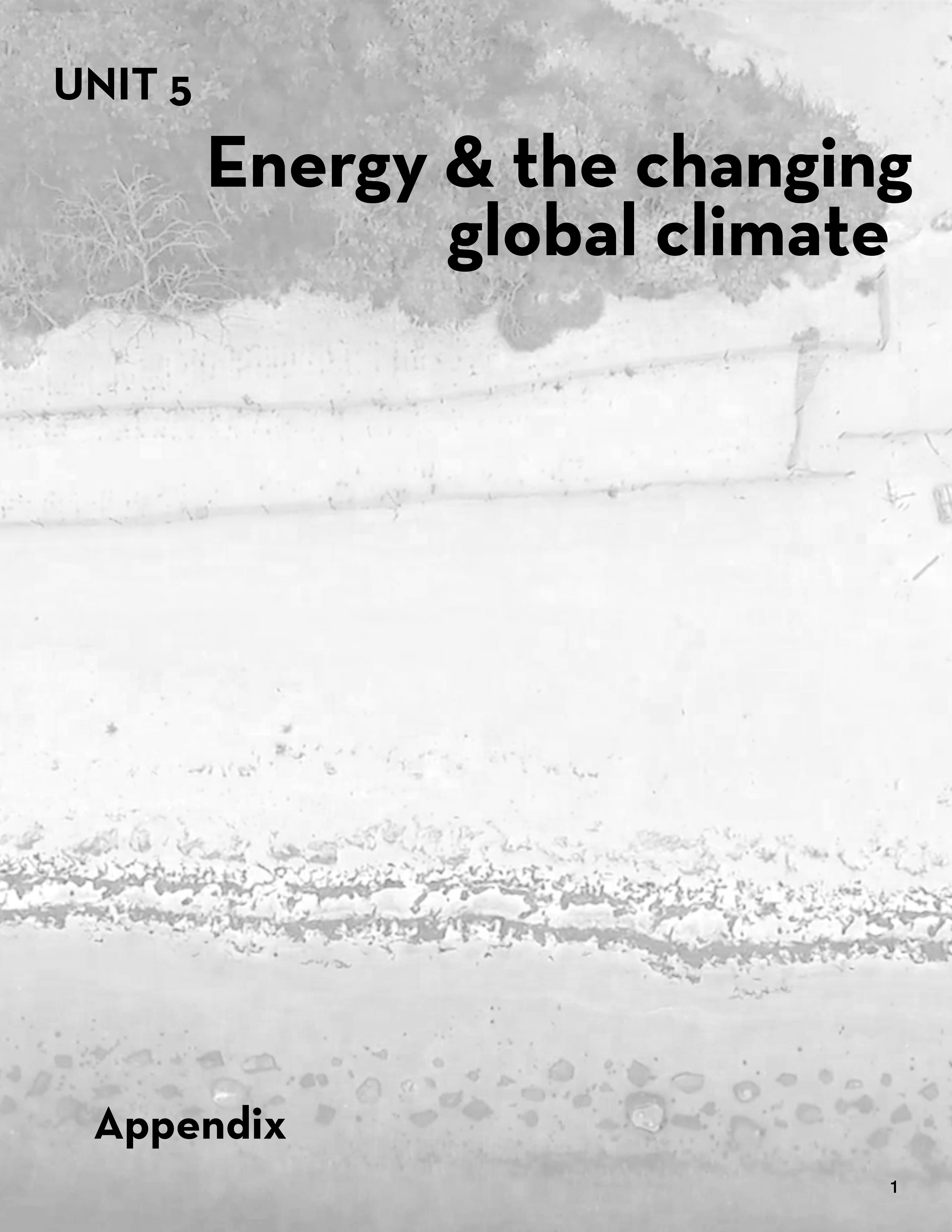

UNIT 5

Energy & the changing global climate

Appendix

Data analysis

Use the interactive graphs to analyze the trends in greenhouse gas concentrations since the year 800,000 BCE. Consider:

> **How has the atmospheric concentration of carbon dioxide changed over time?**
>
> **What are the major inflection points? What could be the cause of this?**
>
> **What does the trend in the last three centuries indicate about the cause of increasing atmospheric carbon dioxide?**

Source

Environmental Protection Agency | Climate indicators explorer

> edap.epa.gov/public/extensions/CCIDataViewer/CCIDataViewer.html

Our World in Data | Global CO_2 atmospheric concentrations

> ourworldindata.org/grapher/global-co-concentration-ppm

Video and data analysis

View the video and graphs, based on data from NASA, that depict trends in arctic sea ice coverage since 1979.

What happens over the course of a year?

What happens over the course of the 40-year interval?

What might be causing these changes?

How might this be an example of a climate feedback loop?

Source

NASA Climate Change | Disappearing Arctic sea ice

youtu.be/hlVXOC6a3ME

climate.nasa.gov/vital-signs/arctic-sea-ice/

Climate change mitigation is a global problem that requires global solutions. To date, these solutions have mostly taken the form of international agreements that set out each country's intended greenhouse gas emission reductions, to be achieved by certain dates. The most recent of these, the 2015 Paris Agreement, aims to make sure the global average temperature increases less than 2°C above pre-Industrial Revolution levels. More than 1°C of warming has already occurred, and scientists warn the world is on track to reach 3°C of warming by the end of the century if mitigation goals are not successfully met. The Paris Agreement is not legally binding; countries' commitments are voluntary, national governments have total autonomy in figuring out how they will meet their commitments, and failure to do so cannot be penalized under international law. Some climate activists have argued that the agreement's commitments are insufficiently aggressive, and scientists warn that many countries are not on track to meet their promised reductions.

Scenario

You are members of a committee under the United Nations Environmental Program, tasked with exploring an update to the Paris Agreement that would attempt to reconcile the voluntary nature of the Agreement with greater oversight. Under the new framework, countries would have to provide a specific plan of measures to be taken in three areas of climate change mitigation: greenhouse gas emission reduction, renewable energy transition, and carbon sequestration. The task of the committee is to rank different proposed policies for accomplishing these goals. These rankings would then be translated into a point system used to score countries' mitigation plans. The framework is to be presented for debate and ratification at the next UN Congress Of Parties to the Agreement, the global meeting of signatories to the international climate accords.

Instructions

With your group, discuss the pros and cons of each strategy, and then rank them according to how much mitigation credit you believe a country should receive for including each strategy in their mitigation plan.

If this strategy tries to change behavior, whose behavior, and how does it do so?

Does this strategy rely on private or public funding? How might this affect its likelihood of success?

What dynamics support or undermine this strategy reaching a scale that would allow it to have the desired effect?

What are the arguments for and against this strategy? Can you think of solutions to any critiques that are mentioned in these policy briefs?

On whom in society does the burden of this strategy fall? Who benefits?

After discussion, come back together as a class and present your ranking, describing what factors you considered, how you ranked each strategy, and why. Then, for each mitigation category, vote as whole class to determine the committee's overall ranking.

A Groups: Regulate greenhouse gas emissions

Carbon taxes

Carbon taxes are a “market based solution” that require owners of businesses responsible for greenhouse gas emissions—like the fossil fuel industry or manufacturers that use fossil fuels—to pay a set fee for each ton of carbon dioxide their industrial activity releases into the atmosphere. Cutting emissions reduces tax payments. The tax may increase over time in order to encourage the complete transition to renewable energy. Critics of this strategy argue that companies may pass the cost of a carbon tax on to consumers, disproportionately impacting those who cannot opt out of high-emissions consumption patterns. For example, in countries like the US where rural populations do not have access to public transit networks, car ownership may be functionally compulsory. If, as in the US, rural populations are generally lower-income than urban populations, then a carbon tax that raised the cost of gasoline could be considered a “regressive tax,” as it would primarily affect the poorest members of society.

Cap-and-trade

Cap-and-trade systems are also “market based,” using laws and regulations to limit (“cap”) carbon emissions from different industrial sectors, in an international system, different countries. These emissions permits can then be bought and sold in a market. For instance, if a given sector of the economy was limited to emitting 500 tons of carbon, and there were 50 companies in that sector, each would be permitted to produce up to 10 tons of carbon emissions. Companies could then buy and sell permits amongst themselves, allowing lower-emitting entities to make additional money off of their emissions cuts. The cap would be lowered over time, in order to encourage the complete transition to renewable energy. Critics of this strategy warn that emissions limits are difficult to enforce and that impacts could potentially be inequitable, as wealthier industries or countries could buy up a lion’s share of emissions permits, limiting industrial activity in already poor regions.

Inter- or intranational legal enforcement

Under present international climate agreements, emissions reduction targets are not binding legal commitments, and there are no penalties for failure to meet targets. Implementing this strategy would could ratify emissions reduction agreements as legally-binding treaties which would be enforceable by international courts, potentially resulting in fines or prison sentences for individuals responsible for violating the terms of the agreements. Or, countries could commit to holding economic actors within their own borders accountable, establishing legal emissions limits, violations of which would be punishable under national law and could result in fines and prison sentences. Lastly, establishing legally binding obligations could allow citizens to file class action lawsuits against their governments in national or international civil courts. Critics warn that imposing hard limits could lead to economic disruption; national legal limits are likely to be challenged in court, delaying the emissions reduction timeline.

Reduce local carbon footprints

National governments may supply funding at the local level to encourage individuals and communities to adopt a less energy-intensive lifestyle. Specific mechanisms could include public education campaigns, financial incentive programs like technology buy-backs or local tax credits, and green building codes to require energy efficiency in newly built structures. National funding can also support the development of energy-efficient national systems like electrified transit and sustainable regional food networks. Critics of this strategy argue that because industry is by far the largest contributor to greenhouse gas emissions, individually-focused interventions potentially distract from the real issue. They also warn that decentralized interventions may be hard to track and impacts may be hard to measure.

B Groups: Transition to renewable energy sources

Corporate renewable energy development subsidies

Developers of renewable energy projects like large-scale wind farms, solar, and geothermal power plants can receive tax credits, wherein the national government forgives large portions of their tax liability. Alternately, rather than forgiving lax liability after the fact, national governments can fund renewable energy developments at the outset through grant-making or providing loans at favorable interest rates. These subsidies both lower the amount of capital necessary to develop projects, and make projects more profitable for potential investors. Critics warn that such subsidies have not historically produced a sufficiently large increase in renewable energy production, making renewable energy sources like wind-powered electricity significantly more costly to the public than non-renewable sources. Critics also argue that configuring subsidies as tax forgiveness favors for-profit energy producers and penalizes not-for-profit producers, who do not pay taxes to national governments.

Consumer- and community-owned renewable energy development subsidies

Subsidies to support the development of renewable energy resources are directed to individual consumers and communities of consumers, often operating through neighborhood-based nonprofits. Funding enables the installation of small-scale renewable energy sources close to the point of consumption, often in the form of solar panels installed on the roofs of buildings. Subsidies enable individuals and groups to install renewable energy infrastructure who otherwise would not have access to sufficient capital. Consumer- and community-owned renewables can stimulate economic development when producers sell extra energy back to the grid. Critics of this strategy warn that it may be difficult to reach an impactful scale of renewable energy development quickly enough through this piecemeal approach, and effects may be hard to measure.

Publicly-owned, renewable, resilient energy grid

This strategy seeks national, public (government) ownership of renewable energy resources alongside efforts to renovate the Grid — the network of energy distribution — for resilience, efficiency, and flexibility. No private investment is required; rather, public funding is secured through levying taxes. This is the main point that critics of this strategy raise: a great deal of revenue would need to be necessary for national governments to create a fully centralized, updated, carbon-neutral Grid. Critics may also argue that government-run projects are less efficient than private projects, but in fact, data shows that publicly-owned energy systems consistently produce less expensive, more reliable power.

C Groups: Sequester atmospheric carbon

Carbon offsets

This "market-based" policy supports the creation and maintenance of carbon sinks in the form of forests and wetlands. Under a system of limited greenhouse gas emissions, industrial and corporate actors can fund or directly administer carbon sink restoration projects in order to "offset" their emissions. For example, if ten acres of forest can absorb one ton of carbon, then a given country that is over its carbon emissions limit by two tons can offset the overage by planting or restoring twenty acres of forest. Critics argue that carbon offsets can be used as a "get out of jail free card" that perpetuate fundamentally unsustainable economic and environmental paradigms. Further, critics warn that the strategy could have inequitable effects, with richer countries paying poorer ones to offset their carbon emissions by maintaining natural landscapes; meanwhile, richer countries would continue to build wealth through industrial production and poorer countries would have less access to those mechanisms.

Green building methods

This strategy leverages the built environment to sequester carbon, both directly, through the inclusion of green space in building and site designs, and indirectly, in the selection of building materials. Green roofs and greenspace in site plans sequester carbon through photosynthesis, while the use of timber in construction represents the sequestration performed by forests where trees are grown and harvested; timber can also replace carbon-intensive materials like steel. Nations may promote these strategies by providing subsidies in the form of tax credits to developers and property owners, funding research and education efforts, or legally mandating certain standards and practices through local building codes. Critics argue that sequestration in the built-environment is insufficient to offset the energy consumption and greenhouse gas emissions of material production, site development, and construction, and that limiting development overall is more important.

Agricultural carbon sequestration

Organic agricultural practices may contribute significantly to carbon sequestration, primarily by increasing the carbon content of soil. This is accomplished by eliminating the use of pesticides and herbicides; replacing industrial fertilizers with organic manure; limiting plowing through no-till or crop-rotation farming; and designing plantings around leguminous and cover crops. Nations can provide subsidies in the form of tax credits to organic farmers, favorable lending to start-up organic farmers, and grants to land-trust programs that protect farmland from future development. Nations can also legally require food producers within their borders to adopt certain practices or meet sequestration requirements. Critics warn that the science behind soil sequestration is underdeveloped, making its long-term benefits or sustainability uncertain, while the carbon footprint of other aspects of farming is significant and well established. Critics also argue that carbon added to soils through manure is not actually sequestered from the atmosphere, but rather derived from plant matter consumed and digested by livestock; the ability to "add" carbon to the soil via this mechanism depends on the expansion of livestock herds, which emit large quantities of methane. Lastly, critics argue that the implementation of this strategy through national policy incentivizes the expansion of agricultural lands, often at the expense of woodlands that might be more effective carbon sinks, while lessening the impetus to reduce greenhouse gas emissions over-all.

5.1 Renewable energy and mitigation | Research and report

The transition to a fully renewable Energy Grid is an essential piece of any mitigation effort. But how do different renewable energy sources stack up in the effort to reduce emissions? Renewables can be evaluated on several different accounts, including their technological efficiency in transforming a natural source of energy into power; their spatial and environmental impact; and their ability to meet the energy demands of contemporary life. In the effort to scale up the renewable Grid, it's important to analyze how different renewable energy sources best serve the needs of communities or industries and whether they represent the best investment of government funding and political capital.

Instructions

Using internet sources, research to compare two renewable energy sources from this list:

- **Solar**
- **Wind**
- **Hydropower**
- **Geothermal**
- **Biofuels**

Answer the following questions about each:

How does this renewable energy technology work?

What kind of energy does it produce, and how can that energy be used?

Where is this renewable energy source most available, globally? Where is it not available?

Evaluate the advantages and disadvantages of each along the following metrics:

- **Ability to scale to meet national and global energy demands**
- **Consistency and availability to meet variable energy demands**
- **Efficiency of technology at converting energy source into electricity, compared to fossil fuels**
- **Cost of technology production, installation, and maintenance**
- **Viability as part of a community-owned or public utility working towards development of an equitable renewable grid**
- **Particular strengths and weaknesses**

Then, having gathered this information, write a research memo recommending which one of the two renewable energy sources you researched should be prioritized for governmental subsidy at the national level. Consider:

Which communities and industries will be best served by this renewable energy resource?

What are the most common points of criticism of, or resistance to this resource? How do you respond to these points?

Data analysis

What are the outcomes in each Shared Socioeconomic Pathway? What things influence the outcome within each pathway?

How do SSPs tell the story of climate change and its environmental impacts?

What is the impact of framing the narrative like this for our understanding of the cause and effect of climate change?

