection as possible signposts for the future? A case study on the Islands of Amrum and Föhr in the North Frisian Wadden Sea (GER). *Journal of Coastal Conservation, 27*(1), 2. doi:10.1007/s11852-022-00921-z

Jordan, P., Fröhle, P., & Manojlovic, N. (2019). *Maintenance of Flood Protection Infrastructure in the North Sea Region – An Analysis of Existing Maintenance Strategies*. Paper presented at the Proceedings of the Coastal Structures, Hanover, Germany, 30, Karlsruhe.

Jordan, P., & Fröhle, P. (2022). Bridging the gap between coastal engineering and nature conservation? A review of coastal ecosystems as Nature-based Solutions for coastal protection. *Journal of Coastal Conservation, 26*. doi:10.1007/s11852-021-00848-x

JSCE. (2022). Male' Seawall Project (Maldives). Japan Society of Civil Engineers, Tokyo: https://www.jsce.or.jp/e/archive/project/pj14.html

Juhola, S., Glaas, E., Linnér, B.-O., & Neset, T.-S. (2016). Redefining maladaptation. *Environmental Science & Policy, 55*, 135-140. doi:10.1016/j.envsci.2015.09.014

Karki, R., ul Hasson, S., Gerlitz, L., Schickhoff, U., Scholten, T., & Böhner, J. (2017). Quantifying the added value of convection-permitting climate simulations in complex terrain: a systematic evaluation of WRF over the Himalayas. *Earth System Dynamics Discussions, 8*, 507-528. doi:10.5194/esd-8-507-2017

Karki, R., ul Hasson, S., Gerlitz, L., Talchabhadel, R., Schickhoff, U., Scholten, T., & Böhner, J. (2020). Rising mean and extreme near-surface air temperature across Nepal. *International Journal of Climatology, 40*(4), 2445-2463. doi:10.1002/joc.6344

Kates, R. W., Travis, W. R., & Wilbanks, T. J. (2012). Transformational adaptation when incremental adaptations to climate change are insufficient. *Proceedings of the National Academy of Sciences, 109*(19), 7156-7161. doi:10.1073/pnas.1115521109

Katzschner, A., Waibel, M., Schwede, D., Katzschner, L., Schmidt, M., & Storch, H. (Eds.). (2016). *Sustainable Ho Chi Minh City: Climate Policies for Emerging Mega Cities*: Springer Publishing House.

Katzschner, L., & Burghardt, R. (2015). Urban climatic map studies in Vietnam: Ho Chi Minh City. In E. Ng & C. Ren (Eds.), *The Urban Climatic Map – A Methodology for Sustainable Urban Planning* (pp. 6). London: Routledge.

Kauppi, P. E., Stål, G., Arnesson-Ceder, L., Hallberg Sramek, I., Hoen, H. F., Svensson, A., Wernick, I. K., Högberg, P., Lundmark, T., & Nordin, A. (2022). Managing existing forests can mitigate climate change. *Forest Ecology and Management, 513*, 120186. doi:10.1016/j.foreco.2022.120186

Kench, P. S. (2012). Compromising Reef Island Shoreline Dynamics: Legacies of the Engineering Paradigm in the Maldives. In J. Cooper & O. Pilkey (Eds.), *Pitfalls of Shoreline Stabilization: Selected Case Studies* (pp. 165-186). Dordrecht: Springer.

Kench, P. S., Ford, M. R., & Owen, S. D. (2018). Patterns of island change and persistence offer alternate adaptation pathways for atoll nations. *Nature Communications, 9*. doi:10.1038/s41467-018-02954-1

Khadka, C., Aryal, K. P., Edwards-Jonášová, M., Upadhyaya, A., Dhungana, N., Cudlin, P., & Vacik, H. (2018). Evaluating participatory techniques for adaptation to climate change: Nepal case study. *Forest Policy and Economics, 97*, 73-82. doi:10.1016/j.forpol.2018.08.017

Kiesel, J., Lorenz, M., König, M., Gräwe, U., & Vafeidis, A. T. (2023). Regional assessment of extreme sea levels and associated coastal flooding along the German Baltic Sea coast. *Natural Hazards and Earth System Sciences, 23*(9), 2961-2985. doi:10.5194/nhess-23-2961-2023

Knottnerus, O. S. (2005). History of human settlement, cultural change and interference with the marine environment. *Helgoläander Meeresuntersuchungen, 59*(1), 2-8. doi:10.1007/s10152-004-0201-7

Kohler, M., Engels, A., Koury, A. P., & Zengerling, C. (2021). Thinking Urban Transformation through Elsewhere: A Conversation between Real-World Labs in São Paulo and Hamburg on Governance and Practical Action. *Sustainability, 13*(22), 12811. doi:10.3390/su132212811

Kothari, U., Arnall, A., & Azfa, A. (2023). Disaster mobilities, temporalities, and recovery: experiences of the tsunami in the Maldives. *Disasters, 47*(4), 1069-1089. doi:10.1111/disa.12578

Kottek, M., Grieser, J., Beck, C., Rudolf, B., & Rubel, F. (2006). World map of the Köppen-Geiger climate classification updated. *Meteorologische Zeitschrift, 15*(3). doi:10.1127/0941-2948/2006/0130

Krieger, D., Brune, S., Pieper, P., Weisse, R., & Baehr, J. (2022). Skillful decadal prediction of German Bight storm activity. *Natural Hazards and Earth System Sciences, 22*(12), 3993-4009. doi:10.5194/nhess-22-3993-2022

Krieger, D., Krueger, O., Feser, F., Weisse, R., Tinz, B., & von Storch, H. (2020). German Bight storm activity, 1897–2018. *International Journal of Climatology, 41*, E2159-E2177. doi:10.1002/joc.6837

Krueger, O., Feser, F., & Weisse, R. (2019). Northeast Atlantic storm activity and its uncertainty from the late nineteenth to the twenty-first century. *Journal of Climate, 32*(6), 1919-1931. doi:10.1175/JCLI-D-18-0505.1

Kulke, E. (2023). Sektoraler Wandel der Wirtschaft. In E. Kulke (Ed.), *Wirtschaftsgeographie Deutschlands* (pp. 3-15). Berlin, Heidelberg: Springer Spektrum.

Kunene Regional Council, Government of the Republic of Namibia (2015). Kunene Regional Development Profile 2015 – The ultimate frontier. Opuwo. Last accessed April 22, 2024, available at https://kunenerc.gov.na/documents/53359/0/Dev_profile.pdf/e20fcb44-46e3-effa-6344-2189605e1c7f

Küster, H. (2015). *Nordsee. Die Geschichte einer Landschaft. Kiel and Hamburg*. Kiel and Hamburg: Wachholtz Murmann Publishers.

Lan, T. H., Nguyen, T. V., & Nguyen, M. V. (2023). *Investing in climate resilience through inclusion of Natural-based Solutions in water and disaster management*. Paper presented at the Presentation during the Workshop "Climate Change", April 2023, German Vietnamese Science Day, Da Nang, Vietnam.

Lan, Y.-J., & Hsu, T.-W. (2021). Planning and Management of Coastal Buffer Zones in Taiwan. *Water, 13*(20). doi:10.3390/w13202925

Li, C., Held, H., Hokamp, S., & Marotzke, J. (2020). Optimal temperature overshoot profile found by limiting global sea level rise as a lower-cost climate target. *Science Advances, 6*(2). doi:10.1126/sciadv.aaw9490

Lin, T.-L., Liu, W.-H., Chang, Y., & Hsiao, S.-C. (2021). Capacity assessment of integrated coastal management for Taiwanese local government. *Marine Policy, 134*. doi:10.1016/j.marpol.2021.104769.

