China Council for International Cooperation on Environment and Development

Climate Adaptation

Scoping Study 2025

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CCICED Scoping Study

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Climate Adaptation in a Broad Perspective: Long-term impacts on food supply, urban life, river transport, and ecology

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** The leader and members of this Scoping Study (SS) serve in their personal capacities. The views and opinions expressed in this Scoping Study report are those of the individual experts participating in the SS Team and do not represent those of their organizations and CCICED.*

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“I'm more interested in the future than in the past, because the future is where I intend to live.”
Albert Einstein

1. Introduction

1.1 Background and Objective

Climate change is here now. Weather extremes are becoming more common all over the world, and damage is expected to increase. The 2014–2023 decade became the hottest on record. All around the world, there were more frequent and more severe extreme weather events that caused casualties, economic damage, social disruption, loss of biodiversity, and reduced harvests. Even when greenhouse gas mitigation policy reaches the Paris Agreement goals, the effects of climate change will continue for decades, and even centuries, to come. The scale of the changes and their impacts will vary across regions though, depending on the local conditions and the local effects of global climate change. This holds equally true for the various regions in China as for regions in other parts of the world. The social, economic, and ecological impacts depend on how successful mitigation and adaptation policy is.

Adaptation to climate change requires action now, as well as over a longer time span. This long time span also means that climate adaptation will not take place in a vacuum. There are other mid- and long-term developments that will also impact society and ask for response. Developments, including technological, demographic, economic, and those related to multipolarity, will impact the potential to act on climate change.

As demonstrated in earlier CCICED Special Policy Studies on climate change[1], this development challenges the fundamentals of society, as vital domains of society will be impacted. To prepare and adapt in a timely manner, four of these vital domains were selected for this Scoping Study. These four domains are food production and supply, urban life, ecology, and waterborne freight transport in deltas.

1.2. Research Objective

These four domains are sensitive to changing weather patterns and other long-term developments. The central research question of this Scoping Study is this: **what are the expected societal challenges in the long run (50 years or longer) that climate change brings about on the domains of food production and supply, urban life, ecology/biodiversity, and waterborne freight transport on rivers and in deltas?** The question also considers expected intersecting long-term societal, technological, and other developments.

The objective of the Scoping Study is to define fundamental developments, impacts, challenges, and related dilemmas that society and economy will or might experience. These should be studied in depth in order to adapt policies, regulations, infrastructure, economic activities,

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[1] https://cciced.eco/research/special-policy-study/scoping-study-managing-river-areas-in-times-of-climate-change/
https://cciced.eco/research/special-policy-study/sps-4-low-carbon-and-resilient-urban-development-and-adaptation-to-climate-change/
https://cciced.eco/research/special-policy-study/green-development-and-climate-adaptation-for-urban-and-rural-areas/

human capacities and skills, etc., in a timely manner. The Scoping Study is to become a trigger for such future in-depth Special Policy Studies.

While drafting this Scoping Study report, it was concluded that most of the challenges and developments related to the impacts of climate change are global. Developments elsewhere in the world have an impact on China, and impacts in China have consequences elsewhere. The large diversity in climatic, geographic and governance/administrative conditions around the globe – and even within China - makes it hard to draw specific, quantified conclusions on the impacts of climate change on the four domains. Lack of detailed information forces to use generic language in this Scoping Study report. More specific Special Policy Studies are needed to specify developments and impacts, show examples of applied resilience solutions, and sketch recommendations for testing new adaptation strategies and interventions.

1.3. Research Contents and Method

The Scoping Study concerns a well-referenced study of literature by leading experts, reviewed by renowned international advisory experts, to gain state-of-the-art insights into the challenges of climate change in a mid- to long-term perspective (50–100 years) on the following domains:

1. **Food production and supply**: Show how harvest patterns (and regions) are expected to change, including the types of crops cultivated; insights into the effects on the food processing industry and the sustainability of the food supply in a changing climate.
2. **Urban life:** Extreme rainfall, drought, and heat put pressure on the life and liveability of the urban environment, including water availability and heat islands, which affect productivity, urban land use, and social systems.
3. **Ecology/biodiversity:** Climate change puts pressure on native flora and fauna—for example, through salination and desiccation of delta areas. Conditions in the habitats of species change and, consequently, so does biodiversity.
4. **Waterborne freight transport on rivers and in deltas**: Flow regimes of rivers will change, influencing the waterborne transportation of goods, the modes and practices of transportation, and required harbour facilities.

The first three domains were selected because of their generic relevance for society and economy, while waterborne freight transport on rivers and in deltas was selected as an example of a critical link in the supply network from producers to clients. Failure of such a link can have far-reaching impacts.

Climate change is not the only factor driving long-term changes in these domains. To take interdependencies into consideration, trends and developments in technology, demography, economy, and multipolarity will be touched upon in a separate section of the Study. This provides context for the situation in which climate adaptation needs to take place. The Scoping Study concludes with a reflection on these developments and formulates future policy-oriented research questions on the societal impacts of climate change and on the development of policy pathways — all of which are potential subjects for future CCICED Special Policy Studies.

The Study is meant to provide global insights, including regional diversity, only to the extent available in literature and to the extent that is relevant in the scope of the study. Specification of geographical areas in China and in other parts of the world that will become more prone to or sensitive to extreme weather and other effects of climate change goes beyond the scope of this study; this could be a subject for more specific Special Policy Studies in a later phase.

1.4. Work Plan

The central research question of the Scoping Study is addressed in a **two-tiered approach**. As a first step, a working document was drafted. This document contains five in-depth essays (chapters)—four on the domains mentioned above, and one on trends and developments interacting with the impacts of climate change on the four domains. The results of these analyses are distilled in this compact Scoping Study report, summarizing the main challenges foreseen for the four domains, reflections, and policy-oriented research questions.

First versions of each chapter of the working document are written by Dutch experts and presented to selected international advisory experts for in-depth peer review, comments, and additions. The revised version of each essay/chapter, including many references, is combined in the final version of this informal working document, *Climate Adaptation in a Broad Perspective: Long-Term Impacts on Food Supply, Urban Life, River Transport, and Ecology*. This working document is available in English, as a background paper on the CCICED website (https://cciced.eco/research/council-document/2025-cciced-background-paper-climate-adaptation-in-a-broad-perspective-long-term-impacts-on-food-supply-urban-life-river-transport-and-ecology/).

The draft of this Scoping Study report was circulated for review among a group of advisory experts and the CCICED special advisors for comments and suggestions. The final version of the Scoping Study report was submitted to the CCICED Secretariat for discussion at the CCICED Annual General Meeting 2025.

1.5. Structure of the Report

The main issues and conclusions on expected impacts of climate change on the four domains as well as their potential intersection with other trends and developments in society is summarized in Chapter 2. To distinguish between expected developments before and after the mid-21st century, the terms "short-term" and "long-term" are used. Building on this information, Chapter 3 includes an analysis of crosscutting themes and issues relevant for long-term climate adaptation strategies for China and other countries around the globe. It is evident that all countries will have to deal with the consequences of climate change and its impacts, including sea level rise, water quality issues, and geohazards. Recommendations on further in-depth studies are formulated in Chapter 4, based on the findings presented in the preceding chapters.

A wealth of scientific and other references underpinning the statement in this Scoping Study report can be found in the working document, *Climate Adaptation in a Broad Perspective: Long-Term Impacts on Food Supply, Urban Life, River Transport, and Ecology*. For the sake of brevity and focus, minimal use of scientific referencing is made in this Scoping Study report, as its objective is to feed a dialogue on future in-depth Special Policy Studies of CCICED and/or similar studies by other organizations around the globe.

2. Impacts of Climate Change on the Short and Long Term

2.1. Potential Impacts on Four Essential Domains

Four sections examine the expected societal challenges in the long run (50 years or longer) that climate change brings about on the domains of food production and supply, urban life, ecology/biodiversity, and waterborne freight transport on rivers and in deltas. Long-term developments in these four domains will, however, not only be influenced by climate change; many other developments will intersect with its impacts. That is why this chapter starts with an overview of potentially intersecting trends and developments.

Many challenges, developments, and references are mentioned in the background paper. Summarizing without skipping essential information is hardly possible given the richness of the climate adaptation literature. Nevertheless, an attempt is made to provide a basis for reflection and recommendations for further studies.

2.2. Intersecting Trends and Developments

To address the diverse impacts of climate change, states and international organizations around the world are devising climate adaptation strategies. For example: China's National Climate Change Adaptation Strategy 2035 [2] aims to improve climate monitoring and early warning systems, protect ecosystems and biodiversity, and stimulate climate resilience in urban systems, economic sectors, and critical infrastructures. And in 2021, the EU presented its renewed commitment to increase climate change preparedness and resilience by 2050. It aims to accelerate adaptation through knowledge generation, data enhancement, and promoting nature-based solutions.