Source

"The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview," K. Riahi et al, Global Environmental Change 42 (2017) 153–168

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The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview

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ABSTRACT

This paper presents the overview of the Shared Socioeconomic Pathways (SSPs) and their energy, land use, and emissions implications. The SSPs are part of a new scenario framework, established by the climate change research community in order to facilitate the integrated analysis of future climate impacts, vulnerabilities, adaptation, and mitigation. The pathways were developed over the last years as a joint community effort and describe plausible major global developments that together would lead in the future to different challenges for mitigation and adaptation to climate change. The SSPs are based on five narratives describing alternative socio-economic developments, including sustainable development, regional rivalry, inequality, fossil-fueled development, and middle-of-the-road development. The long-term demographic and economic projections of the SSPs depict a wide uncertainty range consistent with the scenario literature. A multi-model approach was used for the elaboration of the energy, land-use and the emissions trajectories of SSP-based scenarios. The baseline scenarios lead to global energy consumption of 400–1200 EJ in 2100, and feature vastly different land-use dynamics, ranging from a possible reduction in cropland area up to a massive expansion by more than 700 million hectares by 2100.

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The associated annual CO_2 emissions of the baseline scenarios range from about 25 $GtCO_2$ to more than 120 $GtCO_2$ per year by 2100. With respect to mitigation, we find that associated costs strongly depend on three factors: (1) the policy assumptions, (2) the socio-economic narrative, and (3) the stringency of the target. The carbon price for reaching the target of 2.6 W/m^2 that is consistent with a temperature change limit of 2 °C, differs in our analysis thus by about a factor of three across the SSP marker scenarios. Moreover, many models could not reach this target from the SSPs with high mitigation challenges. While the SSPs were designed to represent different mitigation and adaptation challenges, the resulting narratives and quantifications span a wide range of different futures broadly representative of the current literature. This allows their subsequent use and development in new assessments and research projects. Critical next steps for the community scenario process will, among others, involve regional and sectoral extensions, further elaboration of the adaptation and impacts dimension, as well as employing the SSP scenarios with the new generation of earth system models as part of the 6th climate model intercomparison project (CMIP6).

1. Introduction

Scenarios form an essential part of climate change research and assessment. They help us to understand long-term consequences of near-term decisions, and enable researchers to explore different possible futures in the context of fundamental future uncertainties. Perhaps most importantly, scenarios have been crucial in the past for achieving integration across different research communities, e.g., by providing a common basis for the exploration of mitigation policies, impacts, adaptation options and changes to the physical earth system. Prominent examples of such scenarios include earlier scenarios by the Intergovernmental Panel on Climate Change (SA90, IS92, and SRES) and the more recent Representative Concentration Pathways (RCPs) (Moss et al., 2010; van Vuuren et al., 2011). Clearly, such 'community' scenarios need to cover many aspects: they need to describe different climate futures, but ideally also cover different possible and internally consistent socioeconomic developments. Research has shown that the latter may be just as important for climate impacts and adaptation possibilities as for mitigation options (Field et al., 2014; Morita et al., 2000).

Moss et al. (2010) described the "parallel process" of developing new scenarios by the climate research community. This process includes the Representative Concentration Pathways (RCPs), which cover the climate forcing dimension of different possible futures (van Vuuren et al., 2011), and served as the basis for the development of new climate change projections assessed in the IPCC Fifth Assessment Report (IPCC, 2013; Taylor et al., 2012). Based on two main initial proposals by Kriegler et al. (2012) and Van Vuuren et al. (2012), the design of the socioeconomic dimension of the scenario framework was also established (Ebi et al., 2014; Kriegler et al., 2014a; O'Neill et al., 2014; van Vuuren et al., 2014). The new framework combines so-called Shared Socioeconomic Pathways (SSPs) and the RCPs (and other climate scenarios) in a Scenario Matrix Architecture.

This article is the overview paper of a Special Issue on the SSPs where we describe critical subsequent steps to make the framework operational. Elaborate descriptions of the different SSP elements are summarized in fourteen other articles in this special issue complementing this overview paper. To this end, we present new SSP narratives (O'Neill et al., 2016a) and associated quantitative descriptions for key scenario drivers, such as population (KC and Lutz, 2016), economic growth (Crespo Cuaresma, 2016; Dellink et al., 2016; Leimbach et al., 2016), and urbanization (Jiang and O'Neill, 2016). These projections and their underlying narratives comprise the basic elements of the SSPs and have been further used for the development of integrated scenarios, which elaborate the SSPs in terms of energy system and land-use changes (Bauer et al., 2016; Popp et al., 2016) as well as resulting air pollutant (Rao et al., 2016) and greenhouse gas emissions and atmospheric concentrations. A detailed discussion of integrated scenarios for the individual SSPs (Calvin et al., 2016; Fricko et al., 2016; Fujimori et al., 2016; Kriegler et al., 2016; van Vuuren et al., 2016) complement the special issue.

The SSPs and the associated scenarios presented here are the result of an iterative community process, leading to a number of important updates during the last three years. Considerable attention was paid during the design phase to ensure consistency between the different elements. By providing an integrated description – both in terms of the qualitative narratives as well as the quantitative projections – this paper aims at providing a broad overview of the main SSP results.

The process of developing the SSPs and IAM scenarios involved several key steps. First, the narratives were designed and subsequently translated into a common set of "input tables", guiding the quantitative interpretation of the key SSP elements and scenario assumptions (e.g., on resources availability, technology developments and drivers of demand such as lifestyle changes – see O'Neill et al. (2016a) and Appendix A of the Supplementary material). Second, the narratives were translated into quantitative projections for main socioeconomic drivers, i.e., population, economic activity and urbanization. Finally, both the narratives and the associated projections of socio-economic drivers were elaborated using a range of integrated assessment models in order to derive quantitative projections of energy, land use, and emissions associated with the SSPs.

For the quantitative projections of economic growth and the integrated energy-land use-emissions scenarios, multiple models were used, which provided alternative interpretations of each of the SSPs. Among these interpretations so-called "marker" SSPs were selected as representative of the broader developments of each SSP. The selection of markers was guided by two main considerations: the internal consistency of the full set of SSP markers, and the ability of the different models to represent distinct characteristics of the storylines. Identifying the markers involved an iterative process with multiple rounds of internal and external reviews. The process helped to ensure that marker scenarios were particularly scrutinized in terms of their representativeness for individual SSPs and that the relative differences between models were well represented in the final set of SSP markers. It is important to note that while the markers can be interpreted as representative of a specific SSP development, they are not meant to provide a central or median estimate. The "non-marker" scenarios are important, since they provide insights into possible alternative scenario interpretations of the same basic SSP elements and storylines, including a first-order estimate of the (conditional) uncertainties attending to model structure and interpretation/implementation of the storylines. In addition, the non-marker scenarios help to understand the robustness of different elements of the SSPs (see also Section 7). An important caveat, however, is that the SSP uncertainty ranges are often based on different sample sizes, as not all modelling teams have so far developed a scenario for each of the SSPs. Note also that our results should not be regarded as a full representation of the underlying uncertainties. The results are based on a relatively limited number of three models for the GDP projections and six models for the IAM scenarios. Additional models or other variants of the SSP narratives would influence some of our results. As part of future research, additional SSP scenarios are expected to be generated by a wide range of IAMs to add further SSP interpretations. This will further increase the robustness of uncertainty ranges for individual SSPs and estimates of differences between SSPs. The set of results comprises quantitative estimates for population, economic growth, energy system parameters, land use, emissions, and concentrations. All the data are publicly available through the interactive SSP web-database at https://secure.iiasa.ac.at/web-apps/ene/SspDb.

The current set of SSP scenarios consists of a set of baselines, which provides a description of future developments in absence of new climate policies beyond those in place today, as well as mitigation scenarios which explore the implications of climate change mitigation policies. The baseline SSP scenarios should be considered as reference cases for mitigation, climate impacts and adaptation analyses. Therefore, and similar to the vast majority of other scenarios in the literature, the SSP scenarios presented here do not consider feedbacks from the climate system on its key drivers such as socioeconomic impacts of climate change. The mitigation scenarios were developed focusing on the forcing levels covered by the RCPs. The resulting combination of SSPs with RCPs constitutes a first comprehensive application of the scenario matrix (van Vuuren et al., 2014) from the perspective of emissions mitigation (Section 6.3). Importantly, the SSPs and the associated scenarios presented here are only meant as a starting point for the application of the new scenario framework in climate change research. Important next steps will be the analysis of climate impacts and adaptation, the adoption of SSP emissions scenarios in the next round of climate change projections and the exploration of broader sustainability implications of climate change and climate policies under the different SSPs.

In the remainder of the paper we first describe in Section 2 the methods of developing the SSPs in more detail. Subsequently, Section 3 presents an overview of the narratives. The basic SSP elements in terms of key scenario driving forces for population, economic growth and urbanization are discussed in Section 4. Implications for energy, land-use change and the resulting emissions in baseline scenarios are presented in Section 5, while Section 6 focuses on the SSP mitigation scenarios. Finally, Section 7 concludes and discusses future steps in SSP research.

2. Methods

2.1. Basic elements and baseline scenarios

The SSPs have been developed to provide five distinctly different pathways about future socioeconomic developments as they might unfold in the absence of explicit additional policies and measures to limit climate forcing or to enhance adaptive capacity. They are intended to enable climate change research and policy

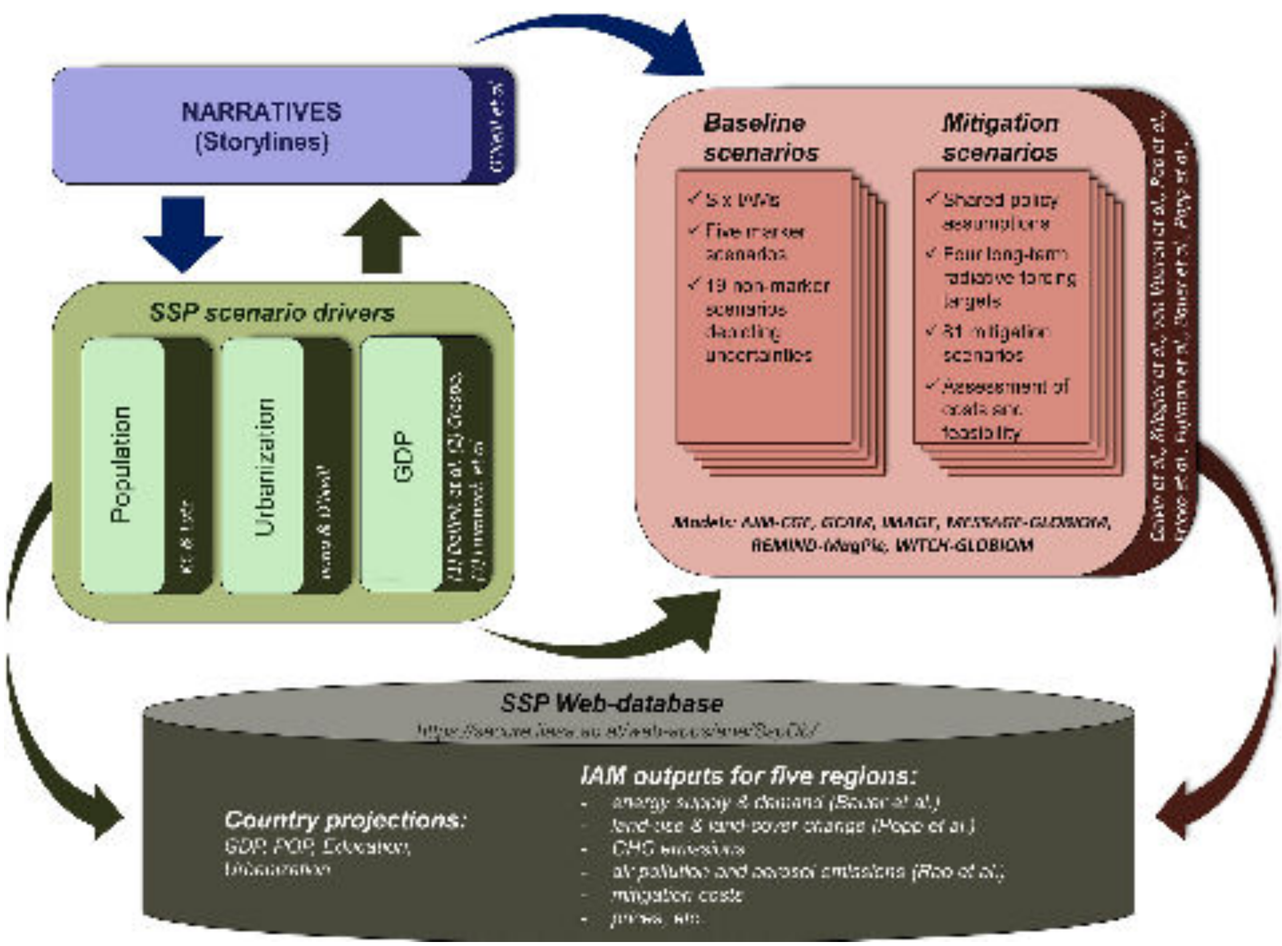

Fig. 1. Schematic illustration of main steps in developing the SSPs, including the narratives, socioeconomic scenario drivers (basic SSP elements), and SSP baseline and mitigation scenarios.

analysis, and are designed to span a wide range of combinations of challenges to mitigation and adaptation to climate change. The resulting storylines, however, are broader than these dimensions alone – and in fact some of their elements nicely align with scenarios from earlier exercises in the past (Nakicenovic and Swart, 2000; van Vuuren and Carter, 2014).

The development of the SSPs comprised five main steps as illustrated in Fig. 1:

- Design of the *narratives*, providing the fundamental underlying logic for each SSP, focusing also on those elements of socioeconomic change that often cannot be covered by formal models.
- *Extensions of the narratives* in terms of model “input tables”, describing in qualitative terms the main SSP characteristics and scenario assumptions (see Supplementary material).
- Elaboration of the basic elements of the SSPs in terms of *demographic and economic drivers* using quantitative models.
- Elaboration of developments in the energy system, land use and greenhouse gas and air pollutant emissions of the *SSP baseline scenarios* using a set of Integrated Assessment Models (IAMs)
- Elaboration of these elements by IAMs for the *SSP mitigation scenarios*.

The narratives of the SSPs (O’Neill et al., 2016a) were developed using large expert teams that together designed the storylines and ensured their internal consistency. Similarly, different interdisciplinary groups of experts (5–10 people) participated in the development of the model input tables, ensuring sufficient discussion on the interpretation of the different elements (see, e.g., O’Neill et al. (2016a), KC and Lutz (2016), and Appendix A and E of the Supplementary material).

For each SSP, a single population, education (KC and Lutz, 2016) and urbanization projection (Jiang and O’Neill, 2016) was developed, while three different economic modeling teams participated in the development of the GDP projections (Crespo Cuaresma, 2016; Dellink et al., 2016; Leimbach et al., 2016). The GDP projections by Dellink et al. were selected as the representative ‘marker’ SSP projections. As a next step, the IAM models used the marker GDP and population projections as quantitative inputs for developing the SSP scenarios. Six alternative IAM models were used for the quantification of the SSP baseline scenarios. For each SSP a single IAM interpretation was selected as the so-called representative marker scenario for recommended use by future analyses of climate change, its impacts and response measures (recognizing that often the full space of available scenarios cannot be analyzed). In addition to the marker scenario, each SSP was interpreted by other IAM models, leading to multiple non-marker IAM scenarios for each SSP narrative. The multi-model approach was important for understanding the robustness of the results and the (conditional) uncertainties associated with the different SSPs.

Differences between the full set of SSP scenarios include those that are attributable to differences across the underlying narratives, differences in the quantitative interpretation of a given narrative, and differences in IA model structure. For a given SSP, it is useful to have a variety of different quantitative scenarios, since they help to highlight the range of uncertainty that attends to model structures and different interpretations of SSPs. Similarly, multiple SSP scenarios derived from a single IAM helps highlight differences due to variation of the SSP input assumptions alone (see, e.g., the marker papers listed in Table 1). In sum six IAM models participated in the scenario development and five models provided the associated marker scenarios of the five SSPs (see Table 1). Finally, the GHG and aerosol emissions from the IAM models were used in the simple climate model MAGICC-6 (Meinshausen et al., 2011a, 2011b) in order to provide insights into possible consequences for concentrations and related climate change. More documentation on the model systems used in this paper can be found in Appendix D of the Supplementary material.