Liu, X., Meinke, I., & Weisse, R. (2022). Still normal? Near-real-time evaluation of storm surge events in the context of climate change. *Natural Hazards and Earth System Sciences, 22*(1), 97-116. doi:10.5194/nhess-22-97-2022

Lorenz, K., & Lal, R. (2016). Chapter Three – Environmental Impact of Organic Agriculture. In D. L. Sparks (Ed.), *Advances in Agronomy* (Vol. 139, pp. 99-152): Academic Press.

Lotter, D. W., Seidel, R., & Liebhardt, W. (2003). The performance of organic and conventional cropping systems in an extreme climate year. *American Journal of Alternative Agriculture, 18*(3), 146-154. doi:10.1079/AJAA200345

Lower Saxony State Chancellery (2016). State Chancellery of Lower Saxony. Home of Diversity. Niedersachsen. Klar. Last accessed November 23, 2023, available at https://www.niedersachsen.de/download/116564/Broschuere_Heimat_

Luu, D. (2023). Public awareness raising in Go Vap District, Ho Chi Minh City. Last accessed June 26, 2024, available at https://tuoitre.vn/quan-go-vap-tuyen-truyen-ung-pho-voi-bien-doi-khi-hau-20230517130633814.html

Lyra, A., Tavares, P., Chou, S. C., Sueiro, G., Dereczynski, C., Sondermann, M., Silva, A., Marengo, J., & Giarolla, A. (2018). Climate change projections over three metropolitan regions in Southeast Brazil using the non-hydrostatic Eta regional climate model at 5-km resolution. *Theoretical and Applied Climatology, 132*, 663-682. doi:10.1007/s00704-017-2067-z

Magnan, A. K., & Duvat, V. K. E. (2020). Towards adaptation pathways for atoll islands. Insights from the Maldives. *Regional Environmental Change, 20*(4), 119. doi:10.1007/s10113-020-01691-w

Magnan, A. K., Oppenheimer, M., Garschagen, M., Buchanan, M. K., Duvat, V. K. E., Forbes, D. L., Ford, J. D., Lambert, E., Petzold, J., Renaud, F. G., Sebesvari, Z., van de Wal, R. S. W., Hinkel, J., & Pörtner, H.-O. (2022). Sea level rise risks and societal adaptation benefits in low-lying coastal areas. *Scientific Reports, 12*(1), 10677. doi:10.1038/s41598-022-14303-w

Magnan, A. K., Schipper, E. L. F., Burkett, M., Bharwani, S., Burton, I., Eriksen, S., Gemenne, F., Schaar, J., & Ziervogel, G. (2016). Addressing the risk of maladaptation to climate change. *Wiley Interdisciplinary Reviews: Climate Change, 7*(5), 646-665. doi:10.1002/wcc.409

Malatesta, S., & Schmidt di Friedberg, M. (2017). Environmental policy and climate change vulnerability in the Maldives: From the 'lexicon of risk' to social response to change. *Island Studies Journal, 12*(1), 53-70. doi:10.24043/isj.5

Marengo, J. A., Ambrizzi, T., Alves, L. M., Barreto, N. J. C., Simões Reboita, M., & Ramos, A. M. (2020). Changing trends in rainfall extremes in the metropolitan area of São Paulo: causes and impacts. *Frontiers in Climate, 2*, 3. doi:10.3389/fclim.2020.00003

Martes, L., & Köhl, M. (2022). Improving the Contribution of Forests to Carbon Neutrality under Different Policies – A Case Study from the Hamburg Metropolitan Area. *Sustainability, 14*(4), 2088. doi:10.3390/su14042088

Martes, L., Köhl, M., Sillmann, J., & Pfleiderer, P. (2023, in print). Using climate envelopes and ESM simulations for modelling climate-change induced forest risks.

Mason, D., Iida, A., Watanabe, S., Jackson, L. P., & Yokohari, M. (2020). How urbanization enhanced exposure to climate risks in the Pacific: A case study in the Republic of Palau. *Environmental Research Letters, 15*(11), 114007. doi:10.1088/1748-9326/abb9dc

Masselink, G., Beetham, E., & Kench, P. (2020). Coral reef islands can accrete vertically in response to sea level rise. *Science Advances, 6*(24), eaay3656. doi:10.1126/sciadv.aay3656

Massey, E., & Huitema, D. (2013). The emergence of climate change adaptation as a policy field: the case of England. *Regional Environmental Change, 13*, 341-352. doi:10.1007/s10113-012-0341-2

McNamara, K. E., Clissold, R., Piggott-McKellar, A., Buggy, L., & Azfa, A. (2019). What is shaping vulnerability to climate change? The case of Laamu Atoll, Maldives. *Island Studies Journal, 14*(1), 81-100. doi:10.24043/isj.67

MEE. (2015a). *Guidance manual for climate risk resilient coastal protection in the Maldives*. Malé, Maldives: Ministry of Environment & Energy Retrieved from https://www.environment.gov.mv/v2/wp-content/files/publications/20211201-pub-manual-coastal-protection.pdf

MEE. (2015b). *Maldives Climate Change Policy Framework*. Malé, Maldives: Ministry of Environment & Energy Retrieved from http://www.environment.gov.mv/v2/download/418/.

MEE. (2017). *State of the Environment 2016*. Malé, Maldives: Ministry of Environment & Energy Retrieved from http://www.environment.gov.mv/v2/en/download/4270

Mees, H. L. P., Driessen, P. P. J., & Runhaar, H. A. C. (2014). Legitimate adaptive flood risk governance beyond the dikes: the cases of Hamburg, Helsinki and Rotterdam. *Regional Environmental Change, 14*, 671-682. doi:10.1007/s10113-013-0527-2

MEEW. (2007). *National Adaptation Programme of Action: The Republic of Maldives*. Malé, Maldives: Ministry of Environment, Energy and Water Retrieved from https://unfccc.int/resource/docs/napa/mdv01.pdf

Meinke, I., Maneke, M., Riecke, W., & Tinz, B. (2014). Norddeutscher Klimamonitor –Klimazustand und Klimaentwicklung in Norddeutschland innerhalb der letzten 60 Jahre (1951–2010). *DMG Mitt, 1*, 2-11. Retrieved from https://www.hzg.de/imperia/md/content/klimabuero/norddeutscher_klimamonitor.pdf

Meinke, I., Rechid, D., Tinz, B., Maneke, M., Lefebvre, C., & Isokeit, E. (2018). Klima der Region–Zustand, bisherige Entwicklung und mögliche Änderungen bis 2100. In H. von Storch, I. Meinke, & M. Claußen (Eds.), *Hamburger Klimabericht–Wissen über Klima, Klimawandel und Auswirkungen in Hamburg und Norddeutschland* (pp. 16-34).

Meinke, I. (2020). Norddeutschland im Klimawandel – Was wissen wir über Klima, Klimawandel und Auswirkungen in Norddeutschland. Helmholtz-Zentrum Geesthacht, Geesthacht: https://www.hereon.de/imperia/md/content/klimabuero/klimaberichte/hzg_norddeutschland-im-klimawandel_e-book.pdf

MELUND. (2022). *Generalplan Küstenschutz des Landes Schleswig-Holstein*. Ministerium für Energiewende, Landwirtschaft, Umwelt, Natur und Digitalisierung des Landes Schleswig-Holstein (MELUND), Kiel.

MELUR. (2014). *Bericht der Arbeitsgruppe Halligen 2050. Möglichkeiten zur langfristigen Erhaltung der Halligen im Klimawandel*. . Ministerium für Energiewende, Landwirtschaft, Umwelt und ländliche Räume des Landes Schleswig-Holstein, Kiel.

MELUR. (2015). *Strategie für das Wattenmeer 2100*. Ministerium für Energiewende, Landwirtschaft, Umwelt und ländliche Räume des Landes Schleswig-Holstein, Kiel.