Climate change acts as a threat multiplier across social, economic, and political systems. As more states emphasize the need for climate adaptation, it is important to understand how climate change will intersect with major global trends between now and 2100. The further in the future, the harder it is to foresee the outcomes of this complex of developments. Certainly, in the second half of this century, climate-related developments are expected to contribute to profound global transformations due to the severity of its impacts. Power dynamics are likely to shift, favouring those countries that can adapt swiftly and sustainably. Meanwhile, ecological tipping points, such as disrupted water cycles, melting permafrost, changing ocean currents, and biodiversity loss, could trigger irreversible and cascading consequences for the planet. Overall, climate change will be a defining force that shapes global developments throughout the course of the 21st century.

This section examines the geopolitical, geoeconomic, technological, environmental, and societal trends that will interact with climate change, and explores the opportunities and challenges this

[2] Chinese Ministry of Ecology and Environment (生态环境部), National Development and Reform Commission (NDRC; 国家发展和改革委员会), Ministry of Science and Technology (MOST; 科学技术部), Ministry of Finance (财政部), Ministry of Natural Resources (自然资源部), Ministry of Housing and Urban-Rural Development (住房和城乡建设部), Ministry of Transport (交通运输部), Ministry of Water Resources (水利部), Ministry of Agriculture and Rural Affairs (农业农村部), Ministry of Culture and Tourism (文化和旅游部), National Health Commission (国家卫生健康委员会), Ministry of Emergency Management (应急管理部), People's Bank of China (PBOC; 中国人民银行), Chinese Academy of Sciences (CAS; 中国科学院), China Meteorological Administration (中国气象局), National Energy Administration (国家能源局), and National Forestry and Grassland Administration (国家林业和草原局) (2022) **National Climate Change Adaptation Strategy 2035**, http://www.ncsc.org.cn/SY/syqhbh/202206/W020221026516413083356.pdf

will present for nations, economies, and societies. A split is made between the period 2025–2050 and the "long-term" period 2050–2100, as developments in the coming 25 years are easier to foresee than in the period beyond 2050.

Geopolitical Shifts and Pressures

In the coming decades, the international system will continue transitioning from unipolarity to a system of multipolarity, in which a variety of great powers project their influence and interests on the international stage and question the legitimacy and equity of existing international regimes and norms. Instead, regional dynamics will shape multilateral cooperation, which will be increasingly centred around pragmatic coalitions of countries with specific shared interests. In this fragmenting international order, however, the increasingly pressing impacts of climate change can become a unifying factor between competing states, as opportunities arise to forge new coalitions and regional agendas to tackle the impacts.

A country's capacity to adapt to climate change is shaped by access to financial and technological resources, socio-economic resilience, stability of governance structures, and quality of knowledge systems. Consequently, adaptation is poised to become an increasingly strategic factor in shaping bilateral relations and international cooperation, in which climate financing is a key issue. Equity between the Global South, the North, East, and West is an issue. Public-private partnerships are likely becoming a more important vehicle for funding climate adaptation than the traditional aid flows.

In the long run, say after 2050, insufficient climate action poses risks to global stability. Demographic and economic shifts result in migration, while the population is aging and starts shrinking, both in China and in the rest of the world. These processes, however, show significant regional variability around the globe, potentially bringing extra societal tensions between those that are safe and those that are vulnerable to climate change. Flood- and drought-prone regions will also experience destabilizing effects from internal displacement and resource scarcity. Governments that fail to take effective actions undermine their legitimacy and may increase authoritarian sentiments among populations experiencing climate stress.

Geoeconomic and Technological Trends

While shifting geopolitical dynamics reshape global governance, technological innovations, resource competition, and extreme weather events will increasingly define the geoeconomic dimension of climate adaptation in the decades to come. Technological advancements (e.g., in circularity, control technology, forecasting, nature-based solutions, artificial intelligence, and robotization) are expected to offer significant economic opportunities and solutions for climate adaptation. As technology becomes central to the successful creation of climate resilience, states will seek control over critical raw materials and green technology supply chains. Meeting the demands of climate adaptation and mitigation in the second half of this century will require fundamental economic transformation. Regional imbalances and inequalities between the Global North and South may lead to unequal access to new technologies but will also offer new avenues for new alliances and cooperation on climate adaptation.

Much is expected from the use and development of artificial intelligence. This and other technological innovations carry the risk of a false sense of security and protection, based on the expected success, which can hinder the development of more robust climate adaptation strategies. Potential risks also include limited access to critical raw materials (CRMs), construction materials, like sand, metals, and cement, and green technologies that depend on a sufficient supply of water. Resource nationalism and strategic use of trade dependencies drive states to increase protection and control of natural resources to ensure the security of supply in times of crises. States already in control of these supply chains can leverage their dominance for economic and political gains. As a result, new resource-based partnerships may emerge.

Extreme weather is expected to become more frequent and more disruptive for food production, ecosystems, power and water supply, transport (supply chains) of products, etc. Consequences are higher prices and inflation, even globally. Consequently, financial systems will have to adapt to the financial needs of global climate adaptation and the increasing risks posed by extreme weather and sea level rise impacts. Adaptation may increasingly present itself as a viable sector for private investments. Insurance companies are already active on the private market with so-called cat(astrophe)-bonds and other products.

In long-term perspective, climate-centric economies will be essential to meet the existential demands of global climate adaptation and mitigation. These economies will emerge in those countries with established economies, where climate policy, innovation, and public support converge. That is why regional imbalances and inequalities between the Global North and South may persist, and new ones may develop. Climate-centric economies will compete on their ability to adapt, not just grow. Societies will have to deprioritize GDP growth, seek new sources of non-material prosperity, implement circular resource flows, and establish redistributive economic institutions.

Beyond 2050, the fifth industrial revolution will shape future societies and labour markets, intersecting with climate-induced inequalities between countries. While AI-based innovations are the hallmark of the fourth industrial revolution, the integration of humans, artificial intelligence, and robotics is theorized to constitute the fifth industrial revolution, expected to unfold by mid-century. Socio-economic differences between countries, however, create unequal capacities between states for workforce development, potentially deepening existing economic inequalities. New global coalitions and alliances will be needed to avoid large scale social instability.

Prices of food production are expected to increasingly rise and become more volatile, as crop yields decrease due to the new climatic conditions, soil erosion, and extreme weather events. Crop diversification, crop migration (to places with better growing conditions), improving water and soil management, and refining weather forecasts and early warning systems may reduce these expected developments in yields and prices.

Environmental and Societal Developments

Climate change will influence patterns of governance, social stability, and conflict risks in vulnerable areas. As two thirds of the global population will reside in cities by 2050, urban resilience and climate adaptation will prove crucial to mitigate disaster risks and ensure liveability and human well-being. Regions unable to adapt in a timely manner will face the destabilizing effects of resource and land scarcity and, consequently, an increased risk of intercommunal and transboundary conflicts. Throughout the century, biodiversity loss compounds these pressures.

These destabilizing effects are projected to give rise to internal and cross-border migration flows that could reach 87–133 million people by 2060, with sub-Saharan Africa and South and East Asia bearing the heaviest displacement burdens. This migration generates pressures on host communities, complicates international relations, and overwhelms the governance capacity in fragile states. To manage these climate-related migration flows, it will be crucial to invest in climate adaptation measures and integrate climate migration into development policy.

For the next decades, urbanization is projected to increase. All around the world this leads to increased vulnerability of societies. But, at the same time, it offers opportunities to strengthen their capacities to reduce climate risks. Implementing adaptation measures to strengthen climate resilience by strengthening society's threshold, coping, recovery, and adaptive capacity, as well as effectively managing urban growth and urban renewal will be crucial to untap these opportunities and to avert the intersecting risks to urban liveability.

Biodiversity loss creates challenges for ecological stability and human well-being, particularly after 2050. Public health is at risk, as the likelihood of zoonotic disease transmissions rises and medicinal plant species used in traditional and industrial medicine are at risk of extinction.

As climate impacts accelerate into the second half of the 21st century, environmental stress will increasingly overwhelm fragile states' ability to govern effectively. Within states lacking adaptive capacity, this lack of resilience will hit hardest on disadvantaged groups already facing socio-economic inequalities. Without sufficient adaptive and transformative capacity, these states will become increasingly reliant on external actors—ranging from powerful countries to regional blocs and multinational firms—to manage essential governance functions. Their sovereignty will be challenged; climate-resilient states will consolidate control while others experience a dilution of authority in line with their vulnerability. Over time, the ability to manage environmental risk will become a key criterion for political legitimacy and international influence.

2.3. Food Production and Supply

Impacts

Climate change already has a significant impact on food production. Approximately three quarters of the global harvested areas experienced drought-induced yield losses between 1983 and 2009. Cereal production declined by 9% to 10% due to extreme weather events, and precipitation and temperature changes reduced global average yields of soybeans by 4.5% and maize by 4.1% between 1964 and 2007. As climate continues to change, impact on food production will further aggravate.