2.2. Development of mitigation scenarios

We use the baseline SSP scenarios as the starting point for a comprehensive mitigation analysis. To maximize the usefulness of our assessment for the community scenario process, we select the nominal RCP forcing levels of 2.6, 4.5, and 6.0 W/m^2 in 2100 as the long-term climate targets for our mitigation scenarios. A key reason for selecting these forcing levels is to provide a link between the SSPs and the RCPs developed in the initial phase of the community scenario process. Establishing this link is important as it will enable the impacts, adaptation and vulnerability (IAV) community to use the information on the SSPs in conjunction with the RCP climate projections archived in the CMIP5 database (Taylor et al., 2012). We thus try to get as close as possible to the original RCP forcing pathways, which sometimes deviate slightly from the 2100 forcing level indicated by the RCP-label (see Section 2 and Section 5 of the Supplementary material). In addition, we explore mitigation runs for a target of 3.4 W/m^2. This intermediate level of radiative forcing (approximately 550 ppm CO_2-e) is located between very stringent efforts to reduce emissions given by

Table 1
IAM models as used for the development of the SSP scenarios (for further details on SSP scenarios by model see also Table 2 of the Supplementary material).

Model name (hosting institution)	SSP Marker	SSP coverage (# of scenarios)	Model category	Solution Algorithm
AIM/CGE (NIES)	SSP3 (Fujimori et al., 2016)	SSP1, SSP2, SSP3, SSP4, SSP5 (22 scenarios)	General equilibrium (GE)	Recursive dynamic
GCAM (PNNL)	SSP4 (Calvin et al., 2016)	SSP1, SSP2, SSP3, SSP4, SSP5 (20 scenarios)	Partial equilibrium (PE)	Recursive dynamic
IMAGE (PBL)	SSP1 (van Vuuren et al., 2016)	SSP1, SSP2, SSP3, (13 scenarios)	Hybrid (systems dynamic model and GE for agriculture)	Recursive dynamic
MESSAGE-GLOBIOM (IIASA)	SSP2 (Fricko et al.,2016)	SSP1, SSP2, SSP3, (13 scenarios)	Hybrid (systems engineering partial equilibrium models linked to aggregated GE)	Intertemporal optimization
REMIND-MAgPIE (PIK)	SSP5 (Kriegler et al.,2016)	SSP1, SSP2, SSP5, (14 scenarios)	General equilibrium (GE)	Intertemporal optimization
WITCH-GLOBIOM (FEEM)	–	SSP1, SSP2, SSP3, SSP4, SSP5 (23 scenarios)	General equilibrium (GE)	Intertemporal optimization

RCP2.6 (approximately 450 ppm CO_2-e) and less stringent mitigation efforts associated with RCP4.5 (approximately 650 ppm CO_2-e). Exploring the level of 3.4 W/m^2 is particularly policy-relevant, considering, for example, recent discussions about scenarios and the attainability of the 2 °C objective, which is broadly in line with scenarios aiming at 2.6 W/m^2 (Kriegler et al., 2015, 2014b; Riahi et al., 2015; Victor and Kennel, 2014). On the other hand, recent developments in international climate policy (e.g., the newly adopted Paris Agreement under the United Nations Framework Convention on Climate Change) have renewed attention to the importance of exploring temperature levels even lower than 2 °C, in particular a long term limit of 1.5 °C. These developments were too recent to be taken up already, but are considered in forthcoming work.

Finally, since policies and their effectiveness can be expected to vary consistent with the underlying socioeconomic storylines, we define so-called Shared Policy Assumptions: SPAs (Kriegler et al., 2014a). The SPAs describe the climate mitigation policy environment for the different SSPs. They are discussed in more detail in Section 6 of the paper (and the Appendix B and Section 6 of the Supplementary material).

3. SSP narratives

The SSP narratives (O'Neill et al., 2016a) comprise a textual description of how the future might unfold in terms of broad societal trends. Their main purpose is to provide an internally consistent logic of the main causal relationships, including a description of trends that are traditionally difficult to capture by models. In this sense, the SSP narratives are an important complement to the quantitative model projections. By describing major socioeconomic, demographic, technological, lifestyle, policy, institutional and other trends, the narratives add important context for a broad user community to better understand the foundation and meaning of the quantitative SSP projections. At the same time, the narratives have been a key input into the modeling process, since they underpin the quantifications and guided the selection of assumptions for the socioeconomic projections and the SSP energy and land-use transitions described in this special issue.

Consistent with the overall scenario framework, the narratives are designed to span a range of futures in terms of the socioeconomic challenges they imply for mitigating and adapting to climate change. Two of the SSPs describe futures where challenges to adaptation and mitigation are both low (SSP1) or both high (SSP3). In addition, two "asymmetric cases" are designed, comprising a case in which high challenges to mitigation is combined with low challenges to adaptation (SSP5), and a case where the opposite is true (SSP4). Finally a central case describes a world with intermediate challenges for both adaptation and mitigation (SSP2).

In Table 2 we provide a short summary of the global narratives, which have been used throughout all the papers of this special issue. O'Neill et al., (2016a) provides a more detailed description and discussion of the narratives. In addition, the Supplementary material (Section 4 and Appendix A) includes specific descriptions of how the global narratives were extended to provide further guidance on scenario assumptions concerning energy demand and supply, technological change, and land-use changes.

While the SSPs employ a different scenario design and logic compared to earlier IPCC scenarios, such as the SRES scenarios (Nakicenovic and Swart, 2000), their narratives as well as some of their scenario characteristics show interesting similarities. Analogies between the SRES scenarios and the SSPs were identified already during the SSP development phase (Kriegler et al., 2012; O'Neill et al., 2014), and a systematic attempt to map the SSPs to SRES and other major scenarios was conducted by van Vuuren and Carter (2014). They find that particularly the "symmetric" SSPs (where both the challenges to mitigation and to adaptation are either high or low) show large similarities to some of the SRES scenario families. For example, there is a clear correspondence between the sustainability focused worlds of SSP1 and SRES B1.

Table 2
Summary of SSP narratives.

SSP1	Sustainability – Taking the Green Road (Low challenges to mitigation and adaptation) *The world shifts gradually, but pervasively, toward a more sustainable path, emphasizing more inclusive development that respects perceived environmental boundaries. Management of the global commons slowly improves, educational and health investments accelerate the demographic transition, and the emphasis on economic growth shifts toward a broader emphasis on human well-being. Driven by an increasing commitment to achieving development goals, inequality is reduced both across and within countries. Consumption is oriented toward low material growth and lower resource and energy intensity.*
SSP2	Middle of the Road (Medium challenges to mitigation and adaptation) *The world follows a path in which social, economic, and technological trends do not shift markedly from historical patterns. Development and income growth proceeds unevenly, with some countries making relatively good progress while others fall short of expectations. Global and national institutions work toward but make slow progress in achieving sustainable development goals. Environmental systems experience degradation, although there are some improvements and overall the intensity of resource and energy use declines. Global population growth is moderate and levels off in the second half of the century. Income inequality persists or improves only slowly and challenges to reducing vulnerability to societal and environmental changes remain.*
SSP3	Regional Rivalry – A Rocky Road (High challenges to mitigation and adaptation) *A resurgent nationalism, concerns about competitiveness and security, and regional conflicts push countries to increasingly focus on domestic or, at most, regional issues. Policies shift over time to become increasingly oriented toward national and regional security issues. Countries focus on achieving energy and food security goals within their own regions at the expense of broader-based development. Investments in education and technological development decline. Economic development is slow, consumption is material-intensive, and inequalities persist or worsen over time. Population growth is low in industrialized and high in developing countries. A low international priority for addressing environmental concerns leads to strong environmental degradation in some regions.*
SSP4	Inequality – A Road Divided (Low challenges to mitigation, high challenges to adaptation) *Highly unequal investments in human capital, combined with increasing disparities in economic opportunity and political power, lead to increasing inequalities and stratification both across and within countries. Over time, a gap widens between an internationally-connected society that contributes to knowledge- and capital-intensive sectors of the global economy, and a fragmented collection of lower-income, poorly educated societies that work in a labor intensive, low-tech economy. Social cohesion degrades and conflict and unrest become increasingly common. Technology development is high in the high-tech economy and sectors. The globally connected energy sector diversifies, with investments in both carbon-intensive fuels like coal and unconventional oil, but also low-carbon energy sources. Environmental policies focus on local issues around middle and high income areas.*
SSP5	Fossil-fueled Development – Taking the Highway (High challenges to mitigation, low challenges to adaptation) *This world places increasing faith in competitive markets, innovation and participatory societies to produce rapid technological progress and development of human capital as the path to sustainable development. Global markets are increasingly integrated. There are also strong investments in health, education, and institutions to enhance human and social capital. At the same time, the push for economic and social development is coupled with the exploitation of abundant fossil fuel resources and the adoption of resource and energy intensive lifestyles around the world. All these factors lead to rapid growth of the global economy, while global population peaks and declines in the 21st century. Local environmental problems like air pollution are successfully managed. There is faith in the ability to effectively manage social and ecological systems, including by geo-engineering if necessary.*

Similarly, the fragmented world of SRES A2 shares many scenario characteristics with SSP3, which is describing a world dominated by regional rivalry. The middle-of-the-road scenario SSP2 corresponds well to the dynamics-as-usual scenario SRES B2. And finally, SSP5 shares many storyline elements with the A1FI scenario of SRES, both depicting high fossil-fuel reliance and high economic growth leading to high GHG emissions. For further details about the mapping of the SSPs and earlier scenarios see van Vuuren and Carter (2014).

4. Demographic and economic drivers

The second step in developing the SSPs comprised the translation of the qualitative narratives into quantitative

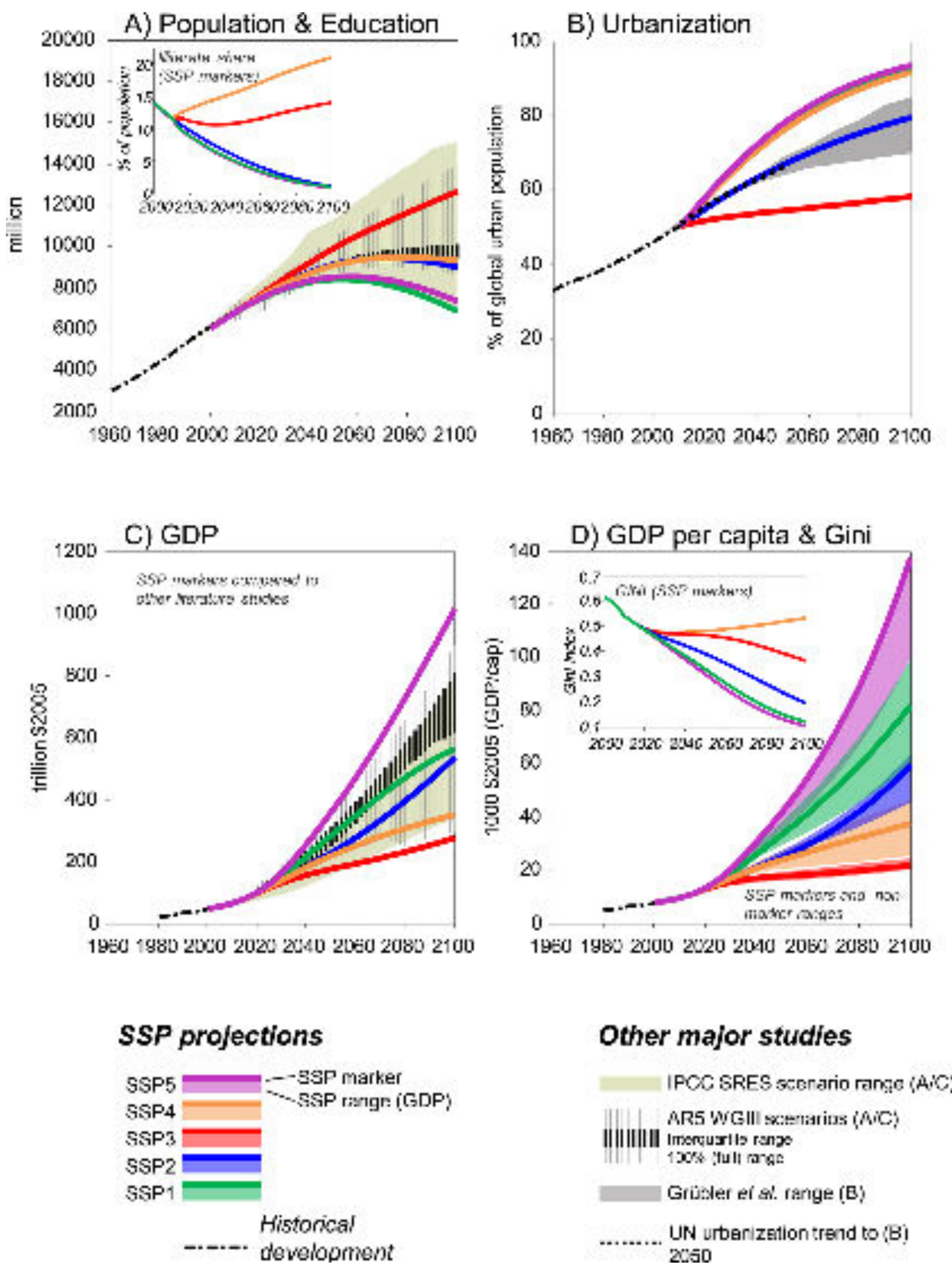

Fig. 2. Development of global population and education (A), urbanization (B), GDP (C), and GDP per capita and the Gini index (D). The inset in panel A gives the share of people without education at age of ≥15 years, and the inset in panel D denotes the development of the global (cross-national) Gini index. The SSPs are compared to ranges from other major studies in the literature, such as the IPCC AR5 (Clarke et al., 2014); IPCC SRES (Nakicenovic and Swart, 2000), UN, and Grübler et al. (2007). The colored areas for GDP (panel D) denote the range of alternative SSP GDP projections presented in this Special Issue (Dellink et al. (2016),Crespo Cuaresma (2016), Leimbach et al. (2016)).

projections for the main socioeconomic drivers of the SSPs: population, education, urbanization, and economic development. These projections comprise the basic elements of the SSPs and were constructed at the country level. Aggregated results for the world are shown in Fig. 2.

The SSP population projections (KC and Lutz, 2016) use a multi-dimensional demographic model to project national populations based on alternative assumptions on future fertility, mortality, migration and educational transitions. The projections are designed to be consistent with the five SSP storylines. They are cross-classified by age and gender as well as the level of education – with assumptions for female education strongly influencing fertility and hence population growth. The alternative fertility, mortality, and migration assumptions are derived partly from the storylines, reflecting also different educational compositions of the population. The outcomes in terms of total global population sizes of the SSPs cover a wide range. Consistent with the narratives, population is lowest in the SSP1 and SSP5 reaching about 7 billion people by 2100 and the highest in SSP3 reaching 12.6 billion in 2100. The middle of the road scenario (SSP2) depicts a population peaking at 9.4 billion (Fig. 2). Compared to the SRES scenarios (Nakicenovic and Swart, 2000), i.e., the previous set of socioeconomic community scenarios, the new set covers a lower range. This is primarily due to the decline of fertility rates in emerging economies over the last two decades as well as the recent expansion of education among young women in least developed countries. Outcomes in terms of educational composition, which has important implications for economic growth and for vulnerability to climate change impacts, also vary widely across SSPs. In SSP1 and SSP5 composition improves dramatically, with the global average education level in 2050 reaching about the current level in Europe. SSP2 also shows substantial increases in educational composition, while in SSP3 and SSP4 increases are small and the global average education level even declines somewhat late in the century.