Messner, D. (2015). A social contract for low carbon and sustainable development: Reflections on non-linear dynamics of social realignments and technological innovations in transformation processes. *Technological Forecasting and Social Change, 98*, 260-270. doi:10.1016/j.techfore.2015.05.013

MHE. (2011). Survey of climate change adaptation measures in Maldives. Ministry of Housing and Environment, Male, Maldives: www.undp.org/maldives/publications/survey-climate-change-adaptation-measures-maldives

Ministry of Environment, Forestry and Tourism,. (2021). Namibia's Climate Change Adaptation Communication to the United Nations Framework Convention on Climate Change (UNFCCC). Government of Namibia: https://unfccc.int/sites/default/files/resource/namibia-adapta tion-communication-to-the-unfccc.pdf

Ministry of Foreign Affairs. (2024). Government Portal of the Republic of China (Taiwan). Last accessed February 20, 2024, available at https://www.taiwan.gov.tw/about.php

MoE. (2010). *National Adaptation Program of Action*. Kathmandu, Nepal: Government of Nepal, Ministry of Environment. Last accessed July 5, 2024, available at https://unfccc.int/resource/docs/napa/npl01.pdf.

MoE. (2011). *Local adaptation plan of action (LAPA) framework*. Kathmandu: Ministry of Environment (MoE), Government of Nepal

MoITFE. (2019). *Provincial Adaptation Program of Action (PAPA) to Climate Change (draft)*. Pokhara: Ministry of Industry, Tourism, Forest and Environment (MoITFE), Gandaki Province, Nepal

Morais, N. L. d. (2019). *Capacidade adaptativa específica do município de São Paulo às mudanças climáticas: uma análise a partir do mapeamento das áreas de risco, sistema de alerta e planos de contingência de Defesa Civil*. Universidade de São Paulo,

Moreira, F. d. A., Dalla Fontana, M., Bertolini, A. M., Sepe, P. M., Malheiros, T. F., & Di Giulio, G. M. (2022). Urban Living Labs and the Water-Energy-Food Nexus: Experiences from the GLOCULL Project in São Paulo, Brazil. In *Water-Energy-Food Nexus and Climate Change in Cities* (pp. 275-287): Springer.

MoT. (2015). *Economic Costs and Benefits of Climate Change Impacts and Adaptation to the Maldives Tourism Industry*. Malé, Maldives: Ministry of Tourism, Retrieved from https://archive.tour ism.gov.mv/downloads/publicaltions/Eco nomic.pdf

Mühr, B., Eisenstein, L., Pinto, J. G., Knippertz, P., Mohr, S., & Kunz, M. (2022). CEDIM Forensic Disaster Analysis Group (FDA): Winter storm series: Ylenia, Zeynep, Antonia (int: Dudley, Eunice, Franklin)-February 2022 (NW & Central Europe). Center for Disaster Management and Risk Reduction Technology,

Müller, J.-M., & Gönnert, G. (2018). Aktuelle Entwicklungen im Hamburger Küstenschutz. In *Die Küste* (Vol. 86). Karlsruhe: Bundesanstalt für Wasserbau.

Mulligan, M. J. (2014). Towards a more grounded and dynamic sociology of climate-change adaptation. *Environmental Values, 23*(2), 165-180. doi: 10.3197/096327114X13894344179167

Municipality of São Paulo (2009). Lei 14.933, de 05 de junho de 2009. Institui a Política de Mudança do Clima no Município de São Paulo. São Paulo, SP, Brazil. Last accessed April 22, 2024, available at http://legislacao.prefeitura.sp.gov.br/leis/lei-14933-de-05-de-junho-de-2009.

Municipality of São Paulo. (2011). Guidelines for the Action Plan of the City of São Paulo for mitigation and adaptation to climate change. The Municipal Committee on Climate Change and Eco economy and the Working Groups for Transportation, Energy, Construction, Land Use, Solid Waste and Health, São Paulo, SP, Brazil. Last accessed April 22, 2024, available at https://cetesb.sp.gov.br/inventario-gee-sp/wp-con tent/uploads/sites/34/2014/04/saopaulo_dire trizes.pdf

Municipality of São Paulo. (2014). Lei nº 16.050, de 31 de julho de 2014. Aprova a Política de Desenvolvimento Urbano e o Plano Diretor Estratégico do Município de São Paulo e revoga a Lei nº 13.430/2002, 2014. São Paulo, SP, Brazil. Last accessed April 22, 2024, available at https://legislacao.prefeitura.sp.gov.br/leis/lei-16050-de-31-de-julho-de-2014.

Municipality of São Paulo. (2015). PlanMob/SP 2015. Plano de Mobilidade de São Paulo. Secretaria Municipal de Transportes: São Paulo Transporte S. A. (SPTrans), Companhia de Engenharia de Tráfego (CET). Municipality of São Paulo., São Paulo, SP, Brazil. Last accessed April 22, 2024, available at https://www.prefeitura.sp.gov.br/cidade/secretarias/upload/chamadas/plan mobsp_v072__1455546429.pdf

Municipality of São Paulo. (2016). Lei nº 16.402, de 22 de março de 2016. Disciplina o parcelamento, o uso e a ocupação do solo no município de São Paulo, de acordo com a Lei nº 16.050, de 31 de julho de 2014 – Plano Diretor Estratégico (PDE). São Paulo, SP, Brazil. Last accessed April 22, 2024, available at https://legislacao.prefeitura.sp.gov.br/leis/lei-16402-de-22-de-marco-de-2016.

Municipality of São Paulo. (2017). PMMA. Plano Municipal de Conservação e Recuperação da Mata Atlântica. Last accessed April 22, 2024, available at https://www.prefeitura.sp.gov.br/cidade/secretarias/meio_ambiente/pmma/index.php?p=191882

Municipality of São Paulo. (2018). Lei Nº 16.802 de 18 de Janeiro De 2018. Dá nova redação ao art. 50 da Lei nº 14.933/2009, que dispõe sobre o uso de fontes motrizes de energia menos poluentes e menos geradoras de gases do efeito estufa na frota de transporte coletivo urbano do Município de São Paulo e dá outras providências. Last accessed April 22, 2024, available at https://legislacao.prefeitura.sp.gov.br/leis/lei-16802-de-18-de-janeiro-de-2018.

Municipality of São Paulo. (2020a). Plano de Ação Climática do Município de São Paulo 2020-2050 (PlanClima SP). São Paulo, SP, Brazil. Last accessed April 22, 2024, available at https://www.prefeitura.sp.gov.br/cidade/secretarias/upload/governo/secretaria_executiva_de_mudancas_climaticas/arquivos/planclimasp/PlanClimaSP_BaixaResolucao.pdf

Municipality of São Paulo. (2020b). Plano Municipal de Conservação e Recuperação de Áreas Prestadoras de Serviços Ambientais (PMSA). São Paulo, SP, Brazil. Last accessed April 22, 2024, available at https://ligueospontos.prefeitura.sp.gov.br/wp-content/uploads/2020/08/PMSA-web.pdf .

Municipality of São Paulo. (2020c). Plano Municipal de Arborização Urbana (PMAU). São Paulo, SP, Brazil. Last accessed April 22, 2024, available at https://www.prefeitura.sp.gov.br/cidade/secretarias/upload/meio_ambiente/arquivos/pmau/PMAU_texto_final.pdf

Municipality of São Paulo. (2021). PlanClima SP – Relatório de acompanhamento das ações das secretarias. Last accessed April 22, 2024, available at https://www.prefeitura.sp.gov.br/cidade/secretarias/upload/governo/secretaria_executiva_de_mudancas_climaticas/arquivos/planclimasp/Relatorio_de_acompanhamento.pdf

Municipality of São Paulo. (2022). Plano Municipal de Áreas Protegidas, Áreas Verdes e Espaços Livres (PLANPAVEL). São Paulo, SP, Brazil. Last accessed April 22, 2024, available at https://www.prefeitura.sp.gov.br/cidade/secretarias/upload/meio_ambiente/arquivos/Planpavel/PLANPAVEL-VERSAO-COMPLETA.pdf .