Climate change is particularly damaging in rainfed agricultural areas lacking the buffering effect of irrigation, where crops are fully exposed to rainfall variability. The intensification of the terrestrial hydrological cycle will lead to higher evaporation rates and altered atmospheric moisture transport, increasing the likelihood of both flash flooding and prolonged drought. Historically productive regions, like the American Midwest and eastern China, are increasingly exposed to heat stress, water scarcity, and erratic rainfall.

Focusing on the production of staple crops, including soya, maize, wheat, and rice, significant impacts of climate change are expected across China and the globe. In China, soya is mostly used to feed animals; maize and wheat is for internal use; and rice is an important export product. Given their sensitivity to heat and water stress, climate change affects the production and international flows of these four crops. In-depth knowledge of this global production-supply-consumption network is essential for anticipating future food supply risks. To assess these risks and enhance the robustness of the results, the Global Gridded Crop Model Intercomparison (GGCMI) Phase II dataset and a multi-model ensemble approach were used to simulate crop yield responses under climate stress conditions. Results presented below are for an illustrative +3°C and -30% rainfall scenario.

For **soybeans**, yield declines of 25%–30% are projected by the model for key growing regions in Brazil, Argentina, and the United States. And much of China's soybean imports—93 million tons in 2023—comes from regions with increasing drought hazard. The model also predicts 7% to 50% soybean yield reduction in northeastern China.

Maize plays a central role in China's feed and industrial processing sectors. Over 90% of China's maize demand is met by local production. The +3°C and -30% rainfall scenario could result in yield losses of between 25% to 50% in China's own production areas.

Rice yield losses increase with rising temperature. About 95% of China's rice needs are met by local production, almost entirely under irrigated conditions. Southern and central rice-growing regions, including parts of the Yangtze River Basin, experience yield reductions ranging from 6% to 50%, while parts of northeastern China (e.g., Heilongjiang) show modest yield gains.

For **wheat**, significant yield gains (25%–75%) are predicted by GGCMI in many high-latitude and high-altitude areas due to reduced cold stress and extended growing season. Over 90% of China's wheat demand is met by local production, which is predominantly irrigated. Large parts of the North China Plain show yield gains of 5% to 25% under the +3°C temperature scenario. However, central and southwestern provinces, including parts of Henan, Hubei, and Sichuan, display yield declines of 6% to 25% under the +3°C temperature scenario.

Model-predicted changes in these mean production values can be overshadowed by interannual variability in climate and extreme weather impacts. Moreover, major changes in the water cycle or the risk of pests are not accounted for. On the other hand, assuming zero adaptation in crop management might be too negative an assumption. But, in general, it is concluded that the production of crops for animal feed and, to a lesser extent, rice yields for consumption in China will decrease further with the increase of global climate change. The picture for wheat production is less clear. A transition in both food production and human consumption is necessary, starting soon and certainly after the mid-21st century.

Stakeholders

Impacts will be felt in the whole food system, from farm to fork. The impact of climate change on food supply is not only felt in the country where a crop is produced but also in the parts of the world where these crops are processed and consumed. This food system is global, and many actors are involved: producers (farmers), food processors, local and global markets, traders, local and national governments, the private sector, financial institutions and, of course, consumers. Adaptation therefore requires a comprehensive **food systems approach** to understand the linkages and find leverage points that can reduce impacts and trigger the required transformations in production, consumption, and consumer diet.

Limits to Adaptability and Uncertainties

Sixty-two percent of China's current cropland (110 MHa) is located within two of China's major river basins—the Yellow and the Yangtze river basins—with related flood risk and a reducing input of water from glaciers and snow melt in the Hindu Kush–Karakoram–Himalaya (HKH) region. Forty-four percent of this cropland is irrigated, leading to fierce competition for water resources and large investment in inter-basin water transfer infrastructure from south to north. And in the North China Plain, where surface water is not sufficiently available, groundwater is extracted to supply crops with water, but overexploitation is threatening agricultural production there.

Globalized food production also exacerbates water and ecological problems, especially in the Global South. Through water intensive crop production, drought and erosion are accelerated. Small-scale agriculture in balance with ecosystems is disrupted. Large-scale farming of water-intensive crops, such as avocados, oranges, and tomatoes, replaces the production of staple crops that produce less financial profit to the farmer. Small traditional farms located in less favourable climate conditions run into poverty, creating equity problems in communities.

Such ongoing socio-economic developments in China and beyond may put further pressure on both water resources and society. Although the population is projected to slowly decrease after 2040, an ongoing trend in dietary preferences toward increased meat consumption can still lead to increasing land and water demand. This changing diet is observed related to economic prosperity and urbanization, with more red meat, dairy products, refined grains, and edible oils. This development, however, seems in conflict with the projected reduction in the yields of animal fodder, such as soya, and the lack of arable land and water resources.

Reflection

The consequence of all these developments—the uncertainties due to climate change, climate variability, socio-economic, geopolitical, technological, and environmental developments—is the need for fundamental adaptation of the food supply system, including the human diet, including less meat and more locally produced food to enhance circularity and reduce transport emissions. This adaptation provides an opportunity for product diversification, spreading production, reducing its environmental footprint of mankind, and rural and ecological revitalization. China's National Climate Change Adaptation Strategy 2035 formulates firm ambitions for this, both in terms of goals and enabling conditions for implementation. Pilots and demonstration projects are underway, but upscaling will be a significant challenge.

Food is produced, traded, and consumed in a global market system. Self-sufficiency is no longer a feasible policy objective. Impacts of climate change may lead to significant socio-economic and ecological inequalities around the globe. These impacts can be mitigated—or aggravated—by trade policies, geopolitical relationships, and global food production and processing players that dominate the market.

2.4. Urban Life

Impact

Cities are extremely vulnerable to climate change. Many metropolitan areas are situated in flood plains and delta areas, where the combination of sea level rise, land subsidence, and freshwater salinization calls for coordinated action at multiple levels of scale and authority.

The density of people, property, and economic activity makes urban areas superefficient but also highly vulnerable to flooding, heat, drought, and related disasters. Flooding can result from many hazards, including extreme rainfall, rivers, sea level, storm surges, and groundwater. It causes casualties, as well as disease and economic, social, and psychological damage and disruption. Geohazards, like landslides, are also related to extreme rainfall and/or river erosion. Extreme heat, also known as the "silent killer," is aggravated by the urban heat island effect. And drought causes not only water shortages but also problems with water quality, leading to public health issues and ecological damage, as well as geohazards, like land subsidence, and related damage to buildings and infrastructure. Yet, cities are still expanding due to demographic growth and inward migration. Although the size of the total population will decrease after the mid-21st century, the population in climate-resilient cities is expected to continue increasing due to the concentration of economic activities and climate migration, while climate vulnerable settlements will become less populated.

Many urban areas are situated in flood-prone areas; areas that are suffering the most from uncertainties in the changes in sea level, extreme rainfall, river floods, droughts, and heat waves. Consequently, most urban areas around the globe need to adapt their infrastructure, buildings, green areas, and industrial zones, and how they are maintained and managed, to new climatic conditions.

Life in cities depends on external resources, like food, energy, drinking water, and waste treatment; resources coming from their rural environment that are vulnerable to extreme weather, climate change, and sea level rise, too. The growing use of these resources currently exceeds the efficiency improvements and savings achieved in the urban environment; their environmental footprint will continue to increase in the coming decades. Moreover, efficiency considerations made residents and businesses rely on "just in time" delivery on demand. The redundancy that is present in natural ecosystems has been exchanged for economically efficient uses of land, materials, labour, and money. Resource supply insecurities have major disruptive effects, jeopardizing critical urban functions, paralyzing city life, and potentially leading to casualties, health risks, and economic damage. Exposure to extreme weather is expected to become more frequent and severe. Climate-resilient new urban development and adaptation of existing buildings, public and private spaces, and infrastructure is needed. And as structural adaptation of cities and the planned development of new cities takes decades, authorities should start this process sooner than later.

At the global scale, diversity in cities is large; geographical conditions, population, socio-economic conditions, and cultural differences create substantial differences in vulnerability to climate change and sea level rise. Climate change is expected to drive migration patterns, as individuals with economic means move to more climate-adaptive places, further creating new inequalities. This dynamic may lead to a redefinition of citizenship within urban environments. Inequalities between the Global North and Global South and the Global East and Global West create unequal opportunities in the capacity to reduce climate risks. The most disadvantaged groups in society are often living in the more vulnerable areas. Unplanned and disruptive patterns of migration of people and/or businesses, as a result of seeking protection, will in the second half of the century lead to a downward spiral of economic, social, and cultural decline of cities, ending where cities become stranded assets. The adaptation and upgrading of unplanned migration within and across regions and borders are expected to take decades, meanwhile leading to poor living conditions.