Similarly, the quantification of the urbanization trends follow the storylines (Jiang and O'Neill, 2016). The projections show that the world continues to urbanize across all SSPs, but rates of urbanization differ widely across them, with urbanization reaching between 60% (SSP3), 80% (SSP2), and 92% (SSP1, SSP4, SSP5) by the end of century (Fig. 2). This range is much wider compared to earlier projections (Grübler et al., 2007). The middle of the road SSP2 projection is close to the UN median projection (UN, 2014). In SSP3, urbanization is constrained by slow economic growth, limited mobility across regions and poor urban planning that makes cities unattractive destinations. By contrast, urbanization is assumed to be rapid in both SSP1 and SSP5, which are associated with high income growth. Note, however, that in SSP1 urbanization is desired given the high efficiency that compact urban areas may achieve, while in SSP5 cities become attractive destinations due to other reasons, such as rapid technological change that allows for large-scale engineering projects to develop desirable housing.

There are three sets of economic (GDP) projections for each SSP (Crespo Cuaresma, 2016; Dellink et al., 2016; Leimbach et al., 2016). They were developed together with the demographic projections, in order to maintain consistency in assumptions with education and ageing. The three economic projections differ, however, in terms of their focus on different drivers of economic development (technological progress, efficiency improvements in energy use, income convergence dynamics or human capital accumulation). We employ Dellink et al. (2016) as the marker scenarios for all SSPs to ensure consistency. The overall range of the SSPs is comparable to the range of earlier GDP projections in the literature (Fig. 2). The highest SSP GDP projection (SSP5) depicts a very rapid

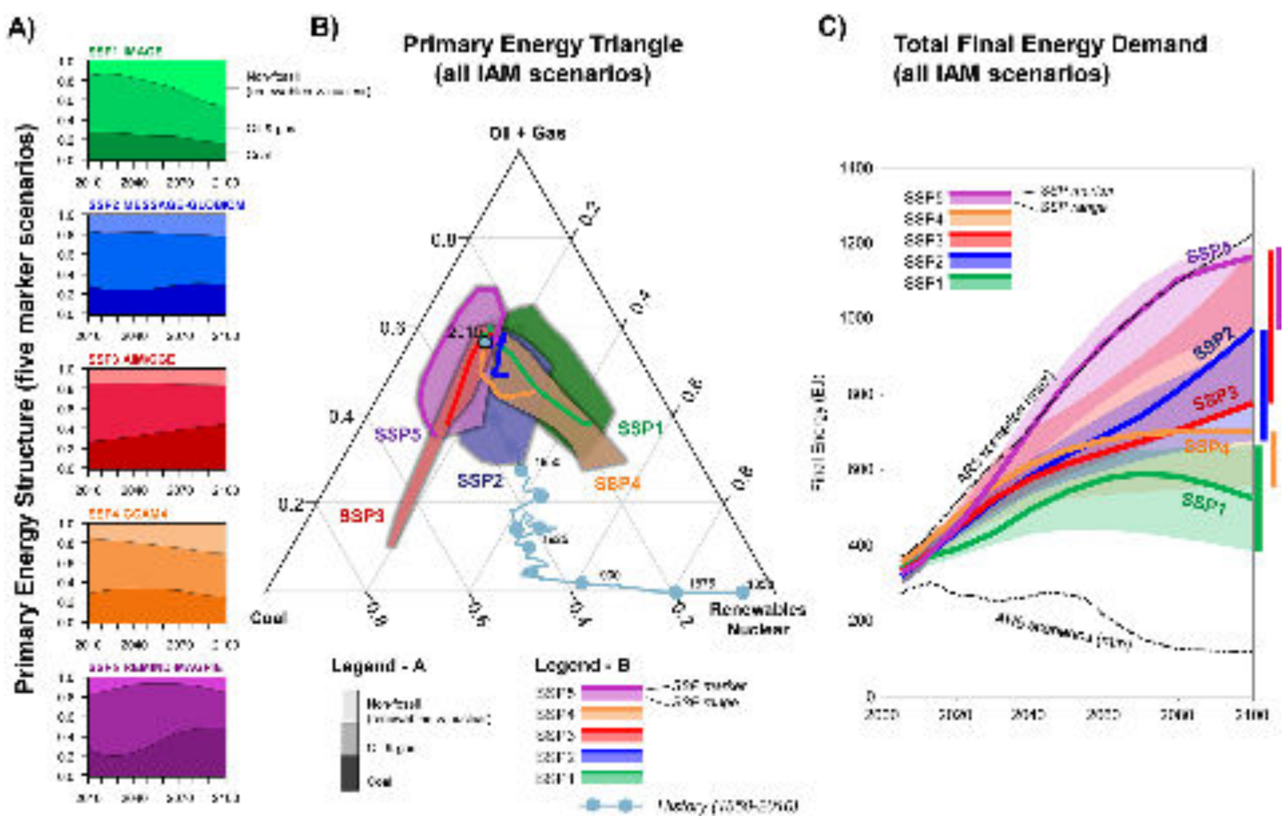

Fig. 3. Primary energy structure (Panel A + B) and final energy demand (Panel C) of the SSP marker scenarios and corresponding ranges.

development and convergence among countries with long-term global average income levels approaching almost 140,000 US $2005 per year in 2100. By contrast, the lowest projection (SSP3) depicts a development failure with strong fragmentation, leading to slow growth or long-term stagnation in most countries of the world. In the SSP3 world average income stays thus around 20,000 US$2005 per year in 2100–this income level is broadly representative of the lowest long-term economic projections in the literature. In all scenarios, economic growth is projected to slow down over time, with average growth rates in the second half of the century roughly half of those in the first half. This slow-down is most marked in middle income countries. Note that all GDP projections were performed using international dollar in purchasing power parity (PPP) rates. An international dollar would buy in the cited country a comparable amount of goods and services a U.S. dollar would buy in the United States.

The SSP GDP projections also depict major differences in terms of cross-national inequality. Consistent with the narratives, SSP4 is characterized by the highest levels of inequality, representing a trend-reversal of the recent years (see the cross-country Gini index shown in panel D of Fig. 2). Due to high fragmentation of the world, inequality also remains relatively high in SSP3 (compared to the other SSPs). The most equitable developments are depicted by SSP1 and SSP5, both featuring a rapid catch-up of the currently poor countries in the world.

5. SSP baseline scenarios

5.1. Energy system

The SSP baseline scenarios describe alternative path-dependent evolutions of the energy system consistent with the SSP narratives and the associated challenges for mitigation and adaptation. Overall, the SSPs depict vastly different energy futures, featuring a wide range of possible energy demand developments and energy supply structures (Fig. 3). These differences emerge due to a combination of assumptions with respect to the main drivers of the energy system, including technological change, economic growth, emergence of new energy services, energy intensity of services, and assumptions with respect to costs and availability of future fossil fuel resources and their alternatives (see Appendix A of the Supplementary material and Bauer et al. (2016) for further details).

The scale and structure of the future energy supply systems in the SSP scenarios are critical determinants of the challenges for mitigation and adaptation. Two of the SSP baseline scenarios (SSP3 and SSP5) have a heavy reliance on fossil fuels with an increasing contribution of coal to the energy mix (Fig. 3: panel A and B). In these two SSPs, the challenges for mitigation are thus high. By contrast, SSP1 and SSP4 depict worlds with low challenges to mitigation, and consequently increasing shares of renewables and other low-carbon energy carriers. The “middle of the road” narrative of SSP2 leads to a balanced energy development compared to the other SSPs, featuring a continuation of the current fossil-fuel dominated energy mix with intermediate challenges for both mitigation and adaptation. These characteristics are also shown by the “SSP triangle” in Fig. 3. The corners of the triangle depict hypothetical situations where the energy system would rely either fully on coal, “oil & gas” or “renewables and nuclear”. In this energy triangle, baseline scenarios for SSP3 and SSP5 are moving with time closer to the left corner dominated by coal, while SSP1 and SSP4 scenarios are developing toward the renewable and nuclear corner. The SSP2 scenario stays in the middle of the triangle.

The SSP baselines also span a wide range in terms of energy demand (Fig. 3: Panel C), which is another major factor influencing the future challenges to mitigation and adaptation. At the upper end of the range, the SSP5 scenario exhibits a more than tripling of energy demand over the course of the century (primarily driven by rapid economic growth). As a result, SSP5 is characterized by high challenges to mitigation. Challenges to mitigation are lowest in SSP1 and SSP4 (Fig. 3: Panel C), and this is reflected in the scale of energy demand in these scenarios. Demand is particularly low in the SSP1 scenarios peaking around 2060 and declining thereafter due to successful implementation of energy efficiency measures and behavioral changes. This leads to a global decoupling of energy demand from economic growth. Consistent with its intermediate mitigation challenges, final energy demand roughly doubles in the SSP2 scenario in the long term (2100) depicting a middle of the road pathway. Overall, the range of energy demand projections associated with the SSPs is broadly representative of the literature (covering about the 90th percentile range of the scenarios assessed in the IPCC AR5 (Clarke et al., 2014)).

Last but not least, the SSPs provide very different interpretations for energy access and poverty, which is an important indicator of the challenge to adaptation across the SSPs. The SSP3 and SSP4 baseline scenarios, for example, depict a failure of current policies for energy access, leading to continued and increased use of biomass in the households of developing countries (as defined today). By contrast, the use of coal and traditional biomass in households is reduced significantly in the other three baseline scenarios, which all portray comparatively more equitable worlds and thus also lower challenges for adaptation.

5.2. Land-use change

While there is a relatively long tradition of modeling comparisons in the area of energy-economic modeling (Clarke et al., 2009; Clarke et al., 2014; Edenhofer et al., 2010; Kriegler et al., 2015; Kriegler et al., 2014b; Riahi et al., 2015; Tavoni et al., 2015), there are fewer examples of systematic cross-model comparisons of land-use scenarios. Notable exceptions include (Nelson et al., 2014; Popp et al., 2014; Schmitz et al., 2014; Smith et al., 2010; Von Lampe et al., 2014). In this context, the SSPs are the first joint community effort in developing land-use scenarios based on common narratives as well as a harmonized set of drivers.

All SSP scenarios depict land-use changes in response to agricultural and industrial demands, such as food, timber, but also bioenergy. The nature and direction of these changes are, however, fundamentally different across the SSPs. They reflect land-use specific storylines that have been developed based on the SSP narratives (Popp et al., 2016) and which have guided assumptions on regulations, demand, productivity, environmental impacts, trade and the degree of globalization of future agricultural and forestry markets.

The land-use change components of the SSP baseline scenarios cover a broad range of possible futures. For example, the scenarios show that in the future total cultivated land can expand or contract by hundreds of millions of hectares over this century (Fig. 4). Massive growth of population, relatively low agricultural productivity, and little emphasis on environmental protection makes SSP3 a scenario with comparatively large pressure on the global land-use system. The resulting land-use pattern is one with large-scale losses of forests and other natural lands due to an expansion of cropland and pasture land (Fig. 4). In comparison, the SSP1 scenario features a sustainable land transformation with comparatively little pressure on land resources due to low population projections, healthy diets with limited food waste, and high agricultural productivity. Consistent with its narrative, this scenario depicts a reversal of historical trends, including a gradual, global-scale, and pervasive expansion of forests and other natural lands. All other SSP scenarios feature modest changes in land-use with some expansion of overall cultivated lands (Fig. 4).

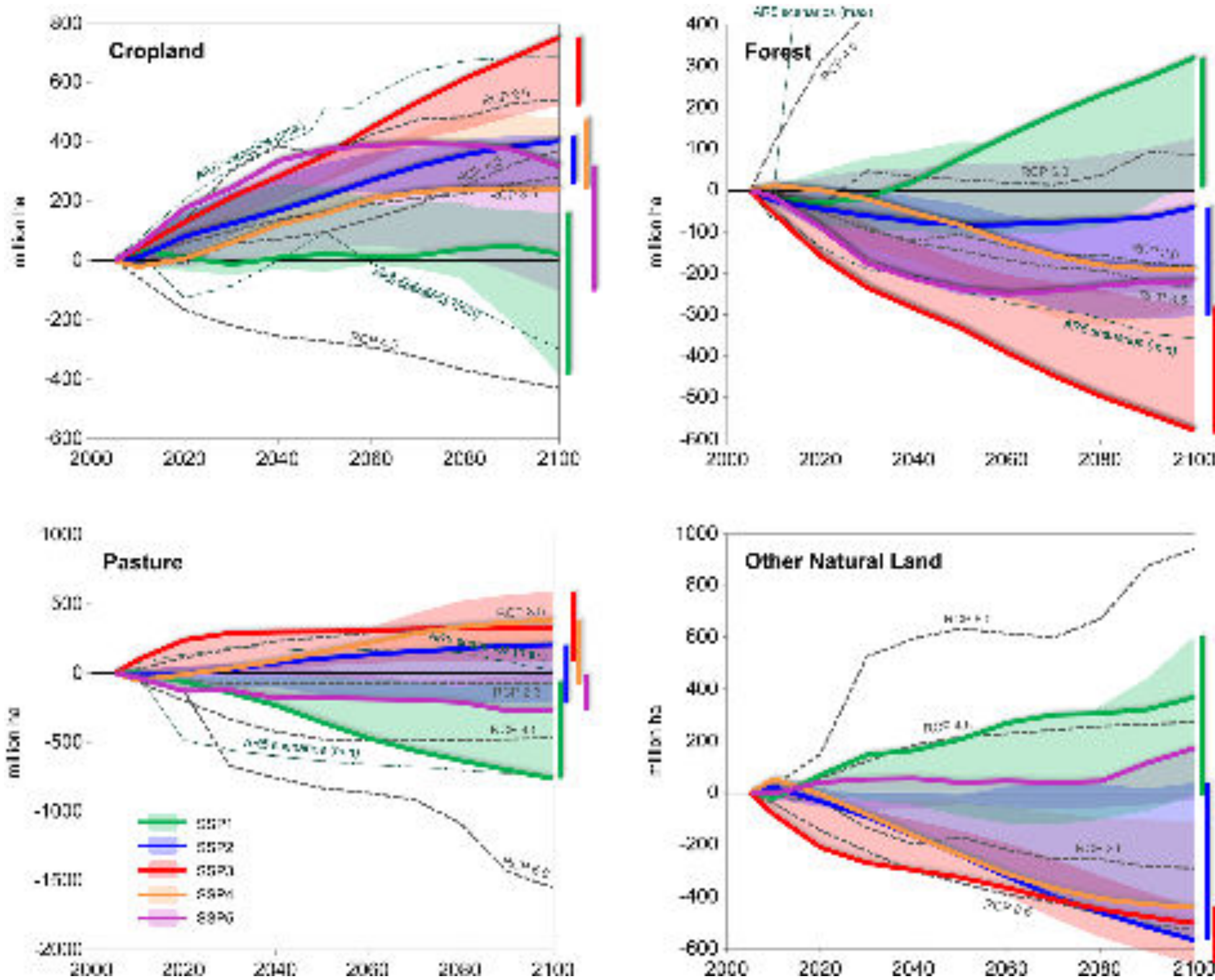

Fig. 4. Changes in cropland, forest, pasture and other natural land for the SSP marker baseline scenarios (thick lines) and ranges of other non-marker scenarios (colored areas). Changes are shown relative to the base year of 2010 = 0. In addition to the SSP baseline scenarios also the development of the RCPs (van Vuuren et al., 2011) and the range of the IPCC AR5 scenarios are shown (Clarke et al., 2014). Note that cropland includes energy crops. Other natural land includes all land-categories beyond forests, pasture, cropland, and build-up areas (the latter category is comparatively small and has not been quantified by all models).

5.3. Baseline emissions and climate change

The pathways for the energy and land-use systems in the SSP scenarios translate into a wide range of GHG and pollutant emissions, broadly representative of the baseline range of the literature (Fig. 5).

This is particularly the case for CO_2 emissions, which are strongly correlated with the future challenges for mitigation. The higher dependence on fossil fuels in the SSP3 and SSP5 baselines result in higher CO_2 emissions and a higher mitigation challenge. Similarly, comparatively low fossil fuel dependence and increased deployment of non-fossil energy sources (SSP1 and SSP4) results in lower CO_2 emissions and lower mitigation challenges (Fig. 5). The SSP2 baseline depicts an intermediate emissions pathway compared to the other baselines, featuring a doubling of CO_2 emissions over the course of the century.