Municipality of São Paulo. (2023). Informes Urbanos: Áreas de risco geológico e o Plano Diretor Estratégico do Município de São Paulo. Cidade de São Paulo Urbanismmo e Licenciamento, São Paulo, SP, Brazil. Last accessed April 22, 2024, available at https://gestaourbana.prefeitura.sp.gov.br/wp-content/uploads/2023/02/56_IU_AREAS-DE-RISCO.pdf .

Mycoo, M., Wairiu, M., Campbell, D., Duvat, V., Golbuu, Y., Maharaj, S., Nalau, J., Nunn, P., Pinnegar, J., & Warrick, O. (2022). Small Islands. Cambridge University Press, Cambridge, UK and New York, NY, US: https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_Chapter15.pdf

Nagel, R., Meyer, P., Blaschke, M., & Feldmann, E. (2023). A meaningful contribution to Climate-Smart Forestry? An evaluation of temporal trends in the carbon balance of unmanaged forests in Germany. *Frontiers in Forests and Global Change, 6*. doi:10.3389/ffgc.2023.1099558

Nalau, J., & Verrall, B. (2021). Mapping the evolution and current trends in climate change adaptation science. *Climate Risk Management, 32*, 100290. doi:10.1016/j.crm.2021.100290

National Research Council. (1998). *People and Pixels: Linking Remote Sensing and Social Science*. Washington, DC: The National Academies Press.

National Science and Technology Council and Ministry of Environment. (2024). National Science Report on Climate Change 2024: Phenomenon, Impacts and Adaptation (Taiwan). Last access June 2, 2024, available at https://www.moenv.gov.tw/File/ECB8550B325D0BDB

Neder, E. A., de Araújo Moreira, F., Dalla Fontana, M., Torres, R. R., Lapola, D. M., Vasconcellos, M. d. P. C., Bedran-Martins, A. M. B., Philippi Junior, A., Lemos, M. C., & Di Giulio, G. M. (2021). Urban adaptation index: assessing cities readiness to deal with climate change. *Climatic Change, 166*(1-2), 16. doi:10.1007/s10584-021-03113-0

Neumann, G. (2018). Hamburg- Location, Size and Population. Last accessed November 22, 2023, available at https://marketing.hamburg.de/facts-and-figures.html

Nguyen, T. T. T., & Waibel, M. (2021). Urban Heat Islands and Implications for Vietnam. Country Report Vietnam. In *Environmental Policy in Vietnam* (Vol. 2, pp. 117-127). Hanoi, Vietnam: Thanh Nien Publishing House.

Nguyen, T. T. T., & Waibel, M. (2022). *Implementation Guideline: Green walls and green roofs: Urban Ecosystem-Based Adaptation to Climate Change in Viet Nam*: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

Nobre, C. A., & Young, A. F. (Eds.). (2011). *Vulnerabilidades das megacidades brasileiras às mudanças climáticas: região metropolitana de São Paulo: relatório final*: Instituto Nacional de Pesquisas Espaciais (INPE).

O’Brien, K. (2012). Global environmental change II: From adaptation to deliberate transformation. *Progress in human geography, 36*(5), 667-676. doi:10.1177/0309132511425767

Olonscheck, D., Suarez-Gutierrez, L., Milinski, S., Beobide-Arsuaga, G., Baehr, J., Fröb, F., Hellmich, L., Ilyina, T., Kadow, C., Krieger, D., Li, H., Marotzke, J., Plésiat, É., Schupfner, M., Wachsmann, F., Wieners, K.-H., & Brune, S. (2023). The new Max Planck Institute Grand Ensemble with CMIP6 forcing and high-frequency model output. Preprints, https://essopenarchive.org/users/612703/articles/640470-the-new-max-planck-institute-grand-ensemble-with-cmip6-forcing-and-high-frequency-model-output?commit=96403bca5b56fa6a84d539be0f31ff2a3d4fe3ab

Oppenheimer, M., Glavovic, B., Hinkel, J., van de Wal, R., Magnan, A. K., Abd-Elgawad, A., Cai, R., Cifuentes-Jara, M., Deconto, R. M., Ghosh, T., Hay, J., Isla, F., Marzeion, B., Meyssignac, B., & Sebesvari, Z. (2019). Sea Level Rise and Implications for Low Lying Islands, Coasts and Communities. https://www.ipcc.ch/srocc/chapter/chapter-4-sea-level-rise-and-implications-for-low-lying-islands-coasts-and-communities/

Ostermann, U. (2019). Wasserhaushalt in Nordostniedersachsen durch Wassernutzung und -management ausgleichen. *Wasser und Abfall*, 21, 39 – 46.

Otto, H. J. (1994). *Waldökologie*. Stuttgart: Ulmer.

Paech, F. (2008). Die ganzen menschlichen Geschichten – Die Hamburger Sturmflut von 1962 im Bewusstsein der Wilhelmsburger Bevölkerung. In Geschichtswerkstatt Wilhelmsburg Honigfabrik eV & Museum Elbinsel Wilhelmsburg eV (Eds.), *Wilhelmsburg – Hamburgs große Elbinsel* (pp. 161-173). Hamburg.

Pagnone, A., Gresse, E. G., López-Rivera, A., Wilkens, J., Engels, A., & Marotzke, J. (2023). Plausibility of attaining the Paris Agreement temperature goals. In A. Engels, J. Marotzke, E. G. Gresse, A. López-Rivera, A. Pagnone, & J. Wilkens (Eds.), *Hamburg Climate Futures Outlook: The plausibility of a 1.5°C limit to global warming — social drivers and physical processes* (pp. 33-50). Hamburg, Germany: Cluster of Excellence Climate, Climatic Change, and Society (CLICCS). doi:10.25592/uhhfdm.11230

Palanisamy, H., Cazenave, A., Meyssignac, B., Soudarin, L., Wöppelmann, G., & Becker, M. (2014). Regional sea level variability, total relative sea level rise and its impacts on islands and coastal zones of Indian Ocean over the last sixty years. *Global and Planetary Change, 116*, 54-67. doi:10.1016/j.gloplacha.2014.02.001

PBMC. (2014). Base científica das mudanças climáticas. Contribuição do Grupo de Trabalho 1 do Painel Brasileiro de Mudanças Climáticas ao Primeiro Relatório da Avaliação Nacional sobre Mudanças Climáticas. Universidade Federal do Rio de Janeiro, Rio de Janeiro, RJ, Brasil: http://pbmc.coppe.ufrj.br/documentos/RAN1_completo_vol1.pdf

Perrings, C. (2006). Resilience and sustainable development. *Environment and Development economics, 11*(4), 417-427. doi:10.1017/S1355770X06003020

Petzold, J., Hawxwell, T., Jantke, K., Gresse, E. G., Mirbach, C., Ajibade, I., Bhadwal, S., Bowen, K., Fischer, A. P., Joe, E. T., Kirchhoff, C. J., Mach, K. J., Reckien, D., Segnon, A. C., Singh, C., Ulibarri, N., Campbell, D., Cremin, E., Färber, L., Hegde, G., Jeong, J., Nunbogu, A. M., Pradhan, H. K., Schröder, L. S., Shah, M. A. R., Reese, P., Sultana, F., Tello, C., Xu, J., The Global Adaptation Mapping Initiative Team, & Garschagen, M. (2023a). A global assessment of actors and their roles in climate change adaptation. *Nature Climate Change, 13*(11), 1250-1257. doi:10.1038/s41558-023-01824-z