Structural adaptation of urban areas and the planned development of climate-resilient new urban areas take decades. This makes urban areas extremely vulnerable for extreme weather and climate change for many decades to come. Authorities should start adaptation processes sooner than later. Adaptation of the urban environment requires complex planning and implementation and actions at different spatial scales, by different stakeholders having different forms of authority (private, public, voluntarily, top-down enforces, etc.). Cities are a system of systems, evolving over time. Understanding the systems and their interaction is a prerequisite for successful adaptation. Consequently, the feasibility of creating a climate-resilient urban environment before 2050—or even 2035—is highly questionable without accelerating urban renewal and more restrictive spatial and urban planning.

Stakeholders

Cities and how they operate, function, develop, and adapt is the result of a complex interplay of many stakeholders, operating at different spatial, administrative, and system scales, with different time horizons. Residents, businesses, financial institutions, housing corporations, developers, and many governmental and non-governmental organizations all play a role in their development. The values, rules, and regulations that drive these stakeholders and how they operate is geographically dependent. Even the general distinction between public and private actors and their role and *modus operandi* have context-specific understandings. Consequently, planning and implementing adaptation measures requires local context sensitivity.

Individuals, particularly homeowners, have a role in climate adaptation, implying responsibilities for their properties. However, their agency to adapt varies significantly due to socio-economic differences, with disadvantaged groups often living in more vulnerable areas and possessing the least capacity to cope with or recover from damage. Furthermore, citizens' expectations of the built environment influence adaptation needs and solutions. Without sufficient awareness of the risk they are running and of the solutions they can implement, citizens lack a driver for action. Rather than taking precautionary actions, they will wait for a disaster to trigger them. And the same holds for businesses and companies.

Local and super-local governments are on the front line of climate impacts, critical for public infrastructure and service delivery. However, existing governing institutions are often ill equipped for novel climate challenges. While traditionally involved in flood risk management and emergency response, their limited capacity and inherent slow adaptability and institutional voids hinder a rapid, adequate response in governance and in implementing adaptation measures.

Financial actors play an essential role in climate adaptation. At the local level, banks play a double role, as they bear the risks of the loans they provide for properties and businesses, and they decide where and for what purpose money can be invested (and where and when not). Central national banks assess adaptation's impact on financial systems and use regulation to guide institutions on climate risks. Supra-national entities, such as multilateral banks (e.g., World Bank, ADB), and international financial actors, like the Network of Central Banks and Supervisors for Greening the Financial System (NGFS), play a crucial role in urban climate adaptation by steering global climate finance. They study scenarios and influence how finance flows to cities, often by setting criteria for "bankable" projects. However, a significant challenge is that most climate finance is structured at the national level, making it difficult for cities, especially in the Global South, to access these funds due to limited technical capacity or creditworthiness. Their influence on investment decisions, including through instruments like municipal bonds, significantly shapes how cities adapt to climate change.

Limits to Adaptability and Uncertainties

The adaptability of the built environment is extremely slow due to the long lifespan, path dependencies, and sunk investments of outdated infrastructure. Urban buildings and infrastructure seem constructed “for eternity” rather than for adaptation or removal at the end of their lifespan, thus reducing adaptability. Renewal is costly, often leading to piecemeal renovations to keep the old system operational, thus contributing to a lock-in of unsustainable systems. Transitioning to adaptive urban systems requires fundamental changes in regulations, planning, and construction practices and skills of the constructors and maintenance staff—all transitions that are time-consuming and hard to implement. Examples include the construction of temporary buildings with a lifespan of, say, fewer than 30 to 40 years; buildings and infrastructure that are easily adaptable to new, so far unknown, conditions; floating solutions; circular use of building materials, etc. Our governing institutions, rules, and regulations have not been designed to address these challenges. Their slow adaptability makes them trustworthy and reliable but also reduces the ability to quickly or adequately respond. They also tend to shape adaptation pathways along sectorial and administrative borders, failing to deliver integrated responses needed for these new challenges, or worse, that result in mal-adaptation that aggravates systems' lock-in.

Another important reason for inadaptability is the strong financial lock-ins in current real estate and real estate markets that prevent public and private actors, including citizens as homeowners, to invest in climate risk reduction. Any investment in real estate mostly at risk will generate limited short-term financial value up to a tipping point (where costs of climate damage outnumber the financial revenues of investment).

Scarcity of resources (land, water, energy, building materials, finances) often limit the breadth of feasible adaptation solutions, and so does the current building practice. For example, engineers and planners are trained to build in steel, bricks, and concrete rather than in circular, easily adaptable materials, such as wood and degradable materials like mycelium, paper, and straw. The expectation of the uninformed citizens (the clients of the builders) is another barrier in climate-resilient urban development and renewal. Misalignment between adaptation financing mechanisms and the specific needs of the cities, businesses, and residents aggravates the transition hurdle.

Reflection

The majority of the world's population lives in cities, many of which are located in areas highly vulnerable to climate change. The need to increase climate resilience through adaptation is urgent, as demonstrated by the many catastrophic climate event that the world is suffering from. Due to the longevity of buildings and infrastructure and the capital-intensiveness of their renewal, urban adaptation is, however, complex and slow. Governments, developers, constructors, business owners, residents, banks, and insurers are insufficiently aware of the risks, the need to act from now on, and the wide availability of climate-resilient, sustainable, circular interventions. Implementation of these solutions, however, requires a solid long-term adaptation policy, strategy, and regulatory framework, including an investment agenda for short- and long-term actions.

Extreme weather resilience of urban systems is often weak. Extreme weather events exceeding design standards often cause substantial damage and casualties. Systems and investments in coping and recovery capacity to minimize the damage of extreme events are very limited, though their return on investment is promising. Approaches and technologies to enhance urban resilience to extreme weather events should be developed and implemented.

The effectiveness of urban adaptation heavily depends on coordination across sectors, spatial and administrative scales with various stakeholders, given that cities are unique configurations of geography, people, cultures, and institutions. This necessitates new alliances, new institutional capacities, and integrated approaches, as current institutions frequently operate within rigid sectoral and administrative borders, often leading to stagnation or maladaptation. Policymakers must focus on establishing multilevel arrangements to coordinate financing for climate adaptation pathways, especially since cities face significant barriers in accessing climate finance, which is often structured nationally. This requires a shift from traditional, siloed governance toward more integrated and flexible models.

2.5. Ecology/Biodiversity

Impacts

Climate change is currently ranked the third most significant direct driver of ecology/biodiversity loss. Human activities, like land-use change for food production and urbanization, and overexploitation of natural resources to cover the growing per capita consumption, are major causes, intersecting with changes in climate. All ecosystems—terrestrial, fresh water, and marine—are under pressure due to climate change. In addition to human pollution emissions, desiccation and salinization of water resources reduce ecosystem services provided by natural systems. This has profound and wide-ranging impacts on the economy and society and is, in the end, threatening human health and well-being.

Climate change leads to a shift of ecological/bioclimatic zones. This is a slow but already ongoing process. Also, zones for food and bioenergy production are shifting, with significant consequences for the ecosystem protection in nature conservation areas, farming, food production and processing industries, and their related labour force. Biodiversity in and beyond nature conservation areas will change. New areas with high biodiversity might emerge. This has consequences for the agreed-upon protection policies and makes adaptive nature conservation planning and management essential. To develop this new fundamental approach is a challenge for the next decades.

Terrestrial ecosystems particularly affected by combined human and climate pressures are tropical and temporal/boreal forests and tundra. The most vulnerable freshwater ecosystems are snow and glacier melt-fed rivers, rivers in monsoon areas and under damming, wetlands, and inland lakes. The most vulnerable marine ecosystems include the Arctic Ocean, coastal zones, coral reefs, and mangrove systems. Due to the mix of climate- and human-induced pressures, the regenerative capacity of these ecosystems is jeopardized in many places. Planetary boundaries are exceeded. Without fundamental adaptations of the environmental protection policies and practices, this will eventually lead to the collapse of the ecosystem, maybe even before the mid of this century.

Actions to increase resilience of biodiversity and ecosystem services to climate change are simple yet intrinsically linked with actions that limit human influence on ecosystems: minimize stress or disturbances, reduce fragmentation, increase natural habitat extent, enhance connectivity and heterogeneity, and protect small-scale refugia where microclimate conditions can allow species to persist.

Biodiversity in agricultural and urban areas is strongly impacted by human interventions. The monoculture of agricultural crops and the use of pesticides and fertilizers have drastically reduced the biodiversity in rural areas. Urban areas modify their local and regional climate through the urban heat island effect and by altering precipitation patterns, which together will have significant impacts on net primary production, ecosystem health, public health, and biodiversity. Ecosystem-based planning and design approaches help reduce the impact of urbanization on biodiversity and the ecosystem services provided by nature. But despite this introduction of blue-green networks of nature-based solutions, the number of species in flora and fauna is limited and its biodiversity unbalanced.