CH_4 is the second largest contributor to global warming (after CO_2). Current global emissions are dominated by non-energy sources like manure management from livestock, rice cultivation and enteric fermentation. To a lesser extent energy-related sources, including the production and transport of coal, natural gas, and oil, contribute to the emissions. Population growth and food demand is a strong driver of future CH_4 emissions across the SSPs. It is thus not surprising that CH_4 emissions are highest in the SSP3 baseline and lowest in SSP1. The combination of different energy and non-energy drivers leads in all other SSPs to intermediate levels of CH_4 emissions in the long term. Perhaps noteworthy is the rapid increase of CH_4 emissions in the SSP5 baseline in the near term, which is primarily due to the massive expansion of the fossil fuel infrastructure, particularly for the extraction and distribution of natural gas.

Important sources of N_2O emissions today include agricultural soil, animal manure, sewage, industry, automobiles and biomass burning. Agricultural soils and fertilizer use are the by far largest contributors of N_2O emissions, and remain so across all the SSPs. Emissions are highest in the SSP3 and SSP4 baselines due to high population and/or fertilizer use. N_2O emissions are lowest in SSP1, featuring sustainable agricultural practices and low population assumptions.

In summary, we find that total CO_2 and CO_2-eq. greenhouse gas emissions and the resulting radiative forcing correlate well with the challenges to mitigation across the SSPs. The results show at the same time, however, that plausible and internally consistent scenarios will not follow strictly the same ranking across all emissions categories (or across all SSP characteristics). It's thus important to note that the aggregated challenge for mitigation and adaptation is not only determined by the baseline but also the climate policy assumptions. The latter critically influence the

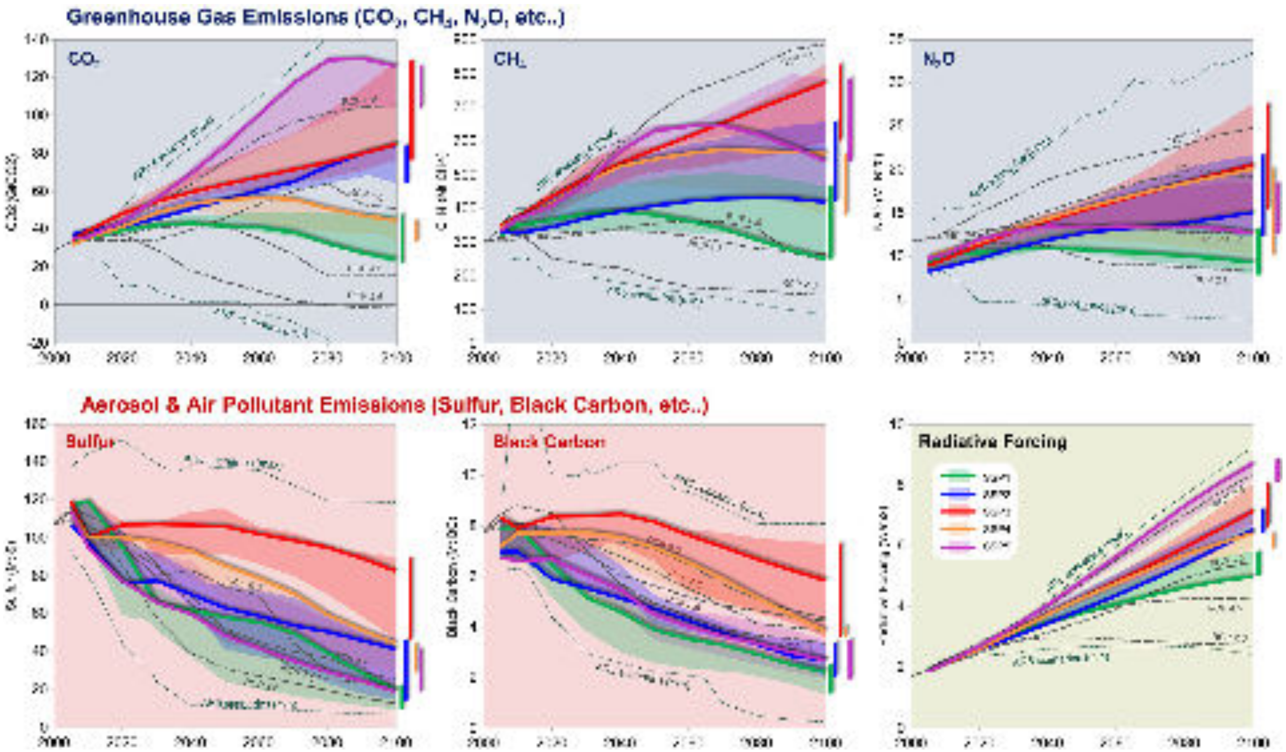

Fig. 5. Global emissions and global average change in radiative forcing. SSP baseline marker scenarios (and ranges of SSP non-marker baseline scenarios) are compared to the RCPs (van Vuuren et al., 2011) and the full range of the IPCC AR5 scenarios (Clarke et al., 2014).

effectiveness of climate policies, which are introduced on top of the baselines (see next section).

An important feature of the SSPs is that they cover a much wider range for air pollutant emissions than the RCPs (Rao et al., 2016). This is so since all the RCPs included similar assumptions about future air pollution legislation, assuming that the stringency of respective emissions standards would increase with raising affluence. It was not intended that the RCPs cover the full range of possible air pollutant emissions. In contrast, the SSPs are based on distinctly different air pollution storylines consistent with the overall SSP narratives. Particularly the upper bound projection of SSP3 features a world with slow introduction of air pollution legislation as well as implementation failures, leading to much higher air pollution emissions levels than in any of the RCPs (see Fig. 5). For further details of the air pollution dimension of the SSPs, see Rao et al. (2016) in this special issue.

The resulting radiative forcing of the climate system is shown in the last panel of Fig. 5. The SSP baselines cover a wide range between about 5.0–8.7 W/m^2 by 2100. Perhaps most importantly, we find that only one single SSP baseline scenario of the full set (SSP5) reaches radiative forcing levels as high as the one from RCP8.5. This is consistent across all IAM models that attempted to run the SSPs. As the SSPs systematically cover plausible combinations of the primary drivers of emissions, this finding suggests that 8.5 W/m^2 can only emerge under a relatively narrow range of circumstances. In contrast, an intermediate baseline (SSP2) only produces a forcing signal of about 6.5 W/m^2 (range 6.5–7.3 W/m^2). The lack of other SSP scenarios with climate forcing of 8.5 W/m^2 or above has important implications for impact studies, since SSP5 is characterized by low vulnerability and low challenges to adaptation. In order to add a high-end counterfactual for impacts to the current set of SSPs, it might be useful to develop a variant of an SSP that would combine high vulnerability with high climate forcing. This could be achieved for example by adding an alternative SSP3 interpretation with higher economic growth, to test whether such scenarios might lead to higher emissions consistent with RCP8.5 (see e.g., Ren et al. (2015)). The current SSP3 marker scenario leads to a radiative forcing of 7.2 W/m^2 (range 6.7–8.0 W/m^2).

The SSP1 baseline scenarios show the lowest climate signal of about 5 W/m^2 (range of 5.0–5.8 W/m^2). In order to reach radiative forcing levels below 5 W/m^2 it is thus necessary to introduce climate change mitigation policies, which are discussed in the next section.

6. SSP mitigation scenarios

This section provides an overview of the SSP mitigation scenarios. Further details can be found in the five SSP marker scenario papers (Calvin et al., 2016; Fricko et al., 2016; Fujimori et al., 2016; Kriegler et al., 2016; van Vuuren et al., 2016) and two cross-cut papers on the SSP energy (Bauer et al., 2016) and land-use transitions (Popp et al., 2016).

6.1. Shared climate policy assumptions

Mitigation costs and attainability of climate targets depend strongly on the design and effectiveness of future mitigation policies. Likewise, adaptation costs and the ability to buffer climate impacts depend on the scope and effectiveness of adaptation measures. These policies may differ greatly across the SSPs, and need to be consistent with the overall characteristic of the different narratives. Based on concepts from Kriegler et al. (2014a), we thus develop so-called shared climate policy assumptions (SPAs) for the implementation of the SSP mitigation scenarios. The mitigation SPAs describe in a generic way the most important characteristics of future mitigation policies, consistent with the overall SSP narrative as well as the SSP baseline scenario developments. More specifically, the mitigation SPAs describe critical issues for mitigation, such as the level of international cooperation

Table 3
Summary of Shared Climate Policy Assumptions (SPAs) for mitigation. All SPAs foresee a period with moderate and regionally fragmented action until 2020, but differ in the development of mitigation policies thereafter (see Section 6 and Appendix B of the Supplementary material for further details and definitions).

Policy stringency in the near term and the timing of regional participation	Coverage of land use emissions
SSP1, SSP4	*SSP1, SSP5*
Early accession with global collaboration as of 2020	Effective coverage (at the level of emissions control in the energy and industrial sectors)
SSP2, SSP5	*SSP2, SSP4*
Some delays in establishing global action with regions transitioning to global cooperation between 2020–2040	Intermediately effective coverage (limited REDD*, but effective coverage of agricultural emissions)
SSP3	*SSP3*
Late accession – higher income regions join global regime between 2020–2040, while lower income regions follow between 2030 and 2050	Very limited coverage (implementation failures and high transaction costs)

* REDD: Reducing Emissions from Deforestation and forest Degradation.

(particularly in the short to medium term) and the stringency of the mitigation effort over time. The mitigation SPAs also define the coverage of different economic sectors, and particularly the land-use sector, which traditionally has been a challenging sector for mitigation in many countries.

The definitions of the mitigation SPAs were derived by considering three main guiding principles: (1) The SPA/SSP combination is selected with the primary aim to reinforce the challenges for mitigation described by the relative position of each SSP in the challenges space; (2) the expected overall impact of the mitigation policy is selected to be consistent with the SSP storyline (for example, specific sectors or policy measures are less effective in some of the storylines compared to others); and (3) the mitigation SPAs are defined in broader terms only, providing the modeling teams a high degree of flexibility to choose between different possible policy instruments for the implementation of the SPAs into the IA models. The main assumptions of the mitigation SPAs are summarized in Table 3.

Consistent with the storyline of strong fragmentation, poverty, and low capacity for mitigation, SSP3 assumes an SPA with late accession of developing countries, as well as low effectiveness of the climate policies in the agricultural and land sector (driven by rural poverty and low agricultural productivity). In comparison, the emphasis of SSP1 on sustainability results in this world in a highly effective and collaborative policy environment with globally comprehensive mitigation actions. Other SSPs combine different characteristics of the SPAs as shown in Table 3.

The above SPAs and the different underlying socioeconomic and technological assumptions lead to distinctly different near-term (2030) GHG emissions developments across the SSP scenarios. In the context of the current international agreements, the marker scenarios of SSP1 and SSP4 depict low mitigation challenges and thus describe developments that allow a further strengthening of near-term mitigation measures beyond those described by the intended nationally determined contributions (INDCs) under the Paris agreement (UNFCCC, 2015). On the other hand, the INDCs are not fully achieved in the SSP marker scenarios with high challenges to mitigation (SSP3 and SSP5). Near-term emissions of the middle-of-the-road SSP2 marker scenario are broadly consistent with the INDCs (see Fig. S5 in the Supplementary material).

Finally, it is important to note that while the adaptation dimension have not been quantified in the scenarios (see also Section 7 on Conclusions), the SSPs differ greatly with respect to the challenges to adaptation as well as the associated effectiveness of possible adaptation policies (O'Neill et al., 2014). For example in SSP1, the capacity to adapt to climate change is high given the well-educated, rich population, the high degree of good governance and the high development of technologies. In addition, also the intact ecosystem services contribute to the adaptive capacity. In SSP3, on the other hand the capacity to adapt to climate change is relative low, given the large, poor population, the lack of cooperation and slow technology development. In SSP4, the capacity to adapt to climate change is relatively low for most of the population due the unequal distribution of resources. And finally in SSP5, the capacity to adapt to climate change is high given a well-educated and rich population as well as the high level of technology development. SSP2 depicts intermediate adaptation capacity compared to the other SSP scenarios. In future research, the SPAs will need to be extended by an adaptation dimension in order to integrate climate impacts and adaptation into the scenario analysis.

6.2. Mitigation strategies

The reduction of GHG emissions can be achieved through a wide portfolio of measures in the energy, industry and land-use sectors, the main sources of emissions and thus global warming (Clarke et al., 2014). In the energy sector, the IA models employ a combination of measures to introduce structural changes through, e.g., replacement of carbon-intensive fossil fuels by cleaner alternatives (such as a switch from coal to natural gas, or the upscaling of renewable energy) and demand-side measures geared toward energy conservation and efficiency improvements (Bauer et al., 2016; Calvin et al., 2016; Fricko et al., 2016; Fujimori et al., 2016; Kriegler et al., 2016; Popp et al., 2016; van Vuuren et al., 2016). The latter include also the electrification of energy demand. In addition to structural changes, carbon capture and storage (CCS) can be employed to reduce the carbon-intensity of fossil fuels or can even be combined with bioenergy conversion technologies for the delivery of energy services with potentially net negative emissions. Primary measures in the agricultural sector comprise reduction of CH_4 and N_2O emissions from various sources (livestock, rice, fertilizers) and dedicated measures to reduce deforestation and/or encourage afforestation and reforestation activities.

The mitigation effort required to achieve a specific climate forcing target depends greatly on the SSP baseline scenario. Autonomous improvements in some baselines, e.g., in terms of carbon intensity and/or energy intensity (see SSP1, Fig. 6) can greatly reduce the residual effort needed to attain long-term mitigation targets. By the same token, however, the lack of structural changes in the baseline (SSP5) or relatively high levels of energy intensity (SSP3) inevitably translate into the need for comparatively higher mitigation efforts.

This path-dependency of mitigation is illustrated in Fig. 6. It is shown how the introduction of climate policies leads to concurrent improvements of both the energy and the carbon intensity of the economy. At the same time, the figure also clearly illustrates that the required relative "movement" of the mitigation scenarios (i.e., the combination of measures for carbon and energy intensity) are strongly dependent on the position of the baseline (in Fig. 6). For example, the carbon and energy intensity improvement rates of the SSP3 baseline are slower even than recent historical rates

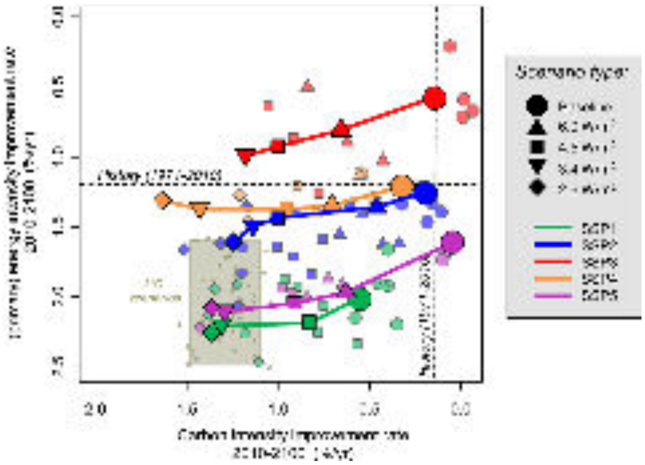

Fig. 6. Annual long-term improvement rates of energy intensity (final energy/GDP) and carbon intensity (CO_2/final energy). Development in the SSP baseline and mitigation scenarios are compared to scenarios consistent with a likely chance to stay below 2 °C from the IPCC AR5 (shaded area). Large icons and colored lines denote the SSP marker and associated mitigation scenarios. Smaller icons denote non-marker IAM interpretations of the SSPs.