Petzold, J., Joe, E. T., Kelman, I., Magnan, A. K., Mirbach, C., Nagle Alverio, G., Nunn, P. D., Ratter, B. M. W., & The Global Adaptation Mapping Initiative Team. (2023b). Between tinkering and transformation: A contemporary appraisal of climate change adaptation research on the world's islands. *Frontiers in Climate, 4*. doi:10.3389/fclim.2022.1072231

Petzold, J., Wiener, A., Neuburger, M., Wilkens, J., Datchoua-Tirvaudey, A., Schnegg, M., Notz, D. P., Gresse, E. G., Scheffran, J., Lüdemann, J., Schmitt, T., & Singer, K. (2021). Diverse ways of knowing in a changing climate (Box 3). In D. Stammer, A. Engels, J. Marotzke, E. G. Gresse, C. Hedemann, & J. Petzold (Eds.), *Hamburg Climate Futures Outlook: Assessing the plausibility of deep decarbonization by 2050* (pp. 51). Hamburg, Germany: Cluster of Excellence Climate, Climatic Change, and Society (CLICCS). doi:10.25592/uhhfdm.9104

PNUD. (2013). O Índice de Desenvolvimento Humano Municipal Brasileiro. Programa das Nações Unidas para o Desenvolvimento (PNUD) Brasília, Brasilia, DF: https://repositorio.ipea.gov.br/handle/11058/2375

Poschlod, B., & Ludwig, R. (2021). Internal variability and temperature scaling of future sub-daily rainfall return levels over Europe. *Environmental Research Letters, 16*(6), 064097. doi:10.1088/1748-9326/ac0849

Puig, D. (2022). Loss and damage in the global stocktake. *Climate Policy, 22*(2), 175-183. doi:10.1080/14693062.2021.2023452

Qi-Bin, Z., & Ouya, F. (2020). Tree rings circle an abrupt shift in climate. *Science, 370*(6520), 1037-1038. doi:10.1126/science.abf1700

Quante, M., & Colijn, F. (2016). *North Sea region climate change assessment*: Springer Nature.

Ranasinghe, R., Ruane, A. C., Vautard, R., Arnell, N., Coppola, E., Cruz, F. A., Dessai, S., Saiful Islam, A., Rahimi, M., & Carrascal, D. R. (2021). Climate change information for regional impact and for risk assessment. doi:10.1017/9781009157896.014

Ratter, B., & Gee, K. (2012). Heimat: A German concept of regional perception and identity as a basis for coastal management in the Wadden Sea. *Ocean & Coastal Management, 68*, 127-137. doi:10.1016/j.ocecoaman.2012.04.013

Ratter, B., & Hennig, A. (2020). Klimawandel und die Folgen – Lokale Herausforderungen auf den Malediven zwischen globaler, regionaler und nationaler Verflechtung. *Geographische Rundschau*(4), 22-27.

Ratter, B., Hennig, A., & Zahid. (2019). Challenges for shared responsibility – Political and social framing of coastal protection transformation in the Maldives. *Die Erde, 150*(3), 169-183. doi:10.12854/erde-2019-426

Ratter, B., & Scheunpflug, L. (2023). Risikobewusstsein Hamburger Bürger*Innen für den Klimawandel 2023. Helmholtz-Zentrum Hereon, https://hereon.de/imperia/md/images/hzg/institut_fuer_kuestenforschung/kso/risikobewusstsein_in_hamburg_2023_ratter-scheunpflug-hereon_vfinal.pdf

Reise, K. (2015). *Kurswechsel Küste. Was tun, wenn die Nordsee steigt?* Kiel and Hamburg: Wachholz.

Restemeyer, B., Woltjer, J., & van den Brink, M. (2015). A strategy-based framework for assessing the flood resilience of cities–A Hamburg case study. *Planning Theory & Practice, 16*(1), 45-62. doi:10.1080/14649357.2014.1000950

Rheinheimer, M. (2003). Mythos Sturmflut. Der Kampf gegen das Meer und die Suche nach Identität, in: Demokratische Geschichte. *Jahrbuch für Schleswig-Holstein, 18*, 9-58.

Rieken, B. (2005). *„Nordsee ist Mordsee". Sturmfluten und ihre Bedeutung für die Mentalitätsgeschichte der Friesen. Münster.* Münster: Waxmann.

RNSP – Rede Nossa São Paulo. (2022). Mapa da Desigualdade 2022. Rede Nossa São Paulo (RNSP), https://www.nossasaopaulo.org.br/wp-content/uploads/2022/11/Mapa-da-Desigualdade-2022_Tabelas.pdf .

Robinson, J. J. (2015). *The Maldives: Islamic Republic, Tropical Autocracy*. London: Hurst.

Rolim, G. d. S., Camargo, M. B. P. d., Lania, D. G., & Moraes, J. F. L. d. (2007). Climatic classification of Köppen and Thornthwaite sistems and their applicability in the determination of agroclimatic zonning for the state of São Paulo, Brazil. *Bragantia, 66*, 711-720. doi:10.1590/S0006-87052007000400022

Roncancio, D. J., & Nardocci, A. C. (2016). Social vulnerability to natural hazards in São Paulo, Brazil. *Natural Hazards, 84*, 1367-1383. doi:10.1007/s11069-016-2491-x

Runhaar, H., Wilk, B., Persson, Å., Uittenbroek, C., & Wamsler, C. (2018). Mainstreaming climate adaptation: taking stock about "what works" from empirical research worldwide. *Regional Environmental Change, 18*, 1201-1210. doi:10.1007/s10113-017-1259-5

Ryan, D. (2015). From commitment to action: a literature review on climate policy implementation at city level. *Climatic Change, 131*(4), 519-529. doi:10.1007/s10584-015-1402-6

Ryan, E. J., Hanmer, K., & Kench, P. S. (2019). Massive corals maintain a positive carbonate budget of a Maldivian upper reef platform despite major bleaching event. *Scientific reports, 9*(1), 6515. doi:10.1038/s41598-019-42985-2

Salomaa, A., & Juhola, S. (2020). How to assess sustainability transformations: a review. *Global Sustainability, 3*, e24. doi:10.1017/sus.2020.17

Saunders, D. (2023, 15 April 2023). The Vietnamese Climate Trap: Climate change is displacing a million farmers in Vietnam's Mekong Delta – but for most, migration is not an option. *The Globe and Mail*. Retrieved from https://www.theglobeandmail.com/opinion/article-vietnam-climate-migrants-crisis/

Scheiber, L., David, C., G., Jalloul, M. H., Visscher, J., Nguyen, H. Q., Leitold, R., Revilla-Diez, J., & Schlurmann, T. (2023). Low-regret climate change adaptation in coastal megacities – evaluating large-scale flood protection and small-scale rainwater detention measures for Ho Chi Minh City, Vietnam. *NHESS, 23*, 2333-2347. doi:10.5194/nhess-23-2333-2023

Schickhoff, U., & Eschenbach, A. (2018). Terrestrische und semiterrestrische Ökosysteme. In H. von Storch, I. Meinke, & M. Claußen (Eds.), *Hamburger Klimabericht – Wissen über Klima, Klimawandel und Auswirkungen in Hamburg und Norddeutschland* (pp. 109-145). Berlin, Heidelberg: Springer Berlin Heidelberg.