Ongoing fragmentation of suitable habitats for wildlife is another threat to biodiversity, as habitats are broken into smaller, isolated patches. In addition, rising temperatures are projected to cause vegetation shifts, e.g., favouring taller, denser vegetation, and will thus promote the expansion of forests into the Arctic tundra, and tundra into polar deserts.

Cropland expansion and ongoing urbanization result in substantial loss of forests and their rich ecosystems. Growing populations and increasing prosperity will place extra demands on both resources and services in urban areas and on their associated land from which they obtain their resources. At the same time, the increasing levels of salt in waters and soils (due to saltwater intrusion in surface water and groundwater, and due to overirrigation in the next decades) as well as ongoing desiccation and desertification could become a leading cause of climate migration globally, leading to significant geopolitical, social, and economic challenges. Timely adaptation of the physical, socio-economic, and geopolitical systems to the new climatic conditions is therefore a challenge for the coming decades.

Stakeholders

Stakeholders in biodiversity are those who benefit from ecosystem services and who manage the land that produces such services. The voice of nature itself is represented by many organizations for nature protection, operating from the local to the global scale, and by governments making legal arrangements for environmental protection and creating organizations for managing and protecting nature conservation areas.

Policymakers involved in the water domain, land-use planning, farming, and the environment all have a stake in protecting biodiversity and ecosystem services provided by the ecological system. However, these actors operate across different spatial scales, and their interests in ecosystem services can vary significantly.

The increasing pressures from climate change, combined with growing demands for agricultural production and fisheries, pose a significant challenge to managing natural resources and ecosystem services, often leading to conflicts among various actors, like farmers, fishers, policymakers, and environmental managers. At the municipal scale, important ecosystem services that represent a mix of individual and localized collective interests include the maintenance of green spaces, erosion regulation, and provision of fuel and food (e.g., fisheries and agriculture). At the municipal and provincial scales, the provision of fresh water and recreation are highly relevant. At the national and international levels, the focus shifts particularly to nature conservation and habitat support. These are typically viewed as broader, long-term, collective interests essential for planetary health and global biodiversity, impacting current and future generations. All these actors must have a role in the dialogue and decision making on a new, adaptive biodiversity enhancement and nature conservation strategy for 2050 and beyond. In view of the complexity of this challenge, this will take many years.

Limits to Adaptability and Uncertainties

Biosphere integrity (rate of biodiversity loss), climate change, land system change, and freshwater use are four of the nine planetary boundaries (PB), i.e., the environmental limits within which humanity can safely operate. Each boundary comes with a “tipping point” beyond which the ecosystem can no longer cope with the pressure. Without specific response measures, at least five PBs will be exceeded in 2030—climate change, nitrogen and phosphorus (biogeochemical) flows, biosphere integrity, land system change, and aerosols. In 2050, seven PBs will be in the high-risk zone, including freshwater use and ocean acidification. Consequently, the regenerative capacity of ecosystems is jeopardized; human demand has already exceeded this capacity since

1980. Geopolitical tensions, economic instability, shifting production areas, and migration will further introduce significant uncertainties for ecosystem and biodiversity protection.

Long-term uncertainties for biodiversity and ecosystems include the battle for resources, like water and space (land), energy greening (including nuclear), circularity, modal shifts in mobility and energy sources, as well as policies on urban, rural, and nature renewal and regeneration. The pressure on freshwater resources from agriculture, industry, and households, and for salinity control in deltas, leads to uncertainties for ecosystem protection. Climate change and anthropogenic modifications to the hydrologic cycle are expected to further increase the extent and severity of desiccation and salinization. Meanwhile, the consumptive use of water from rivers, lakes, reservoirs, and groundwater resources is threatening the ecological flow requirements of the river's flow-dependent ecosystems.

Dealing with conditions of deep uncertainty in long-term transformation and climate resiliency asks for the integrated analysis of uncertainties and the development of adaptive plans. It is, however, hard to foresee and quantify the impact of climate change and the timing of tipping points on ecosystems and the services they provide. For example, what will the pattern of heat stress, water scarcity, and water quality deterioration look like in 20 or 50 years, without and with countermeasures? And what will be the health and social consequences of these phenomena? Despite these uncertainties, the precautionary principle requires EU countries and urges other governments to take action as soon as possible, e.g., by promoting ecosystem-based adaptation and developing adaptive biodiversity protection and nature conservation policies.

Reflection

Biodiversity is essential for the health and well-being of life on Earth, including humanity. Yet, nature has no voice of its own and is threatened by many human activities as well as by developments like climate change. This results in ongoing desiccation, salinization, pollution, and overexploitation of water resources; natural land being converted for agricultural purposes, urban areas, and energy production; water bodies being used for a wide range of functions, etc. All these changes induce and accelerate the negative trend in biodiversity. Biodiversity conservation, restoration, and regeneration are crucial for protecting liveability on this planet.

Ecosystem services provided by nature are to be harvested in a sustainable way, not to exceed the boundaries of the pressure that nature can handle and always protecting the regenerative capacity of the natural system.

Climate change will lead to shifting ecological zones and, hence, to changes in the biodiversity and ecosystem services that nature provides on a specific site. These dynamics ask for an adaptive nature conservation policy, continuous monitoring of biodiversity developments in the ecosystems, and strong, informed leadership and balanced decision making in protecting nature against the many conflicting human interests that demand land, water, energy, and other resources. Innovation in many technologies can help reduce the footprint of humanity on biodiversity if, and only if, these new technologies are successfully mainstreamed in practice.

2.6. Waterborne Freight Transport on Rivers in Deltas

This section focuses on freight transport on inland waterways in deltas. It does not address the vulnerabilities of or societal dependency on the global maritime freight transportation system.

Impacts

Climate-related hazards, like drought, floods, sea level rise, and extreme weather, will increasingly impact freight transport on inland waterways in deltas (rivers, canals, lakes), though with large regional variations. Ports and infrastructure, ranging from large hydraulic structures (locks, weirs) to smaller infrastructures, like dams, embankments, groynes, quay walls, etc., will be affected.

Too little water or low flows due to drought in major rivers have already caused serious disruptions to inland waterborne freight transport in recent years, leading to major economic damage. Especially the European rivers (Rhine, Danube, and Dnieper) are vulnerable to drought. Lowering of water levels in free-flowing rivers and thus lowering of water depths and decreasing navigable river width are leading to less cargo per ship, more ship movements, more emissions, and so on. In a weir-controlled river, the capacity of ship locks is reduced; the connection between rivers and canals could become blocked, and the level of canals will become lower due to evaporation, leakage, and limitations in lock operation. The availability of quays and ports is reduced. Too little water may cause additional actions by the waterway manager, such as increased dredging of shallows in rivers and ports, sailing speed limitations, overtaking prohibitions, one-way traffic in certain stretches, fewer locking cycles to prevent saltwater intrusion, and so on. In general infrastructure suffers little damage during periods of low flow. After a drought event, water levels and locking regimes are almost immediately back to normal again, and navigation can return to business as usual. The full recovery from such an extreme event, however, takes more time for all players, as they have to get back to normal operation again.

Extreme rainfall, melting snow and ice, and sea level rise may cause higher river discharges, resulting in river or flash floods. Too much water in the waterways also affects navigability, for example, due to reduced bridge clearances, sailing speed limitations, traffic blocks on specific stretches, blockage of ship locks and other hydraulic structures, flooding of quays, manoeuvring difficulties due to lateral flow, erosion, dune formation on the riverbed, and so on. After a "too much water" event, either due to extreme rainfall or due to excessive river discharge, extensive recovery will be needed, as the waterway and its infrastructure need repair.

Both too little and too much water lead to less cargo transported per day, delays in the arrival of goods, and partly unavailable ports. The cascading impact of too much water on the delay of goods is often smaller because of the shorter duration of the event. On the other hand, repairs after a flood may take longer than after a period of low flow. Sea level rise is a gradual process, not an incident, and asks for structural and permanent interventions. Sea port basins that are behind (and protected by) a storm surge barrier may become less accessible for seagoing vessels if the barrier closes more often.

Extreme weather has a direct impact on inland waterway transport. Asian (Yangze, Mekong, Ganges), North American (Mississippi), and South American (Amazon, Magdalena, Orinoco) rivers are susceptible to typhoons and tropical cyclones. Such extreme storms and the rise in water level (surge) they cause in delta areas may inflict severe damage to waterways and port infrastructure, and cause problems with vessels' manoeuvring. In particular, container vessels are sensitive to storm winds. Extreme rainfall and fog have the same effects on manoeuvring.

Consequently, climate change has a cascading effect on supply chains that depend on transport over waterways, such as voluminous and heavy bulk goods (coal, ore, sand, gravel, oil, gas, etc.). Capacity reduction influences transport prices. It also leads to shrinking stocks and, at some point in time, to limitations or complete production stop. Just-in-time logistics systems are the first to be impacted. Delays in transport have cascading effects on the entire production chain, which will lead to higher prices for end-products. And if such incidents happen frequently—more likely after the mid-21st century—industries might consider relocation.