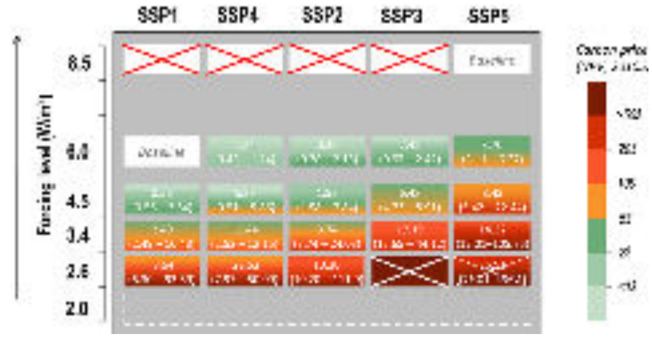

Fig. 8. Carbon prices and the attainability of alternative forcing targets across the SSPs. The colors of the cells are indicative of the carbon price. The numbers in the boxes denote the carbon price of the marker scenarios with the full range of non-marker scenarios in parenthesis. White cells indicate the position of the respective baseline scenarios. Empty (crossed) cells could not be populated. Carbon prices are shown in terms of the net present value (NPV) of the average global carbon price from 2010 to 2100 using a discount rate of 5%. Mitigation costs for other metrics (GDP losses, consumption losses, and abatement costs) are provided as well in Section 1 of the Supplementary material. Note that the SSP columns are ordered according to increasing mitigation challenges (low challenges (SSP1/SSP4), intermediate challenges (SSP2) and high mitigation challenges (SSP3/SSP5)).

(1971–2010). Hence, the distance of the SSP3 baseline to reach stringent climate targets – such as limiting temperature change to below 2 °C (see Fig. 6) – is much larger than, for example, the distance for the SSP1 baseline scenario. As a matter of fact reaching the lowest target of 2.6 W/m^2 from an SSP3 baseline was found infeasible across all IAM models (Fig. 8).

Achieving stringent climate targets requires a fundamental transformation of the energy system, including the rapid upscaling of low-carbon energy (renewables, nuclear and CCS) (Fig. 7). Independently of the SSP, we find that for reaching 3.4 W/m^2 about half of the energy system (range: 30–60%) will need to be supplied by low-carbon options in 2050, while for 2.6 W/m^2 these options need to supply even about 60% (range: 40–70%) of the global energy demand in 2050. This corresponds to an increase of low-carbon energy share by more than a factor of three compared to today (in 2010 the low-carbon share was 17%). In comparison, none of the SSP baselines show structural changes that are comparable to the requirements of 3.4 or 2.6 W/m^2. Only the SSP1 baseline depicts noteworthy increases reaching a contribution of about 30% of low-carbon energy by 2050 (most SSP3 and SSP5 baseline scenarios are showing even a decline of the share of low-carbon energy by 2050 in absence of additional climate policies).

CCS plays an important role in many of the mitigation scenarios even though its deployment is subject to large uncertainties (Fig. 7, right panel). Therefore, depending on the SSP interpretation of different models, the contribution of CCS ranges from zero to almost 1900 GtCO_2. As shown by the marker SSP scenarios, fossil-intensive baselines, such as SSP3 and SSP5, show generally higher needs for CCS compared to less fossil-intensive baselines. Consistent with the narrative of sustainability, the contribution of CCS is lowest in the SSP1 marker scenario (Fig. 7).

Important mitigation options outside the energy sector include reduced deforestation, the expansion of forest land cover (afforestation and/or reforestation) as well as the reduction of the greenhouse gas intensity of agriculture (Fig. 7, middle panel).

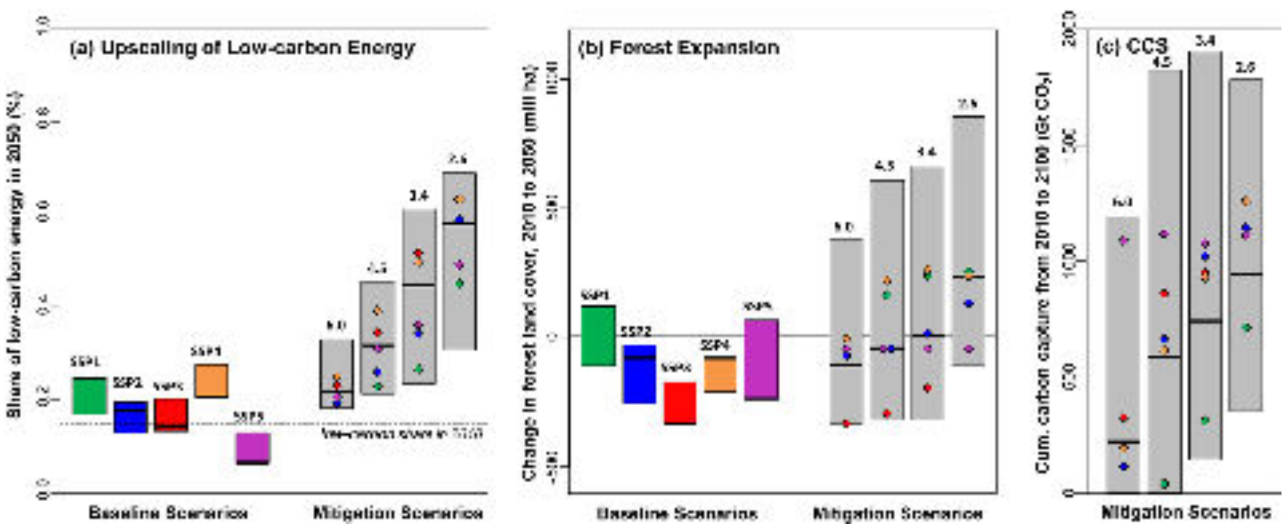

Fig. 7. Major mitigation options in the energy and land-use sector: (a) upscaling of low carbon energy by 2050, (b) expansion of forest land-cover by 2050, and (c) contribution of cumulative CCS over the course of the century. The range of the SSP baseline scenarios are shown as colored bars. Horizontal black lines within the colored bars give the relative position of the SSP baseline marker scenarios. The full range of results for the mitigation scenarios are shown as grey bars. Colored symbols within the grey bars denote the relative position of the marker mitigation scenarios and the horizontal black lines within the grey bars denote the median across the mitigation scenarios. Note that the number of scenarios differs across the different baseline and mitigation bars.

While uncertainties for land-based mitigation options are generally among the largest, we nevertheless find that the mitigation strategies of the marker SSP scenarios reflect well the underlying narratives (see also Popp et al., 2016). The expansion of forest land cover is an important factor in the mitigation scenarios of the SSP1 marker (Fig. 7), followed by SSP2 and SSP4. The IAM model of the SSP5 marker does not consider mitigation-induced afforestation, implying that CO_2 emissions from land use are phased out by reducing and eventually eliminating deforestation in all SSP5 mitigation cases, but no expansion of forest area and associated CO_2 withdrawal occurs. Finally, the SSP3 marker scenario shows a different dynamic due to high pressure on land. Already the SSP3 baseline is characterized by shrinking forest areas. This trend is further accelerated in the mitigation scenarios due to the expansion of bioenergy. SSP3 depicts thus a future world with massive challenges for land-based mitigation, where GHG policies add further pressure on the land system, resulting in competition for scarce resources between food and bioenergy production.

6.3. Mitigation costs and attainability

The comprehensive mitigation experiments enable us to fill the "matrix" of the scenario framework with mitigation costs from different SSP scenarios (see Fig. 8 and Section 1 of the Supplementary material). For each mitigation target (i.e., 2100 forcing level) and each SSP we have computed costs for the SSP marker model as well as associated ranges of other non-marker IAMs.

Mitigation costs are shown in terms of the net present value (NPV) of the average global carbon price over the course of the century. The price is calculated as the weighted average across regions using a discount rate of 5%. We select this cost metric since not all models are able to compute full macroeconomic costs in terms of GDP or consumption losses. Results for those models that report these cost metrics can be found in Section 1 of the Supplementary material.

Our results are consistent with other major comparison studies (Clarke et al., 2014; Kriegler et al., 2015; Riahi et al., 2015) which suggest that carbon prices for achieving specific climate targets may vary significantly across models and scenarios. For example, the average carbon prices for the target of 2.6 W/m^2 differ in our analysis by about a factor of three across the marker scenarios from about 9 \$/tCO_2 in the SSP1 marker to about 25 \$/tCO_2 in the SSP5 marker. Our highest estimate across all scenarios (>100 \$/tCO_2) is representative of about the 90th percentile of comparable scenarios assessed by the IPCC AR5 (category I scenarios, see Clarke et al., 2014), while the lowest in our scenario set is lower than comparable estimates from AR5. In other words, we are able to cover with our limited set of models a large part of the overall literature range. The average carbon price in the middle-of-the-road SSP2-2.6 W/m^2 scenario is about 10 \$/tCO_2 (range: 10–110 \$/tCO_2, Fig. 8). The SSP2 marker costs are somewhat lower than the median cost estimate of the scenarios for similar targets assessed by the IPCC AR5 (30 \$/tCO_2). The wide range of costs is also an important indication that (consistent with our original objective), the scenarios cover a significant range with respect to the challenges for mitigation. Perhaps more importantly, we can consistently relate the differences in the mitigation costs to alternative assumptions on future socioeconomic, technological and political developments. This illustrates the importance of considering alternative SSPs and SPAs and their critical role in determining the future mitigation challenges.

Consistent with the narratives, mitigation costs and thus the challenge for mitigation is found lower in SSP1 & SSP4 relative to SSP3 & SSP5 (Fig. 8). Perhaps most importantly, we find that not all targets are necessarily attainable from all SSPs. Specifically the 2.6 W/m^2 target was found by all models infeasible to reach from an SSP3 baseline, and the WITCH-GLOBIOM model found it infeasible to reach the target in SSP5 (all other models reached 2.6 W/m^2 from SSP5). The fact that IAMs could not find a solution for some of the 2.6 W/m^2 scenarios needs to be distinguished from the notion of infeasibility in the real world. As indicated by Riahi et al. (2015) model infeasibilities may occur for different reasons, such as lack of mitigation options to reach the specified climate target; binding constraints for the diffusion of technologies or extremely high price signals under which the modeling framework can no longer be solved. Thus, infeasibility in this case is an indication that under the specific socioeconomic and policy assumptions of the SSP3 scenario (and to a less extent also SSP5 scenario) the transformation cannot be achieved. It provides useful context for understanding technical or economic concerns. These concerns need to be strictly differentiated from the feasibility of the transformation in the real world, which hinges on a number of other factors, such as political and social concerns that might render feasible model solutions unattainable in the real world (Riahi et al., 2015). Infeasibility, in the case of SSP3, is thus rather an indication of *increased risk* that the required transformative changes may not be attainable due to technical or economic concerns.

In all other SSPs (Fig. 8), IAMs found the 2.6 W/m^2 to be attainable, and it is possible that yet lower forcing levels might be attainable in some of these SSPs. As a matter of fact, some studies indicate that under certain conditions targets as low as 2.0 W/m^2 might still be attainable during this century (Luderer et al., 2013; Rogelj et al., 2015, 2013a, 2013b). As a follow-up research activity to this special issue, the IAM teams are planning to use the SSP framework for a systematic exploration of the attainability of such low targets.

7. Discussion and conclusions

We have shown how different SSP narratives can be translated into a set of assumptions for economic growth, population change, and urbanization, and how these projections can in turn be used by IAM models for the development of SSP baseline and mitigation scenarios. By doing so, this paper presented an overview of the main characteristics of five Shared Socioeconomic Pathways (SSPs) and related integrated assessment scenarios. These are provided to the community as one of the main building blocks of the "new scenario framework" (O'Neill et al., 2014van Vuuren et al., 2014).

This overview paper is complemented by additional articles in this special issue. Together the papers provide a detailed discussion of the different dimensions of the SSPs with the aim to offer the community a set of common assumptions for alternative socioeconomic development pathways. These pathways can be combined with different climate policy assumptions (SPAs) and climate change projections (e.g., the RCPs) and thus facilitate the integrated analyses of impacts, vulnerability, adaptation and mitigation. The SSP scenarios presented here do not consider feedbacks due to climate change or associated impacts (with exception of the IMAGE scenarios which include the effect of fertilization on forest growth due to changing CO_2 concentrations). This makes these scenarios particularly relevant for subsequent impact studies, since it facilitates the superposition of physical climate changes on top of the SSP scenarios to derive consistent estimates of impacts (or adaptation). The narratives, quantitative drivers, and IAM scenarios serve the purpose of providing the IAV, IAM and climate modeling community with information that enables them to use the scenario framework for a new generation of climate research. This special issue should be seen thus as a starting point for new climate change assessments through the lens of the SSPs and the new scenario framework.

We find that while the SSPs and the associated scenarios were designed to represent different characteristics for the challenges to mitigation and adaptation, for many dimensions the resulting quantifications span a wide range broadly representative of the current literature. This is particularly the case for the SSP population and GDP projections as well as for the greenhouse gas emissions of the associated baseline scenarios. For some dimensions the SSPs go even beyond the historical ranges from the literature. This is specifically the case for urbanization where there has been little work in the past to explore the space of possibilities, and for air pollutant emissions. For the latter, the SSP scenarios span a considerably wider range compared to the RCPs, since the SSP scenarios explicitly consider alternative air pollution policy futures (in contrast to the RCPs, which were based on intermediate assumptions for air pollution legislation).

Using multiple models for the development of the economic projections and the SSP scenarios was important in order to understand the robustness of the results and to be able to explore structural model uncertainties in comparison to uncertainties conditional on the interpretation of different SSP narratives. The development of the SSPs and their associated scenarios involved multiple rounds of public and internal reviews and the selection of marker SSP scenarios. While the markers can be interpreted as representative of a specific SSP development, they are not meant to provide a central or median interpretation. For each SSP alternative outcomes are possible, and the different IAMs are used to project conditional uncertainties that might be attributed to model structure and/or the interpretation/implementation of the qualitative storylines. Thus, in order to capture these uncertainties it is generally recommended to use as many realizations of each SSP as possible.

By employing a systematic mitigation analysis across the SSPs, we have also conducted the first application of the scenario framework for the mitigation dimension. We find that mitigation costs depend critically on the SSPs and the associated socioeconomic and policy assumptions. While our study could not reduce the large uncertainties associated with mitigation costs (Clarke et al., 2014), the SSP mitigation experiments have nonetheless helped to illustrate the role of various sources of uncertainty, including the extent to which mitigation costs may depend on different models or different interpretations of storylines.

Another important finding from our assessment is that not all cells of the scenario matrix could be populated. On the high end, only SSP5 led to radiative forcing levels as high as RCP8.5, while at the low end it was not possible to attain radiative forcing levels of 2.6 W/m^2 in an SSP3 world. However, we cannot rule out the possibility that plausible combinations of assumptions could be identified that would enable the currently empty cells to be populated. For example, somewhat higher economic growth assumptions in a variant of SSP3 might lead to higher climate change (8.5 W/m^2; Ren et al., 2015). Such an SSP3 variant would be relevant since it would combine high climate change with high vulnerability. Similarly, the results of the SSPs with low challenges to mitigation, particularly SSP1, indicate that it might be possible to reach yet lower radiative forcing levels than those included in the current matrix. Hence, efforts in the IAM community have started to apply the SSP framework for the development of deep mitigation scenarios that could extend the scenario matrix at the low end.

The next steps of the community scenario process will comprise collaboration with the climate modeling teams of CMIP6 (Eyring et al., 2015) to assess the climate consequences of the SSPs. This work is organized as part of ScenarioMIP (O'Neill et al., 2016b). In addition, the modeling protocol that has been developed as part of this study (see Appendix A–C of the Supplementary material) is made available to the IAM community in order to enable widespread participation of additional IAM modeling teams in quantifying the SSPs. Most importantly, the SSPs and associated scenarios aim to enable impacts, adaptation and vulnerability researchers to explore climate impacts and adaptation requirements under a range of different socio-economic developments and climate change projections. The plan is for an evolutionary expansion of the scenario framework matrix, so that a large body of literature based on comparable assumptions can emerge. Beyond the work on the global SSPs, important extensions are either planned or are under way (van Ruijven et al., 2014). These include extensions with respect to other sectors (e.g., www.isi-mip.org), specific regions (e.g., for the US (Absar and Preston, 2015) and for Europe (Alfieri et al., 2015)), or increased granularity and heterogeneity, for example, with respect to income distributions or spatially downscaled information on key socioeconomic drivers.