Schild, A. (2008). ICIMOD's position on climate change and mountain systems. *Mountain Research and Development, 28*(3), 328-331. doi:10.1659/mrd.mp009

Schild, A., & Sharma, E. (2011). Sustainable mountain development revisited. *Mountain Research and Development, 31*(3), 237-241. doi:10.1659/MRD-JOURNAL-D-11-00069.1

Schipper, E., & F., L. (2020). Maladaptation: when adaptation to climate change goes very wrong. *One Earth, 3*(4), 409-414. doi:10.1016/j.oneear.2020.09.014

Schlünzen, K. H., Hoffmann, P., Rosenhagen, G., & Riecke, W. (2010). Long-term changes and regional differences in temperature and precipitation in the metropolitan area of Hamburg. *International Journal of Climatology, 30*(8), 1121-1136. doi:10.1002/joc.1968

Schlünzen, K. H., Riecke, W., Bechtel, B., Boettcher, M., Buchholz, S., Grawe, D., Hoffmann, P., Petrik, R., Schoetter, R., Trusilova, K., & Wiesner, S. (2018). Stadtklima in Hamburg. In H. von Storch, I. Meinke, & M. Claußen (Eds.), *Hamburger Klimabericht – Wissen über Klima, Klimawandel und Auswirkungen in Hamburg und Norddeutschland* (pp. 37-53). Berlin, Heidelberg: Springer Berlin Heidelberg.

Schmidt, L., Feital, M., Cortekar, J., di Giulio, G., & Engels, A. (2024). Understanding the science-policy interface in urban climate governance from a co-production perspective: Insights from the cases of Hamburg and São Paulo, accepted for publication in Environmental Science and Policy. *Environmental Science & Policy, 156*, 103750. doi:10.1016/j.envsci.2024.103750

Schnegg, M. (2018). Institutional Multiplexity: Social Networks and Community-Based Natural Resource Management. *Sustainability Science, 13*(4), 1017-1030. doi:10.1007/s11625-018-0549-2

Schnegg, M. (2021a). What Does the Situation Say? Theorizing Multiple Understandings of Climate Change. *Ethos, 49*(2), 194-215. doi:10.1111/etho.12307

Schnegg, M. (2021b). Ontologies of Climate Change: Reconciling Indigenous and Scientific Explanations for the Lack of Rain in Namibia. *American Ethnologist, 48*(2), 260-273. doi:10.1111/amet.13028

Schnegg, M. (2023a). Die Sorgen um das Klima von morgen. In M. Bitzer, I. Bosbach, L. Brand, J. F. Burow, C. Ehrens, M. S. Hoffmann, J. John, O. Kedenburg, J. Sellig, L. Stiller, A. Henkel, I. Karle, G. Lindemann, & M. Werner (Eds.), *Zeit und Sorge*. Baden-Baden: Nomos Verlagsgesellschaft mbH & Co. KG.

Schnegg, M. (2023b). There Was No Future in the Past: Time and the Environment in Rural Namibia. *HAU: Journal of Ethnographic Theory*. doi:10.1086/724733

Schnegg, M., & Bollig, M. (2016). Institutions Put to the Test: Community-based Water Management in Namibia During a Drought. *Journal of Arid Environments, 124,* 62-71. doi:10.1016/j.jaridenv.2015.07.009

Schnegg, M., & Breyer, T. (2022). Empathy Beyond the Human. The Social Construction of a Multispecies World. *Ethnos*, 1-22. doi:10.1080/00141844.2022.2153153

Schnegg, M., & Kiaka, R. D. (2018). Subsidized Elephants: Community-based Resource Governance and Environmental (In)justice in Namibia. *Geoforum, 93*, 105-115. doi:10.1016/j.geoforum.2018.05.010

Schnegg, M., O'Brian, C. I., & Sievert, I. J. (2021). It's Our Fault: A Global Comparison of Different Ways of Explaining Climate Change. *Human Ecology, 49*(3), 327-339. doi:10.1007/s10745-021-00229-w

Schnegg, M., Pauli, J., & Greiner, C. (2013). Pastoral Belonging: Causes and Consequences of Part-time Pastoralism in Northwestern Namibia. In M. Bollig, M. Schnegg, & H.-P. Wotzka (Eds.), *Pastoralism in Africa: Past, Present and Future* (pp. 341-362). Oxford: Berghahn.

Schneider, U. A., Rasche, L., & Jantke, K. (2019). Farm-level digital monitoring of greenhouse gas emissions from livestock systems could facilitate control, optimisation and labelling. *Landbauforschung-Journal of Sustainable and Organic Agricultural Systems, 69*(1), 9-12. doi:10.3220/lbf1580734769000

Schreuder, R., & de Visser, C. L. M. (2014). EIP-AGRI Focus Group; Protein Crops. EIP-AGRI, https://library.wur.nl/WebQuery/wurpubs/456350

Schubert, D. (2020). Spatial Restructuring of Port Cities: Periods from Inclusion to Fragmentation and Re-integration of City and Port in Hamburg. In A. Carpenter & R. Lozano (Eds.), *European Port Cities in Transition: Moving Towards More Sustainable Sea Transport Hubs* (pp. 109-126). Cham: Springer International Publishing.

Schwede, D., Waibel, M., Hesse, C., & Nhien, N. T. (2016). Promoting climate adapted housing and energy efficient buildings in Vietnam: chances and challenges. In A. Katzschner, M. Waibel, D. Schwede, L. Katzschner, M. Schmidt, & H. Storch (Eds.), *Sustainable Ho Chi Minh City: Climate Policies for Emerging Mega Cities* (pp. 239-258): Springer Publishing House.

SEADE. (2023a). Produtos SEADE: População urbana e rural. Fundação SEADE – Sistema Estadual de Análise de Dados (SEADE), São Paulo, SP, Brazil.: https://populacao.seade.gov.br/populacao-urbana-e-rural/ .

SEADE. (2023b). Produtos SEADE: PIB Municipal – São Paulo. Fundação SEADE – Sistema Estadual de Análise de Dados (SEADE), São Paulo, SP, Brazil.: https://pib.seade.gov.br/municipal/.

Seneviratne, S. I., Zhang, X., Adnan, M., Badi, W., Dereczynski, C., Di Luca, A., Ghosh, S., Iskandar, I., Kossin, J., Lewis, S., Otto, F., Pinto, I., Satoh, M., Vicente-Serrano, S. M., Wehner, M., & Zhou, B. (2021). Weather and Climate Extreme Events in a Changing Climate. In V. Masson-Delmotte, P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, & B. Zhou (Eds.), *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 1513–1766). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Senf, C., Buras, A., Zang, C. S., Rammig, A., & Seidl, R. (2020). Excess forest mortality is consistently linked to drought across Europe. *Nature Communications, 11*(1), 6200. doi:10.1038/s41467-020-19924-1

Senf, C., Seidl, R., & Hostert, P. (2017). Remote sensing of forest insect disturbances: Current state and future directions. *International Journal of Applied Earth Observation and Geoinformation, 60*, 49-60. doi:10.1016/j.jag.2017.04.004

Setzer, J. (2009). Subnational and *transnational climate change governance: Evidence from the state and city of São Paulo, Brazil*. Paper presented at the Fifth urban research symposium, cities and climate change: Responding to an urgent agenda.

Setzer, J., de Macedo, L. V., & Rei, F. (2015). Combining local and transnational action in the adoption and implementation of climate policies in the city of São Paulo. In *The Urban Climate Challenge* (pp. 101-118): Routledge.

Shakeela, A., & Becken, S. (2015). Understanding tourism leaders' perceptions of risks from climate change: an assessment of policy-making processes in the Maldives using the social amplification of risk framework (SARF). *Journal of Sustainable Tourism, 23*(1), 65-84. doi:10.1080/09669582.2014.918135

Shih, Y.-C. (2017). Coastal Management and Implementation in Taiwan. *Journal of Coastal Zone Management, 19*(4), 2473–3350. doi:10.4172/2473-3350.1000437

Souza, M. A. A. d. (2004). Território e lugar na metrópole: revisitando São Paulo. In A. F. A. Carlos (Ed.), *Geografias de São Paulo: a metrópole do século xxi* (Vol. 2, pp. 21-50). São Paulo: Contexto.