Rivers and canals in deltas are used for inland navigation, but they have other important functions as well, such as discharging water, ice, and sediment; water supply; and ecological, recreational, social, cultural, and landscape functions. Governments will try to find solutions that accommodate all these functions in a balanced way. Safety against flooding is often the leading function; navigability is just one of the other functions. Adaptation of the waterways for the transport function is often expensive. Adaptation of the fleet and transport logistics might be an alternative. Balanced decision making is even more complicated in the case of transboundary rivers and canals.

Stakeholders

Many stakeholders are involved in the adaptation of waterways, the fleet, vessels, and logistic systems of freight transport to climate change, as multimodal and synchromodal logistic solutions are interlinked with transport over waterways. Local, regional, national, and global governments and authorities (e.g., IMO, PIANC), international river commissions, port authorities, shipping companies, industries using waterway transport, consultancies, constructors, dredging companies, financing and insurance sectors, rail and road transport representatives, and skippers all play a role in this adaptation process. And, in the wider context, also parties dealing with drinking water, flood safety, agriculture, industry, ecology/nature, tourism, fishery, etc., are to be involved in the management of the river, as decisions related to these sectors can influence waterway transport.

Solutions that improve navigability under climate change may be implemented only if they offer win-win scenarios for multiple functions. Furthermore, decision making is challenging due to the diverse financial assessments of adaptation needs among these stakeholders. Long-term uncertainties also complicate planning, including how future cargo volumes and types will evolve, how deltas themselves will develop and adapt, and how different transport modalities will evolve and interact.

Limits to Adaptability and Uncertainties

Uncertainties make the modality of inland waterway transport less reliable and less attractive, particularly in the long run. The effects of climate change on flow regimes are an evident source of uncertainty. Another important uncertainty is the future demand for this transport, with initiatives like China's Belt and Road initiative, the energy transition, shifting centres of industrial production, and near sourcing (industries strive to do all steps in the production process at closer distances). Other factors increasing uncertainty are incidents and the geopolitical situation that influence the maritime and international transport of goods. Incidents like the blockage of the Suez Canal, disputes about the Panama Canal, the security situation in the Gulf of Aden all have an impact on the reliability of global waterborne transport.

Another uncertainty is riverbed degradation of trained (engineered) rivers. Only significant maintenance can ensure navigability in the long run. The same holds for training infrastructure, like groins, locks, dams, weirs, etc. Failure of this infrastructure during operation and renovation, replacement, or maintenance may significantly affect the navigability. Also, the ecological restoration of rivers can affect navigability. The existing fleet is expected to become less robust in future low flow situations, as smaller vessels are gradually replaced by larger ones.

Many waterways are still underutilized for transport, while waterborne transport is a very clean mode of transportation in terms of emissions. Hence, stimulation of this mode of transport seems a logical step, although some ports do not yet have the capacity to handle such an increase. New technological and digital developments, like autonomous and remote shipping and electrification of vessels, are on their way to the market, making waterborne transport more reliable and cleaner, but require adaptation of the legal and regulatory setting of the sector.

Reflections

Inland waterborne freight transport is for many reasons attractive, for bulk and container transport in particular. Uncertainties, however, limit application of this mode of transportation; these uncertainties will increase over time, when the hydrological regime of rivers and in deltas is changing due to climate change and sea level rise. Uncertainties are caused by too little water or too much water in the waterways, and the balancing of the interest of the shipping transport sector with other water-related interests, like flood protection, irrigation and drinking water supply, ecology, etc. Industries and retailers depend on just-in-time delivery of goods they have ordered for their production processes and trade. Multimodal and synchromodal logistic solutions, fleet renewal, improved management of waterways and technological innovations, as well as innovations in the regulatory context for the sector can help to stimulate waterborne transport despite the changing hydrological conditions of waterways. A closer cooperation between river managers, transport companies, and skippers in combination with new technologies for monitoring, and smart sediment and river management could further reduce the uncertainties that threaten the sector in the long run.

Industries may relocate to other areas if climate change impacts on waterways hamper supply systems or increase transport costs, or if they cannot rely on waterborne transport for goods. Disruptions to inland waterway transport can lead to a shift to other modes, primarily road transport, potentially causing traffic jams and large societal impacts, which should be avoided given the large volumes moved by water.

A trend toward near-sourcing, where production steps are conducted at closer distances, is gaining ground, potentially impacting transport volumes and distances. There's also a possibility that construction and transportation via pipelines may increase in the future, or other new modalities could develop quickly.

3. Crosscutting Themes and Issues

3.1. Reflections

As can be seen in the previous chapter, several themes and issues are related to all four domains. In this chapter, a crosscutting analysis of these themes is presented. The four domains of society discussed in Chapter 2—food supply, urban life, ecology/biodiversity, and waterborne freight transport on rivers in deltas—will all be significantly impacted by climate change. They are in urgent need of adaptation, as already nowadays the effects of climate change are visible in the records. Everyone, at every age, will experience the consequences of climate change, although the variability of the impact and the vulnerability of the societies and economies around the globe is extremely large. Agricultural practices, urban planning, buildings and infrastructure, the management of nature, vessels and shipping practices, urban, rural, and natural spaces will all need to change before the end of this century. This is in order to improve capacities to deal with both the changes in average climate and with more frequent and more intensive extreme rainfall, flooding, droughts, heat, and related problems, such as water quality issues and geohazards. This need for adaptation is leveraged by intersecting geopolitical, geoeconomic, technological, environmental, and societal trends and developments in society, as well as by the need for renewal of worn-out buildings and infrastructure. Adaptation consists of structural (physical, spatial) measures, as well as non-structural measures, such as changes in policies, regulations, organization, financing mechanisms, awareness and new knowledge creation, innovation, communication, etc. The next sections will address several of these crosscutting themes and issues.

Essential for effective adaptation is a significant number of boundary conditions. These include geopolitical and social stability at the global, national, regional, and local levels; willingness to co-operate even beyond own interests, to share knowledge, data, and resources, to start dialogues in order to gain insights in the drivers, motives, and preferences of other stakeholders, to respect differences in opinions, to find win-win' solutions, and to timely decide and take action. To create all these enabling conditions evidently is a challenge that all stakeholders must monitor, evaluate, and discuss in open dialogue.

3.2. Governance of Adaptation Efforts

Governments play a crucial role in climate adaptation, as they have the responsibility and the power to change the policies, regulations, financing, organizational infrastructure, spatial planning, information and communication processes, etc. Governmental power is, however, split over many levels and organizations, ranging from small-scale local power to international power (EU, UN, etc.); from political power to legal power to the power of communities (academia, non-governmental organizations, action groups) to the economic power of local to multinational businesses. Decisive power on issues regarding adaptation challenges is usually organized according to the subsidiarity principle; Decisive power is allocated to the lowest level of government possible, with the possibility to upscale issues to a higher level; or, for the higher level of government, to overrule local decisions because of higher interests, legislation, or principles to be considered. This distribution of decision-making power between lower and higher levels of government brings interesting challenges for creating climate resilience, as effective interventions can be made at several levels, by several governmental actors using several strategies to achieve the resilience goals.

Timely, pro-active adaptation avoids damage, casualties, social unrest, and instability. Decision-makers in governments and in a private setting of companies and households are challenged to implement adaptation measures in a timely manner. But what is timely in view of the uncertainty in climate change and sea level rise predictions over the long term? Tipping points are hard to specify timewise. That is why there is good reason to implement adaptation measures not only as soon as possible but preferably in combination with the renewal processes for buildings, infrastructure, engineering works, and machinery. The easiest and cheapest approach to adaptation is to synchronize climate adaptation efforts with the reconstruction or replacement that needs to take place anyway. This holds for both public and private investment in a more resilient environment.

Governance comprises a large number of activities, including developing, drafting, and implementing policies, legislation and regulations, providing capacities and skills to implement the policies and to maintain and operate the measures, and creating an effective organization to do the job and arrange the financing for all this. This in a multiscale approach to the problem and in an “arena” full of stakeholders, all having different interests. This requires intensive communication, consultations, and co-creation of the plan. Stakeholder engagement and public-private partnerships are effective ways to find agreement on interventions—win-win situations—and to get things realized. Studying successful governance approaches to climate adaptation in other countries can help define effective approaches for the local, regional, national, and international river basin scale.

3.3. Availability of Resources

Scarcity of natural resources, like water, space, and building materials, limit the capacity to timely and sufficiently adapt our living environment and our ways of doing. Scarcity of quality water is threatening biodiversity, food production, waterborne bulk transport of goods, and water supply for cities, residents, industries, and vegetation. Space is needed for food production. nature conservation, urban development, and water detention. Sand, clay, gravel, rock, and wood are scarce; mining/harvesting these materials in a sustainable way is challenging. The “battle” for all these resources can be fierce at the local, regional, and national scales. Yet, these resources are indispensable for climate adaptation.