All results presented in this special issue are available on-line at the interactive SSP web-database hosted at IIASA: https://secure.iiasa.ac.at/web-apps/ene/SspDb/

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.gloenvcha.2016.05.009.

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Map analysis

The IPCC Interactive Atlas, published as part of the 2021 IPCC Sixth Assessment Report, represents projected environmental conditions in different parts of the world under different warming scenarios. The Climate Center's Surging Seas mapping tool demonstrates how different degrees of warming could impact sea level rise in different global coastal places.The U.S. Climate Resilience Toolkit Climate Explorer projects the environmental impacts of climate change in different US cities under a variety of high- and low-emissions scenarios. Use these tools to explore the projected impact of climate change on different parts of the world, including communities close to home.

How are different variables projected to change under low, medium, and high emissions scenarios?

How do these tools represent variability and uncertainty?

How would this variability affect efforts to plan for the future?

Consider:

- **Sea level**
- **Annual precipitation**
- **Maximum one-day precipitation**
- **Consecutive dry days (drought)**
- **Surface wind**

Source

International Panel on Climate Change | Interactive Atlas

www.interactive-atlas.ipcc.ch

5.1 Adopting adaptations | Role play

When adaptation planning is done at a local level, planners can marshal deep contextual knowledge of an adapting community's needs and aspirations. Adaptations may be best implemented in conjunction with one another; no single adaptation will be sufficient to protect a given place from the long-term effects of climate change. Though every affected place is unique, localities across the globe can learn from one another and share best practices for tackling common problems. And determining which adaptations are the most promising in different situations can be an important tool for allocating resources, including energy sources and human labor.

Scenario

You are members of an advisory council at the United Nations Environmental Program, tasked with developing guidance for national governments about how to approach adaptation: which adaptations to prioritize, and how to link clusters of related or complementary adaptation strategies together. This guidance will be used alongside local knowledge and community input to design and fund adaptation plans.

Each group will consider adaptations to one of two general climate change challenges: water and warming. Water groups are review adaptations for places facing sea level rise, storms and storm surge, increased precipitation, and inland flooding. Warming groups review adaptations for places facing drought, wildfire, diminished air quality, heat waves, water scarcity, and biodiversity loss.

Instructions

With your group, produce three model adaptation plans. Each should include between three and five adaptations from the attached list. Within each plan, rank the adaptations in terms of their scale of efficacy.

Which adaptations should receive the greatest allocation of resources and energy?

Which should be prioritized least?

Are there any adaptations that cannot be combined?

Are any "maladaptive"?

As you discuss, brainstorm ways to make the described adaptation ecosystem- or community-based.

What would the best version of the model adaptation plan look like?

Who would be involved in the planning process?

Write a short paragraph for each model plan, outlining your directives.

After you discuss, come back together as a class and present your ranking, describing what factors you considered, how you ranked each strategy, and why. Then, for each adaptation category, vote as a group to determine the committee's overall ranking.

A Groups: Adapting to water

Elevated buildings

Along the coast, buildings may be elevated above the projected sea level rise. Coastlines and freshwater banks are also liable to flood more suddenly when storms swell rivers and lakes with rain, and drive ocean waves more forcefully inland, overcoming natural and manmade barriers. Storm surge often remains after storms have abated, permanently changing the shoreline. In areas that are at risk of these sudden and intermittent floods, called flood zones, private individuals or governments may pay to elevate existing structures, or governments may begin to require that new buildings be elevated above a certain height. In flood zones, important infrastructure, especially electrical systems and other utilities, should be elevated as well.

Storm-resilient and flood-adapted architecture

Some design elements can help buildings sustain less damage during floods and storm events. Breakaway walls collapse in the event of water or wind impact without endangering the structural integrity of the building. Wind-resistant windows stand up to hurricane or cyclone gales. Materials designated “flood resistant,” like masonry and metal, are less vulnerable to water damage. Designing sites with a graduated structure and resting building foundations on piles or columns helps to insulate buildings from rising water. However, sufficiently intense floods and storms—especially those that include strong winds—can overwhelm these resilient design elements.

Amphibious structures

One way of adapting to climate change in places with dense floodplain settlements is to engineer structures that can float on top of storm surge and sea level. This strategy is being implemented extensively in the Netherlands, where 26 percent of the land is below sea level, and 50 percent is less than 1 meter above sea level. This adaptation also solves a separate issue, which is the limited availability of land for construction. The strategy has been criticized for being expensive, and critics point out that floating housing is less dense than housing built on land, potentially increasing its energy footprint.

Hard coastal infrastructure

“Hard infrastructure” includes traditional coastal barriers to protect against storm surge and flooding, like sea walls, bulwarks, levees, and dikes. These projects can be expensive and take a long time to develop. Once in place, they block the flow of water along the coast, potentially inhibiting animal migration, reducing populations of coastal plants, and otherwise disrupting ecosystems. In addition, hard sea walls near the shore can contribute to erosion, as they amplify wave energy that draws sediment away from the beach.

Soft coastal infrastructure

Coral or oyster reefs, marshes, and mangroves are “soft infrastructure” that provide defense against storm surge and flooding by breaking the energy of waves and storm waters before they reach the shore. Adaptations that establish, conserve, and maintain these forms of natural coastal defense also contribute to the healthy functioning of coastal ecosystems, making them less vulnerable to other climate change impacts like invasive species and pathogens and changing weather patterns and protecting the shoreline against erosion. However, these defenses can’t protect against gradual sea level rise.

A Groups: Adapting to water

Bioswales and rain gardens

Rain gardens are low-lying areas of landscape typically planted with vegetation that naturally occurs at the edges of wetlands, like wildflowers, rushes, grasses, shrubs, ferns, and small trees. Their root systems absorb water to reduce flooding and erosion of the surrounding landscape, while also filtering pollutants before they seep into the groundwater. A bioswale is an engineered channel that collects and directs runoff while filtering out debris and pollution. Bioswales may be vegetated, but they can also be filled with filtering material like mulch; they are useful for managing flood risk, and for recharging groundwater in areas with limited precipitation. When planned at a community or municipal scale, these strategies can be used to create “sponge cities” that strategically absorb inundation, rather than building defenses against flooding.

Permeable pavers and depaving

Anywhere from 50 to 95 percent of the land surface in suburban and urban settlements is covered with impervious paving materials like asphalt and concrete. These both intensify warming in densely settled areas through the heat-island effect, and exacerbate flooding, as water that cannot be absorbed into the ground flows and collects elsewhere. As an adaptation to increased precipitation and greater flood risk, permeable pavers allow water to seep into the soil underneath, reducing stormwater runoff. Meanwhile some advocates promote “depaving,” which removes pavement altogether and allows plants to “rewild” previously paved areas like parking lots.

Insurance

Governments may require that people who own property in a vulnerable area purchase flood or fire insurance to cover the cost of repair and rebuilding in the event of damage. As the climate changes, flood zone boundaries shift, and areas that were previously considered safe are at risk. Whether to require people living in newly vulnerable areas to buy insurance is politically contentious; some policies exempt established property owners from the insurance requirement, or provide subsidies to property owners with qualifying incomes.

Managed retreat

When areas are deemed to be uninhabitable in the long-term according to climate projections, governments may pursue a policy of managed retreat. Buying out property owners; planning and facilitating resettlements; and prohibiting further development in vulnerable areas are a few ways of executing this adaptation strategy, which is highly contentious. In some cases, buildings themselves can be relocated as well. In societies with a large focus on individual property rights, this policy may face legal challenges along with popular resistance. Managed, wholesale resettlement may not be feasible for dense megacities cities.

Changing agricultural practices

Farmers in areas impacted by the changing climate must adapt their practices in response to altered weather patterns. As rainy and dry seasons shift, extend, or contract, farmers must change when and where they plant and harvest crops. Where excessive precipitation waterlogs the soil, or warming leads to water scarcity, farmers may switch to raising more flood- or drought-resistant crops. When water must be conserved, farmers change their irrigation practices or plantings. Farmers raising livestock may also adapt their feeding practices to a less water-intensive feed, or forego livestock in favor of drought-resistant crops. In coastal farming areas where rising sea levels causes saltwater to infiltrate freshwater aquifers, farmers may switch to more salt-tolerant crops, or forego crop farming in favor of raising fish or other livestock.

B Groups: Adapting to warming

Water storage infrastructure

Global warming depletes natural water storage systems like snowpack and glaciers, while localized droughts deplete the water table. Adaptation to warming therefore includes building and maintaining systems that collect and store water when precipitation is relatively more plentiful. Specific interventions include erecting dams, increasing the capacity of existing reservoirs through dredging, constructing new reservoirs, and linking reservoirs to water sources and to one another with pipelines, in order to maximize access to all available water when necessary.

Greywater recycling

Greywater recycling systems reclaim stormwater and some kinds of wastewater, like the water used in showers or laundry machines. Unlike sewage, so-called greywater does not to be chemically treated to become safe for select uses, including irrigation, power generation, and industry, or for replenishing groundwater aquifers. Recycling greywater reduces the amount of energy and potable drinking water put towards these uses. Greywater recycling systems can operate on a larger scale, for industrial or municipal uses, or be attached to individual homes or smaller communities.

Water conservation

This adaptation strategy includes a wide range of behavioral changes to reduce water consumption and waste. Individuals can shorten their showers, reduce garden and lawn irrigation, hand-wash clothes and dishes, and use less electricity, since power generation plants typically require large quantities of water for turbines and cooling. At a municipal level, water conservation can include water meter installation, subsidies for water-efficient appliances and agricultural practice, and public outreach and education to encourage individuals to lower their demand. In drastic circumstances, conservation can also entail water rationing and regulations against certain uses.

Aquifer recharge

In periods of water shortage, water can be pumped or injected underground in order to depleted replenish aquifers and stabilize the water table. In coastal areas, aquifer recharge can also help ameliorate the effect of flooding which saturates of the land with saltwater and raises the salinity of the water table, making groundwater less potable and more hostile to agriculture. Water used to recharge aquifers can include drinking water from public water systems, untreated water from surface collections like ponds and reservoirs, or treated waste or recycled water. There is a small risk of introducing pollutants into the groundwater, but this is rare.

Green infrastructure

Global warming produces an extreme "urban heat island effect," wherein cities with large amounts of asphalt coverage absorb more solar radiation and release more infrared heat, yielding local temperatures 3 to 4.5°C warmer than surrounding rural areas. This can be more than unpleasant: studies have found a significant increase in mortality with each 1°C increase in surface temperature, especially for people over 65. To counteract this effect, some warming-impacted cities are pursuing policies to promote green infrastructure, which entails replacing pavements with street trees, public parks, green roofs, and other vegetated landscaped spaces. The vegetation has a cooling effect: urban parks can be up to 1°C cooler than surrounding, non-green areas, and increasing tree cover by 10 percent can reduce surface temperatures by more than 1°C.

B Groups: Adapting to warming

Cooling architecture

As well as landscape design, building design can have a cooling impact, especially in cities. Reflective roofs and light-colored ground cover can reduce the amount of solar radiation absorbed by hard surfaces. Architecture can support passive cooling through the use of ventilation, shades, awnings, and building materials like stone and ceramic that retain relatively little heat. Integrating vegetation and landscape with structural design can also be effective. Communities can multiply the effects of individual buildings by incorporating cooling architecture practices into local building codes and standards.

Habitat restoration

As the warming land and oceans change local weather patterns, water levels, and surface temperatures, across the world, biodiversity is at risk of being lost. Native species, stressed by changes to their local climates, are more vulnerable to pathogens and habitat loss. Active ecosystem management to help species adapt to the changing climate can include developing and maintaining wildlife corridors and pollinator gardens: connected chains of habitat that enable and encourage native species migration and survival. These adaptations can often deliver dual benefits by filtering stormwater runoff or functioning as cooling green infrastructure.

Species management

Native species also face competition from invasive species, which are able to spread to new ecosystems where predators and diseases to control their population growth are relatively lacking. As well as outcompeting native species for ecosystem resources, species can impact the geomorphology—like when root systems break up rock or destabilize soil—adding a new pressure on native species struggling to adapt. Ecosystem stewards may attempt to physically remove invasive species, or control their spread using herbicides or by introducing species-specific predators or pathogens.

Proactive fire management

A dramatic downstream effect of warming is the greater incidence and spread of natural fires, including forest fires, to which drier ecosystems are clearly more vulnerable. As well as managed retreat or fire insurance programs, people in fire-prone areas can practice proactive fire management to adapt to the warming climate. Prescribed burns are used to intentionally burn swatches of vulnerable forest at strategically-chosen times and locations, minimizing disruption and danger to lives and property. For example, forest managers might choose a time and place where they know wind will blow smoke away from human settlements, limiting the impact on air quality.

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5.2 Imagining adapted communities | Creative writing

Our future is guaranteed to be impacted by climate change in some way. This fact is often presented with a sense of fear, despair, or warning; indeed, collective failure to minimize the extent and effects of climate change will result in enormous, unnecessary suffering, and action must be taken to avert the most extreme effects. But it can also be important, and empowering, to think about the future shaped by climate change in more neutral and objective terms. What will be different? How will we live? What will it feel like to be alive in that moment?

Instructions

Use the tools listed below to project future conditions in one US county—perhaps the place where you live or a place where you have connections to friends or family members—in the event of 2°C of warming. Then, using this information, design a climate-adapted settlement in this place. Combine written and visual material (use collage, drawings, or both) to compose a creative profile of this community. Consider physical, social, and institutional adaptations.

Consider the following questions:

What adaptations have been implemented in this community?

How has adaptation been planned, designed, and executed? How are decisions made?

Who lives there, and how do they live? What kind of work do they do?

What do they eat and where does their food come from?

Who do they live with? What is their home like? How do they get around?

What are their weather conditions like?

What do they worry about? What do they look forward to?

What does and doesn't change alongside the climate?

Sources

US Climate Resilience Toolkit | Climate Explorer

www.crt-climate-explorer.nemac.org/

US Climate Resilience Toolkit | Case studies

www.toolkit.climate.gov/case-studies

Data analysis

Based on this data, how do people decide whether to migrate?

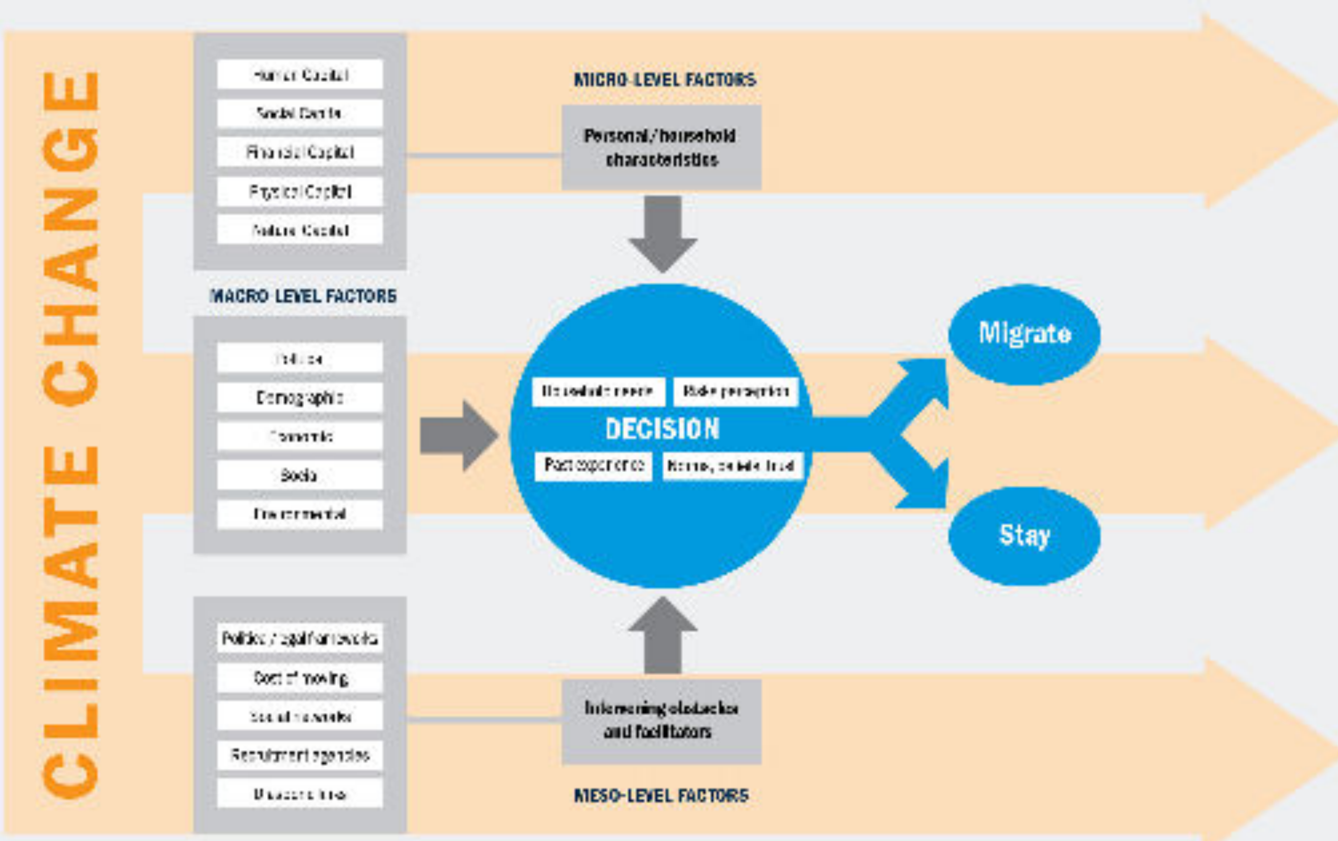
Which of these considerations do you think would matter the most, if you had to make such a decision?