Stadelmann, R. (2008). *Den Fluten Grenzen setzen. Schleswig-Holsteins Küstenschutz; Westküste und Elbe* (Vol. 1). Husum: Husum Verlagshaus.

Stammer, D., Engels, A., Marotzke, J., Gresse, E. G., Hedemann, C., & Petzold, J. (Eds.). (2021). *Hamburg Climate Futures Outlook: Assessing the plausibility of deep decarbonization by 2050*. Hamburg, Germany: Cluster of Excellence Climate, Climatic Change, and Society (CLICCS). doi:10.25592/uhhfdm.9104

State of São Paulo (2009). Lei 13.798 de 09 de novembro de 2009 Institui a Política Estadual de Mudanças Climáticas – PEMC. São Paulo, SP, Brazil. Last accessed April 22, 2024, available at https://www.al.sp.gov.br/repositorio/legislacao/lei/2009/lei-13798-09.11.2009.html.

Statistik Nord. (2022). Bevölkerung insgesamt Nordfriesland. Tabelle aus Freier Datenauswahl für Schleswig-Holstein. Last accessed April 22, 2024, available at https.//www.statistik-nord.de

Statistisches Bundesamt. (2023). Städte (Alle Gemeinden mit Stadtrecht) nach Fläche, Bevölkerung und Bevölkerungsdichte am 31.12.2022. Retrieved from https://www.destatis.de/DE/Themen/Laender-Regionen/Regionales/Gemeindeverzeichnis/Administrativ/05-staedte.html. from Destatis https://www.destatis.de/DE/Themen/Laender-Regionen/Regionales/Gemeindeverzeichnis/Administrativ/05-staedte.html

Steensen, T. (2020). *Die Friesen: Menschen am Meer*. Kiel: Wachholz.

Storlazzi, C. D., Gingerich, S. B., van Dongeren, A., Cheriton, O. M., Swarzenski, P. W., Quataert, E., Voss, C. I., Field, D. W., Annamalai, H., Piniak, G. A., & McCall, R. (2018). Most atolls will be uninhabitable by the mid-21st century because of sea-level rise exacerbating wave-driven flooding. *Science Advances, 4*(4). doi:10.1126/sciadv.aap9741

Sündermann, J., & Pohlmann, T. (2011). A brief analysis of North Sea physics. *Oceanologia, 53*(3), 663-689. doi:10.5697/oc.53-3.663

Süsser, D., Döring, M., & Ratter, B. (2017). Harvesting energy: Place and local entrepreneurship in community-based renewable energy transition. *Energy Policy, 101*, 332-341. doi:10.1016/j.enpol.2016.10.018

Süsser, D., & Kannen, A. (2017). 'Renewables? Yes, please!': Perceptions and assessment of community transition induced by renewable-energy projects in North Frisia. *Sustainability Science, 12*, 563-578. doi:10.1007/s11625-017-0433-5

Swapna, P., Jyoti, J., Krishnan, R., Sandeep, N., & Griffies, S. M. (2017). Multidecadal Weakening of Indian Summer Monsoon Circulation Induces an Increasing Northern Indian Ocean Sea Level. *Geophysical Research Letters, 44*(20), 10,560-510,572. doi:10.1002/2017GL074706

Tainan City Government. (2020). *Tainan City Climate Change Adaptation Project [in Chinese]*. Tainan City Government

Termeer, C. J. A. M., Dewulf, A., & Biesbroek, G. R. (2017). Transformational change: governance interventions for climate change adaptation from a continuous change perspective. *Journal of environmental planning and management, 60*(4), 558-576. doi:10.1080/09640568.2016.1168288

The Republic of the Maldives. (2020). *Strategic National Action Plan For Disaster Risk Reduction And Climate Change Adaptation 2010-2020 – Provisional Draft*. Retrieved from https://www.unisdr.org/preventionweb/files/60595_mal divesstrategicnationalactionplan.pdf

Thomas, A., Theokritoff, E., Lesnikowski, A., Reckien, D., Jagannathan, K., Cremades, R., Campbell, D., Joe, E. T., Sitati, A., & Singh, C. (2021). Global evidence of constraints and limits to human adaptation. *Regional Environmental Change, 21*(3), 1-15. doi:10.1007/s10113-021-01808-9

Travassos, L., Torres, P. H. C., Di Giulio, G., Jacobi, P. R., Dias De Freitas, E., Siqueira, I. C., & Ambrizzi, T. (2020). Why do extreme events still kill in the São Paulo Macro Metropolis Region? Chronicle of a death foretold in the global south. *International Journal of Urban Sustainable Development*, 13(1), 1-16. doi:10.1080/19463138.2020.1762197

Trisos, C. H., Adelekan, I. O., Totin, E., Ayanlade, A., Efitre, J., Gemeda, A., Pörtner, H. O., Roberts, D. C., Tignor, M., & Poloczanska, E. S. (2022). Africa. Cambridge University Press, https://www.ipcc.ch/report/ar6/wg2/chapter/chapter-9/

Tse-Xin Organic Agriculture Foundation. (2021). Last accessed April 22, 2024, available at https://toaf.org.tw/activity/collection/1117-2021-04-14-09-03-25

UNEP. (2023). Emissions Gap Report 2023: Broken Record – Temperatures hit new highs, yet world fails to cut emissions (again). United Nations Environment Programme, Nairobi: https://www.unep.org/emissions-gap-report-2023

UNRISD. (2019). Report on Transformative Adaptation and Social Justice in Ho Chi Minh City. United Nations Research Institute for Social Development (UNRISD), Geneva, Switzerland: https://cdn.unrisd.org/assets/legacy-files/301-info

Valencia Cotera, R., Egerer, S., & Manez Costa, M. (2022). Identifying Strengths and Obstacles to Climate Change Adaptation in the German Agricultural Sector: A Group Model Building Approach. *Sustainability, 14*. doi:10.3390/su14042370

Valverde, M. C., & Rosa, M. B. (2023). Heat waves in São Paulo State, Brazil: Intensity, duration, spatial scope, and atmospheric characteristics. *International Journal of Climatology*. doi:10.1002/joc.8058

van der Pol, T., Gussmann, G., Hinkel, J., Amores, A., Marcos, M., Rohmer, J., Lambert, E., & Bisaro, A. (2023). Decision-support for land reclamation location and design choices in the Maldives. *Climate Risk Management, 40*, 100514. doi:10.1016/j.crm.2023.100514

Vásconez Navas, L. K., Becker, J. N., Heger, A., Gröngröft, A., & Eschenbach, A. (2023a). Are active and former floodplain soils of the lower middle Elbe similar? A study of soil characteristics and possible implications for forest restoration. *CATENA, 222*, 106814. doi:10.1016/j.catena.2022.106814

Vásconez Navas, L. K., Busch, H., Thomsen, S., Becker, J. N., Kleinschmidt, V., Gröngröft, A., & Eschenbach, A. (2023b). *Sap flow velocity under drought and high evaporative demand: a comparison of two hardwood floodplain forest species under different soil conditions*.