Meanwhile, many resources are spoiled after use; recycling/revolving is impossible so far or not yet implemented. And innovative, alternative solutions are not yet sufficiently available or commercially inviable at a large scale. Think of examples like floating urbanization, vertical farming, other building materials, and circular water supply systems.

Scarcity of resources can act both as a driver of climate-related migration but also a constraint on displacement. Though migrants can no longer stay where they used to live, they are not welcome to resettle in other places for the lack of sufficient resources—in the eyes of the original population. Relocation of industrial/economic activities is often easier, as the receiving region expects to benefit from their presence. Governments play a crucial role in decision making on the allocation of scarce resources. They are mostly dealt with in a transactional way, balancing the financial and non-monetary costs and benefits.

Provision of the infrastructure needed to disclose and allocate these resources for climate adaptation is often a responsibility of governments. Depending on the scale of the project, this can be local regional, or national governments, often working in an alliance. Financing institutions can help provide the necessary funding. Continuity of the availability of infrastructure is essential to keep up resilience in the long run. This continuity requirement implies the need for a managing organization being responsible for this.

Many ways can be imagined on how to organize the availability of natural resources for creating climate resilience in an environmentally friendly way. An in-depth analysis of practices for the allocation of water, space, and building materials (including circular solutions) could lead to a reduction of the environmental footprint of human activity at all spatial scales.

3.4. Governance of Biodiversity

Finding a balance between preservation of biodiversity, disclosing natural resources, and socio-economic development is a delicate challenge in a world where conditions are changing. Climate change will have an impact on present ecosystems and services they provide. Habitats will change and species will disappear and, hopefully, move to new places, where conditions for survival and reproduction are better. Existing nature reserves can lose their role as hotspots of biodiversity, while new hotspot areas emerge and require protection. This will likely lead to conflicts with other spatial claims on land and water bodies. A revision of the current nature protection strategy toward a strategy that allows for more dynamics—while enhancing biodiversity as a whole—seems necessary.

As nature has no legal or political voice of its own, it is primarily up to governments to protect existing and emerging hotspots of biodiversity against the pressures of economic activities, such as farming, urbanization, densification, industrialization, and related transport of goods and people. Another challenge for them is to minimize loss of biodiversity in urban and agricultural areas. Policies and regulations on land use, pesticides, fertilizer use, the use of nature-based, "Green" infrastructure, and nature compensation (to balance biodiversity and ecosystem losses caused by projects like infrastructure development) all help reduce the human footprint on biodiversity in these areas.

The loss of ecosystem services provided by natural areas and by agricultural land can lead to socio-economic changes and likely to migration of economic activities, labour, and people. Changes in habitat conditions can, in the end, threaten social stability, particularly along the countryside with small villages and local economies. Equity then becomes an issue in the governance of these areas.

A well-structured dialogue is needed amongst governments and overarching international organizations on new ways to deal with the changes in biodiversity due to climate change, developing adaptive biodiversity protection and nature conservation policies. How can biodiversity be strengthened, new hotspots be developed, and old hotspots be redeveloped so that the socio-economic impact is minimized?

3.5. Innovation in Adaptation

All four domains seem to rely on innovation to strengthen their climate resilience. New solutions are to be found. In addition to adaptive solutions that protect society and the environment from damage caused by extreme weather events and slow changes in average climate conditions and mean sea level, innovations are needed to minimize the damage and accelerate and improve recovery afterward. Artificial intelligence is often mentioned as a powerful tool but uses enormous quantities of resources, like energy and cooling water. As resources are scarce and reduced, wise use and circularity will become increasingly important issues in the search for better solutions. A new way forward could be found in the fifth industrial revolution, by integration of humans, artificial intelligence, and robotics. The role of governments in facilitating innovative developments by research, testing, and mainstreaming is evident.

Application of innovative technologies often require important changes in the regulatory framework, permitting, and funding. Governments play a crucial role in creating the enabling governance conditions for the market introduction of new products. Market parties often appreciate the role of governments as launching customers. For businesses and private persons, the risk of being one of the first to apply a (likely *almost* mature) new solution is simply too large. Governments are better capable of dealing with this risk of (partial) failure.

The need for innovative solutions for climate and extreme weather resilience has specific characteristics and requirements. Solutions are first meant to avoid or at least minimize the damage of extreme weather events, but they should preferably at the same time provide benefits for society and biodiversity in the day-to-day situation. Multifunctional, green solutions are preferred. These terms of reference ask for an adaptable, integrated combination of nature-based, traditional grey, and smart-control technologies. This is referred to as green-grey infrastructure (GGI). Living labs to develop and test such solutions in practice are an effective way to evaluate and improve their performance.

3.6. Financing Adaptation and Resilient Development

As adaptation is urgent, so is sufficient financing for the necessary climate adaptation measures. This is part of the necessary transition toward a more circular, sustainable, healthy, and adaptable living environment. Article 7, paragraph 9, of the Paris Agreement states that, “[e]ach Party shall, as appropriate, engage in adaptation planning processes and the implementation of actions, including the development or enhancement of relevant plans, policies and/or contributions”. Many countries and regions, however, cannot afford to pay the costs of transformation and will need a private or multilateral budget to co-fund the required efforts. It is up to the governments and their overarching organizations to organize the required budget in a coordinated way, in consultation with the financial sector.

Investments for creating climate resilience by the private sector are made piecemeal and unstructured. Industries have so far hardly spent any money on the protection of their assets against extreme weather and flooding, while the damage of such catastrophes can result in the end of their business and have far-reaching impacts further on in the production chain. Governments could use financial stimuli, like subsidies and tax exemptions, to create financial boundary conditions for necessary adaptation investments in the private sector. And with government funding, more fundamental research on new solutions and pathways toward a climate-resilient society could be initiated—such low TRL[3]- and SRL[4]-level developments can only be funded by national or international governments and multinational businesses.

A political dilemma is the degree to which private, commercial actors should be made responsible for the planning, construction, maintenance, operation, and financing of resilient infrastructure. This could also be done by a governmental agency. Proponents of the market-approach claim that competition between companies is the best way of controlling cost; opponents claim that a not-for-profit agency brings the best value for money.

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[3] TRL = technology readiness level
[4] SRL = symbiosis readiness level

4. Recommendations for Future Research

4.1. Special Policy Studies on Adaptation

Climate change poses major challenges to the world. Since climate change has become inevitable, climate adaptation policy has become inevitable as well. The central recommendation of this Scoping Study is to give climate adaptation a central place on the CCICED research agenda in the coming years. More specifically, it is recommended to **create a task force on climate adaptation** and to **perform Special Policy Studies on climate adaptation policy in four key societal domains**: food production and supply, urban life, ecology/biodiversity, and waterborne freight transport on rivers in deltas. These four domains are increasingly vulnerable to changing weather patterns, extreme weather events, and sea level rise.

Climate is not the only change we are facing. Other important trends and developments relate to geopolitical shifts and pressures, geoeconomic and technological developments, and environmental and societal developments. These trends intersect with the potential ways to deal with climate adaptation. Innovation in technologies and governance is an essential element of these developments. Essential is to include an analysis of such trends and developments in the recommended Special Policy Studies. Successful government policy must address the challenges of climate change across the different domains in an integrated way. However, the societal and economic contexts in the various domains differ significantly. The time scale on which the effects of climate change become noticeable also varies, as does the geographic scale on which they occur. The geographic scale does not always correspond with the political-administrative scale at which policies are made. The stakeholders in the different domains also differ; costs and benefits of policies do not always accrue to the same parties; equity is an issue.

Other crosscutting issues include the four domains' resilience to extreme weather conditions, as well as the creation of enabling conditions for adaptation, such as financing—short term and long term—and impacts on resources, like water, space, raw materials, and energy. This makes formulating and implementing socially acceptable, effective, and efficient climate adaptation policies complicated—but no less necessary. It is recommended to address these crosscutting themes in each of the studies. Alternatively, a crosscutting theme could be used to study how this is addressed in several domains. To maintain coherence between policy options in the individual domains, the next section elaborates on a number of these crosscutting observations—issues that have relevance when identifying feasible policy options.

4.2. Crosscutting Issues

4.2.1. Climate Adaptation: A multidimensional strategic policy challenge

Climate change represents a **multifaceted threat and a significant threat multiplier**. Climate change will continue to impact core societal systems—**profoundly, and for decades to centuries**. While regional impacts vary, the scale and complexity of the challenge are global. Consequently, climate adaptation is a multiscale endeavour, covering all dimensions in space, from global to local, and in time, from today until the next century.

The four domains—**food production and supply, urban life, ecology/biodiversity, and waterborne freight transport**—are interconnected: stress in one area can rapidly cascade into others, creating systemic risks.

Climate change does not act in isolation. **Geopolitical tensions, demographic and economic shifts, technological disruption, social transformations, spatial development, and increasing resource scarcity** (land, water, capital, technology, raw materials) all interact with climate risks. These trends compound the policy challenges, raising the stakes and complicating governance, financing, and coordination efforts.