von Grebmer, K., J., B., Resnick, D., Wiemers, M., Reiner, L., Bachmeier, M., Hanano, A., Towey, O., Ní Chéilleachair, R., Foley, C., Gitter, S., Larocque, G., & Fritschel, H. (2022). 2022 Global Hunger Index: Food Systems Transformation and Local Governance. Welthungerhilfe and Concern Worldwide, Bonn and Dublin: https://www.researchgate.net/publication/375604671_2023_GLOBAL_HUNGER_INDEX_THE_POWER_OF_YOUTH_IN_SHAPING_FOOD_SYSTEMS

von Storch, H., Gönnert, G., & Meine, M. (2008). Storm surges—An option for Hamburg, Germany, to mitigate expected future aggravation of risk. *Environmental Science & Policy, 11*(8), 735-742. doi:10.1016/j.envsci.2008.08.003

von Szombathely, M., Hanf, F. S., Bareis, J., Meier, L., Oßenbrügge, J., & Pohl, T. (2023). An Index-Based Approach to Assess Social Vulnerability for Hamburg, Germany. *International*

Journal of Disaster Risk Science, 1-13. doi:10.1007/s13753-023-00517-7

Wadey, M., Brown, S., Nicholls, R. J., & Haigh, I. (2017). Coastal flooding in the Maldives: an assessment of historic events and their implications. *Natural Hazards, 89*(1), 131-159. doi:10.1007/s11069-017-2957-5

Wagner, O., Irrek, W., Berlo, K., Bierwirth, A., Petersen, R., Richter, N., Thomas, S., Jansen, U., März, S., Arens, S., Kaselofsky, J., Hillebrand, P., Jungbluth, C., Lecour, F., & Wolff, T. (2011). Klimaschutzkonzept für den Kreis Nordfriesland. Wuppertal Institut für Klima, Umwelt, Energie, Wuppertal: https://www.nordfriesland.de/PDF/Kurzfassung_Klimaschutzkonzept_Nordfriesland.PDF?ObjSvrID=2271&ObjID=2777&ObjLa=1&Ext=PDF&WTR=1&_ts=1520938962

Waibel, M. (2009). *New Consumers as Key Target Groups for Sustainability before the Background of Climate Change in Emerging Economies: The Case of Ho Chi Minh City, Vietnam*. Paper presented at the Proceedings of the 5th Urban Research Symposium of the Cities and Climate Change: Responding to an Urgent Agenda, Marseille, France.

Waibel, M. (Ed.) (2013). *Ho Chi Minh MEGA City* (Vol. 14). Berlin, Germany: Regiospectra Verlag.

Waibel, M. (2014). Trying rather to convince than to force people: The approach of the Handbook for Green Housing. In B. Mahrin (Ed.), *Capacity Development – Approaches for Future Megacities* (pp. 143-152). Berlin: Jovis.

Waibel, M. (2016). Vietnams Metropolen: Herausforderungen und Lösungsansätze zur Förderung einer nachhaltigen Stadtentwicklung. *Geographische Rundschau, 68*(2), 4-9. Retrieved from https://www.researchgate.net/publication/301560803_Vietnams_Metropolen_Herausforderungen_und_Losungsansatze_zur_Forderung_einer_nachhaltigen_Stadtentwicklung

Waibel, M. (2019). Metropolen vor den Herausforderungen einer nachhaltigen Stadtentwicklung im Kontext von Globalisierung und Klimawandel – das Beispiel Ho Chi Minh City in Vietnam. *Geographie heute, 345*, 38-41. Retrieved from https://www.researchgate.net/publication/301560803_Vietnams_Metropolen_Herausforderungen_und_Losungsansatze_zur_Forderung_einer_nachhaltigen_Stadtentwicklung

Wakefield, S. (2019). Miami Beach forever? Urbanism in the back loop. *Geoforum, 107*, 34-44. doi:10.1016/j.geoforum.2019.10.016

Wang, H.-W., Castillo, D., & Chen, G. W. (2024). Managing residual flood risk: Lessons learned from experiences in Taiwan. P*rogress in Disaster Science,* 23. doi:10.1016/j.pdisas.2024.100337

Wang, H.-W., Dodd, A., Kuo, P.-H., & LePage, B. (2018). Science as a Bridge in Communicating Needs and Implementing Changes towards Wetland Conservation in Taiwan. *Wetlands, 38*, 1223–1232. doi:10.1007/s13157-018-1096-4

Water Resource Agency. (2020). Assessment of coastal risks to climate change-related impacts (2/2) [in Chinese].

Wendland, S., Hankers, B., Bock, M., Böhner, J., Squar, J., Lembrich, D., & Conrad, O. (2023). Ein Simulationsmodell zur Erfassung von Abflussrisiken in der Landwirtschaft. *Informatik Spektrum, 46*(1), 15-23. doi:10.1007/s00287-023-01522-2

Wiedergrün, S. (2022). *Studie zu Handlungslogiken in der Landwirtschaft, Metropolregion Hamburg*.

Wiener, A., Aykut, S. C., Gresse, E. G., López-Rivera, A., & Wilkens, J. (2023). The Social Plausibility Assessment Framework: from social drivers to the plausibility of deep decarbonization. In A. Engels, J. Marotzke, E. G. Gresse, A. López-Rivera, A. Pagnone, & J. Wilkens (Eds.), *Hamburg Climate Futures Outlook: The plausibility of a 1.5°C limit to global warming — social drivers and physical processes* (pp. 26-28). Hamburg, Germany: Cluster of Excellence Climate, Climatic Change, and Society (CLICCS).

Wiesner, S., Bechtel, B., Fischereit, J., Gruetzun, V., Hoffmann, P., Leitl, B., Rechid, D., Schlünzen, K. H., & Thomsen, S. (2018). Is it possible to distinguish global and regional climate change from urban land cover induced signals? A mid-latitude city example. *Urban Science, 2*(1), 12. doi:10.3390/urbansci2010012

Wiesner, S., Eschenbach, A., & Ament, F. (2014). Urban air temperature anomalies and their relation to soil moisture observed in the city of Hamburg. *Meteorologische Zeitschrift, 23*(2), 143-157. doi:10.1127/0941-2948/2014/0571

World Bank Group. (2021a). Climate Risk Country Profile: Nepal. The World Bank Group and the Asian Development Bank, Washington, DC and Manila: https://www.adb.org/publications/climate-risk-country-profile-nepal

World Bank Group. (2021b). Climate Risk Country Profile: Maldives. The World Bank Group (WBG), https://climateknowledgeportal.worldbank.org/sites/default/files/2021-08/15649-WB_Maldives%20Country%20Profile-WEB.pdf

Worldbank. (2023). Namibia. Last accessed July 3, 2023, available at https://www.worldbank.org/en/country/namibia/overview

Wright, E. O. (2010). *Envisioning Real Utopias*. London: Verso Books.

Yang, R.-Y., Wu, Y.-C., & Hwung, H.-H. (2012). Beach Erosion Management with the Application of Soft Countermeasure in Taiwan. In S. Curkovic (Ed.), *Sustainable Development: Authoritative and Leading Edge Content for Environmental Management* (pp. 349–370): IntechOpen.

Yuan, X., Wang, L., & Wood, E. F. (2018). Anthropogenic intensification of southern African flash droughts as exemplified by the 2015/16 season. *Bulletin of the American Meteorological Society, 99*(1), S86-S90. doi:10.1175/BAMS-D-17-0077.1

Zevenbergen, C., Cashman, A., Evelpidou, N., Pasche, E., Stephen, G., & Ashley, R. (2010). *Urban Flood Management* (1 ed.). London: CRC Press.

Zevenbergen, C., Fu, D., & Pathirana, A. (2018). Transitioning to sponge cities: Challenges and opportunities to address urban water problems in China. *Water, 10*(9), 1230. doi:10.3390/w10091230

Zscheischler, J., Westra, S., Van Den Hurk, B. J. J. M., Seneviratne, S. I., Ward, P. J., Pitman, A., AghaKouchak, A., Bresch, D. N., Leonard, M., & Wahl, T. (2018). Future climate risk from compound events. *Nature Climate Change, 8*(6), 469-477. doi:10.1038/s41558-018-0156-3

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