4.2.2. Adaptation Governance: A call for integrated and collaborative policy action

Timely adaptation means starting now; adaptation processes are extremely slow due to the long lifecycles of existing infrastructure and other assets. Planning and implementation are transitional in nature, requiring fundamental and comprehensive systemic change. **Institutional inertia and sectoral fragmentation** hinder integrated action. Without deliberate change, we risk locking in unsustainable practices that undermine long-term resilience.

Adaptation to climate change demands a **long-term, systemic, and integrated policy approach**—coordinating across infrastructure, logistics, regulation, finance, and human capital, skills, and capacities. Solutions must be **cross-sectoral, multilevel, multiscale, and inclusive**, and they must involve government, industry, civil society, and local communities. Restructuring organizations and creating new alliances to this end seem necessary to go beyond siloed responses. Water governance must be strengthened not only within existing jurisdictions but through **new, multilateral, multiscale governance frameworks**. The uneven distribution of climate impacts and adaptation efforts across regions and populations makes equity an essential policy issue.

Policymakers have a decisive role to play. Strategic leadership to create durable coalitions and institutional innovation will be essential to drive effective climate adaptation and resilience-building over the coming decades. **Stakeholder engagement and public-private partnerships** are essential ingredients of effective and successful planning and implementation of adaptation actions. **Synchronization of adaptation efforts** with public and private investment in renewal, reconstruction, or replacement activities needs to take place anyway.

Adaptation may lead to inequity between those who have and those who have not been able to adapt as well as those in hazardous places versus those in safer environments. This could **trigger migration, a shift of economic activities to other regions, and threaten social stability** at the local, regional, and international scales.

Uncertainty about the timing, location, and scale of climate impacts and, consequently, the **effectiveness of adaptation measures** makes long-term planning difficult. Policymakers, businesses, and individuals must embrace **decision-making under deep uncertainty (DMDU)** frameworks to make robust choices that remain adaptable and viable across multiple future scenarios.

4.2.3. Resources Availability

Water is a critical and vulnerable resource. Increasing exposure to droughts, heat, salinization, extreme rainfall events, sea level rise, and all related problems with water quality and geohazards intensify the complexity of water management. Balancing competing demands—from agriculture, drinking water supply, nature conservation, cooling and shipping, recreation, etc.—requires a **strategic, cross-sectoral approach to fresh water as an essential resource**.

Competition for resources can lead to shifting problems to a neighbouring area, a downstream water system, from land to water, from water to land, to next generations, or from the private to the public arena. **An adaptation planning principle should be to never shift problems**.

Too much water is as destructive as freshwater shortages. Adaptation of infrastructure and buildings and strengthening of coping and recovery capacity of society is needed to **minimize the damage of flooding** caused by extreme rainfall events, fluvial flooding, storm surges, and sea level rise. At the same time**, sponge policies should retain the surplus of water** as a resource for periods of drought.

Governance of space and land use is an essential element of climate adaptation. **New strategies and approaches are needed to deal with sea level rise, storm (typhoon) surges, extreme rainfall, and salinization** threatening large urban and agricultural areas located in river deltas and other low-lying coastal zones. In the longer term, the **living environment of billions of people** and **the production and supply of their food is at risk**.

More space for detention and retention of water is needed for flood protection, drought resilience, heat stress reduction, and related problems with extreme weather. This space is to be found above ground and subsurface. **Urban renewal and land-use planning** should facilitate the creation of such spaces, as permanent land use, or as incidental or temporary ecosystem service.

Changes in cropping patterns, hotspot of biodiversity in need for protection, economic activities, and population (due to migration) because of climate change and intersecting developments will cause changes in land use and related land and water management. **Control over spatial development is needed** at the local, regional, national, and international scales to avoid conflicts.

4.2.4. Protection of Biodiversity and Ecosystems: A Non-negotiable Priority

Ecological zones will shift. Biodiversity in existing protected areas, as well as in urban and agricultural areas **will change**. New hotspots of biodiversity will emerge. This asks for a **transition in nature conservation policies**, moving from nature conservation—preserving the historic biodiversity—toward a dynamic approach, maximizing biodiversity as a whole.

Ecological tipping points pose serious, irreversible, and cascading consequences for the planet. Actions to restore and protect terrestrial, freshwater, and marine ecosystems are essential and urgent, despite uncertainties. Although the societal value of preserving biodiversity is undisputed, financing interventions to achieve this remain complex.

4.2.5. Innovation Next Level

Innovative solutions for climate and extreme weather resilience are **aimed at minimizing the damage of extreme weather events, while at the same time maximizing the benefits** for society and biodiversity in the day-to-day situation. **Green-grey infrastructure**, integrating nature-based, grey solutions with smart control, is a promising development. Combinations with local food production could be interesting.

Governments play a crucial role in creating enabling governance conditions for developing new solutions, creating regulatory conditions for implementation, and introducing new products to the market. They can provide testing grounds, like living labs, for piloting and demonstrating new solutions; act as launching customers; and stimulate the wider market through subsidies, regulations, and capacity building.

4.2.6. Investment Challenges

Major investments in adaptation of urban and rural areas are urgently needed, but they are currently constrained by **fragmented funding mechanisms, short-term financial horizons, and limited alignment between public and private capital flows**. Even as damages and losses accumulate, not all stakeholders perceive the urgency to act.

Transport makes society and economy tick. **Transport of containers and bulk goods on rivers** is an **essential link in the economic network. Adaptation of rivers, canals, and/or vessels is needed** to sustain the essential role of waterborne freight transport. A new policy is needed to secure the long-term future of this link in the transport network.

The absence of predictable financial benefits of adaptation limits the participation of private actors in climate adaptation. Policymakers must lead in **creating an enabling environment for investment in the resilience of nature, society, and economy**, including clear incentives, risk-sharing mechanisms, and long-term financial strategies for public and private investors.

4.3. Research Questions to Be Addressed and Disciplines Involved

To identify effective and efficient climate adaptation policies in future Special Policy Studies, and to address all relevant issues mentioned above, many sub-questions can be formulated. Each of these questions requires specific combinations of expertise to investigate options and alternatives and to come up with policy recommendations. Below is a first attempt to outline the fields of expertise needed in these Special Policy Studies.

How can effective cross-sectoral and multilevel cooperation be fostered in climate adaptation policymaking? Effective adaptation requires coordination across governance levels, sectors, and societal actors. Structural collaboration is essential. How to operationalize subsidiarity in this context? Relevant disciplines for this question are multilevel governance, public administration, political science, communication, and stakeholder engagement.

How can robust governance, financing, and decision-making models be developed for water management under deep uncertainty of climate change and intersecting future developments? *Climate change intensifies variability in water supply, demand, water quality, and related geohazards. Policymakers require frameworks that are just, efficient, and resilient to long-*

term uncertainties. Relevant disciplines for this question are water governance, land-use management, decision sciences (including DMDU), hydrology, climate science, and legal studies.

How can decision making under deep uncertainty (DMDU) approaches be effectively integrated into public policy processes? *Traditional planning tools fall short under structural uncertainty. DMDU enables adaptive interventions and forward-looking strategies.* Relevant disciplines for this question are public policy and administration, systems thinking, resilience management, innovation management, and behavioural sciences.

What are effective strategies for preventing or overcoming institutional and infrastructural lock-ins in climate-sensitive systems? *Rigid institutional structures can block transitions to climate resilience. Insight into unlocking mechanisms is critical.* Relevant disciplines for this question are transition studies, innovation systems, institutional economics, and systems dynamics.

What are the most effective allocation models for balancing competing freshwater demands across sectors, such as agriculture, drinking water, green water for nature, and transport? R*ising water stress is driving conflicts between uses and users. Equitable and adaptive allocation mechanisms are urgently needed. How to operationalize the subsidiarity principle in this context?* Relevant disciplines for this question are environmental economics, hydrology, water management, agricultural science, urban planning and design, ecology, transport studies, and water law.

What are effective control mechanisms for the adaptation of land use—including the related land and water management and building regulations—to cope with climate change and its impacts on food production, urbanization, biodiversity protection, and industrial activities? *Changing crops, migration, creation of new nature protection areas, shifting /relocation of industrial activities, and the need for space for water detention will produce new tensions in the battle for space. Equitable and adaptive space allocation mechanisms are urgently needed. How to operationalize the subsidiarity principle in this context?* Relevant disciplines for this question are spatial planning and design, environmental economics, hydrology, water management, agricultural science, urban planning and design, ecology, public policy, and administration.

What types of financing models can sustainably engage private sector actors in creating a climate- and extreme weather-resilient urban, rural, and natural environment, in biodiversity protection and ecosystem restoration? *Private investment in climate and extreme weather resilience and nature-based solutions is still limited. Financial innovation is needed to mobilize capital and de-risk investments.* Relevant disciplines for this question are environmental finance, biodiversity conservation, business, and ecological,