Based on this graphic, what might impact whether people are able to or inclined to migrate away from areas near Jones Beach that are vulnerable to sea level rise?

Source

Graphic and table from Groundswell: Preparing for Internal Climate Migration, K. Rigaud et al, World Bank, 2018.

Figure 2.1: Foresight model adapted to illustrate climate change, livelihoods, and household migration behaviour



Source: Extended and adapted from Foresight (2011) and McLeman (2013)

Table 2.1, "Summary of research findings on the interconnectivity between climate change, livelihoods and migration," from *Groundswell: Preparing for Internal Climate Migration*, K. Rigaud et al, World Bank, 2018.

Finding	Characteristics/implications	Strength* of evidence
Migration is a key component of sustainable livelihoods and household adaptive capacity in low and middle income countries	Migration is one of many possible ways in which households adapt to and cope with climatic and nonclimatic risks/uncertainty. In countries with weak institutions, migration may be the only form of adaptation available. Households that lack migration options are inherently more vulnerable and less adaptable to the impacts of climatic variability and change.	Broad base of evidenc wide range of empirica in multiple regions
Reliance on migration to meet rural livelihood needs is growing	Growing reliance on migration is a common trend across less developed countries. Seasonal migration is common in regions with highly seasonal climates. Migration for longer durations is becoming increasingly common. Most migrants are young adults.	Broad base of evidenc wide range of empirica in multiple regions
Most climate-related migration takes place across short distances within countries or across contiguous borders	Local migration has relatively low costs. The destination may be urban or rural, depending on wage-earning opportunities.	Broad base of evidenc wide range of empirica in multiple regions

Table 2.1, "Summary of research findings on the interconnectivity between climate change, livelihoods and migration," from *Groundswell: Preparing for Internal Climate Migration*, K. Rigaud et al, World Bank, 2018.

Households that receive remittances from migrants have greater long-term social and economic prospects	Remittances from international migrants are typically of greater value than remittances received from internal migrants. Within communities, remittances increase socioeconomic inequality. Remittances can help improve prospects for disaster recovery and to some extent for preparedness and adaptation, but the overall contribution to building climate resiliency is uncertain.	Broad base of evidenc wide range of empirica in multiple regions
Rural to urban migration rates are high and growing	Rural to urban migration rates are growing especially rapidly in Sub-Saharan Africa, although that region is less urbanized than others.	Conclusive statistical e
Households that participate in rural to urban resource-sharing networks have greater food security	Such networks are likely to grow in importance as impacts of climate change on food production systems strengthen. Households lacking access to such networks are more vulnerable.	Strong empirical evider Sub-Saharan Africa an America
Migration is a key means of recovering from extreme weather events, including floods and droughts	After an extreme event, households send young adults to seek wage labor opportunities to rebuild lost/damaged housing and livelihood assets. The duration and destination of migration vary by context.	Strong empirical evider Central America, East and South and Southe

Table 2.1, "Summary of research findings on the interconnectivity between climate change, livelihoods and migration," from *Groundswell: Preparing for Internal Climate Migration*, K. Rigaud et al, World Bank, 2018.

People in remote areas have worse migration opportunities and adaptation prospects	Remoteness and isolation are important factors in the vulnerability of mountain populations and some dryland areas. People living in areas with good access to roads, markets, and social infrastructure have a greater range of adaptation options and potential migration destinations.	Strong empirical evidence from dryland areas of Africa, the Andes, and Nepal
Gender dimensions can change over time, but have important implications for climate migration	Where only men migrate, women, children, people with disabilities, and the elderly left behind are at greater risk of food insecurity and personal safety. Land degradation and climatic variability can force higher levels of gendered migration or longer-duration migration. Gender dimensions can change over time.	Case study evidence from Bangladesh, Nepal, and Pakistan; more research needed in other countries and regions
Empirical research shows persuasively that climate resilience must be built urgently given the known risks, but there remains uncertainty about which strategies hold the greatest promise and how to implement them	The impacts of extreme heat, dryness, and variability in precipitation on regional migration patterns will grow through 2050 but can be moderated by sound development strategies. Climate impacts on food systems, water resources, and livelihoods accelerate in nonlinear fashion after 2050, as will the risks of large-scale displacements and distress migration. Business as usual will fall far short of meeting future adaptation needs.	Climate model evidence increasingly strong Models of future crop yields vary but decline for several crops Systems understandings of general climate–migration dynamics are increasingly strong, with strong agreement across the research literature Further empirical research on resilience-building needed across most regions

5.3 Mapping migration pathways | Investigation

In "The Great Climate Migration" published by ProPublica and The New York Times with funding from the Pulitzer Center, a team of journalists and academics used existing data to project climate change migration patterns through the rest of the 21st century. The authors sought to determine where people from communities on the frontline of climate change are likely to migrate, and the impact of migration on those destinations.

Instructions

Read the first excerpt from "The Great Climate Migration", which tells the story of Delmira de Jesús Cortez Barrera. Also review the table from the World Bank report "Groundswell: Preparing for Internal Climate Migration."

Map out Cortez's migration pathway. What are the "push-pull" factors influencing her choices at each step?

How does climate change intersect with other pressures to influence Cortez's decision to migrate and her pathway?

How does Cortez's migration story reflect, or not, the dynamics described in the table?

Where in Cortez's migration pathway are there opportunities for the Salvadoran government and the international community to help?

What kind of aid should Cortez and migrants in similar positions receive? How might aid have changed the outcome in her case?

What feelings does this story bring up for you?

Sources

The sources are excerpted here and avaliable in full online:

"The Great Climate Migration" Abrahm Lustgarten and Meridith Kohut, July 23, 2020, co-published by ProPublica and The New York Times

www.pulitzercenter.org/stories/great-climate-migration

Groundswell: Preparing for Internal Climate Migration, K. Rigaud et al, World Bank, 2018.

www.openknowledge.worldbank.org/handle/10986/29461

Excerpt from "The Great Climate Migration" by Abrahm Lustgarten, Pro Publica, July 23, 2020

Delmira de Jesús Cortez Barrera moved to the outskirts of San Salvador six years ago, after her life in the rural western edge of El Salvador collapsed. Now she sells pupusas on a block not far from where teenagers stand guard for the Mara Salvatrucha gang. When we met last summer, she was working six days a week, earning $7 a day, or less than $200 a month. She relied on the kindness of her boss, who gave her some free meals at work. But everything else for her and her infant son she had to provide herself. Cortez commuted before dawn from San Marcos, where she lived with her sister in a cheap room off a pedestrian alleyway. But her apartment still cost $65 each month. And she sent $75 home to her parents each month — enough for beans and cheese to feed the two daughters she left with them. "We're going backward," she said.

Her story — that of an uneducated, unskilled woman from farm roots who can't find high-paying work in the city and falls deeper into poverty — is a familiar one, the classic pattern of in-country migration all around the world. San Salvador, meanwhile, has become notorious as one of the most dangerous cities in the world, a capital in which gangs have long controlled everything from the majestic colonial streets of its downtown squares to the offices of the politicians who reside in them. It is against this backdrop of war, violence, hurricanes and poverty that one in six of El Salvador's citizens have fled for the United States over the course of the last few decades, with some 90,000 Salvadorans apprehended at the U.S. border in 2019 alone.

Cortez was born about a mile from the Guatemalan border, in El Paste, a small town nestled on the side of a volcano. Her family were jornaleros — day laborers who farmed on the big maize and bean plantations in the area — and they rented a two-room mud-walled hut with a dirt floor, raising nine children there. Around 2012, a coffee blight worsened by climate change virtually wiped out El Salvador's crop, slashing harvests by 70 percent. Then drought and unpredictable storms led to what a U.N.-affiliated food-security organization describes as "a progressive deterioration" of Salvadorans' livelihoods.

That's when Cortez decided to leave. She married and found work as a brick maker at a factory in the nearby city of Ahuachapán. But the gangs found easy prey in vulnerable farmers and spread into the Salvadoran countryside and the outlying cities, where they made a living by extorting local shopkeepers. Here we can see how climate change can act as what Defense Department officials sometimes refer to as a "threat multiplier." For Cortez, the threat could not have been more dire. After two years in Ahuachapán, a gang-connected hit man knocked on Cortez's door and took her husband, whose ex-girlfriend was a gang member, executing him in broad daylight a block away.

In other times, Cortez might have gone back home. But there was no work in El Paste, and no water. So she sent her children there and went to San Salvador instead.

[…]

People move to cities because they can seem like a refuge, offering the facade of order — tall buildings and government presence — and the mirage of wealth. I met several men who left their farm fields seeking extremely dangerous work as security guards in San Salvador and Guatemala City. I met a 10-year-old boy washing car windows at a stoplight, convinced that the coins in his jar would help buy back his parents' farmland. Cities offer choices, and a sense that you can control your destiny.

These same cities, though, can just as easily become traps, as the challenges that go along with rapid urbanization quickly pile up. Since 2000, San Salvador's population has ballooned by more than a third as it has absorbed migrants from the rural areas, even as tens of thousands of people continue to leave the country and migrate north. By midcentury, the U.N. estimates that El Salvador — which has 6.4 million people and is the most densely populated country in Central America — will be 86 percent urban. Our models show that much of the growth will be concentrated in the city's slumlike suburbs, places like San Marcos, where people live in thousands of ramshackle structures, many without electricity or fresh water. In these places, even before the pandemic and its fallout, good jobs were difficult to find, poverty was deepening and crime was increasing. Domestic abuse has also been rising, and declining sanitary conditions threaten more disease. As society weakens, the gangs — whose members outnumber the police in parts of El Salvador by an estimated three to one — extort and recruit. They have made San Salvador's murder rate one of the highest in the world.

Cortez hoped to escape the violence, but she couldn't. The gangs run through her apartment block, stealing televisions and collecting protection payments. She had recently witnessed a murder inside a medical clinic where she was delivering food. The lack of security, the lack of affordable housing, the lack of child care, the lack of sustenance — all influence the evolution of complex urban systems under migratory pressure, and our model considers such stresses by incorporating data on crime, governance and health care. They are signposts for what is to come.

A week before our meeting last year, Cortez had resolved to make the trip to the United States at almost any cost. For months she had "felt like going far away," but moving home was out of the question. "The climate has changed, and it has provoked us," she said, adding that it had scarcely rained in three years. "My dad, last year, he just gave up."

Table 2.1, "Summary of research findings on the interconnectivity between climate change, livelihoods and migration," from *Groundswell: Preparing for Internal Climate Migration*, K. Rigaud et al, World Bank, 2018.

Finding	Characteristics/implications	Strength* of evidence
Migration is a key component of sustainable livelihoods and household adaptive capacity in low and middle income countries	Migration is one of many possible ways in which households adapt to and cope with climatic and nonclimatic risks/ uncertainty. In countries with weak institutions, migration may be the only form of adaptation available. Households that lack migration options are inherently more vulnerable and less adaptable to the impacts of climatic variability and change.	Broad base of evidenc wide range of empirica in multiple regions
Reliance on migration to meet rural livelihood needs is growing	Growing reliance on migration is a common trend across less developed countries. Seasonal migration is common in regions with highly seasonal climates. Migration for longer durations is becoming increasingly common. Most migrants are young adults.	Broad base of evidenc wide range of empirica in multiple regions
Most climate-related migration takes place across short distances within countries or across contiguous borders	Local migration has relatively low costs. The destination may be urban or rural, depending on wage-earning opportunities.	Broad base of evidenc wide range of empirica in multiple regions

Table 2.1, "Summary of research findings on the interconnectivity between climate change, livelihoods and migration," from *Groundswell: Preparing for Internal Climate Migration*, K. Rigaud et al, World Bank, 2018.

Households that receive remittances from migrants have greater long-term social and economic prospects	Remittances from international migrants are typically of greater value than remittances received from internal migrants. Within communities, remittances increase socioeconomic inequality. Remittances can help improve prospects for disaster recovery and to some extent for preparedness and adaptation, but the overall contribution to building climate resiliency is uncertain.	Broad base of evidenc wide range of empirica in multiple regions
Rural to urban migration rates are high and growing	Rural to urban migration rates are growing especially rapidly in Sub-Saharan Africa, although that region is less urbanized than others.	Conclusive statistical e
Households that participate in rural to urban resource-sharing networks have greater food security	Such networks are likely to grow in importance as impacts of climate change on food production systems strengthen. Households lacking access to such networks are more vulnerable.	Strong empirical evider Sub-Saharan Africa an America
Migration is a key means of recovering from extreme weather events, including floods and droughts	After an extreme event, households send young adults to seek wage labor opportunities to rebuild lost/damaged housing and livelihood assets. The duration and destination of migration vary by context.	Strong empirical evider Central America, East and South and Southe

Table 2.1, “Summary of research findings on the interconnectivity between climate change, livelihoods and migration,” from *Groundswell: Preparing for Internal Climate Migration*, K. Rigaud et al, World Bank, 2018.

People in remote areas have worse migration opportunities and adaptation prospects	Remoteness and isolation are important factors in the vulnerability of mountain populations and some dryland areas. People living in areas with good access to roads, markets, and social infrastructure have a greater range of adaptation options and potential migration destinations.	Strong empirical evidence from dryland areas of Africa, the Andes, and Nepal
Gender dimensions can change over time, but have important implications for climate migration	Where only men migrate, women, children, people with disabilities, and the elderly left behind are at greater risk of food insecurity and personal safety. Land degradation and climatic variability can force higher levels of gendered migration or longer-duration migration. Gender dimensions can change over time.	Case study evidence from Bangladesh, Nepal, and Pakistan; more research needed in other countries and regions
Empirical research shows persuasively that climate resilience must be built urgently given the known risks, but there remains uncertainty about which strategies hold the greatest promise and how to implement them	The impacts of extreme heat, dryness, and variability in precipitation on regional migration patterns will grow through 2050 but can be moderated by sound development strategies. Climate impacts on food systems, water resources, and livelihoods accelerate in nonlinear fashion after 2050, as will the risks of large-scale displacements and distress migration. Business as usual will fall far short of meeting future adaptation needs.	Climate model evidence increasingly strong Models of future crop yields vary but decline for several crops Systems understandings of general climate–migration dynamics are increasingly strong, with strong agreement across the research literature Further empirical research on resilience-building needed across most regions

5.3 Climate debt and climate justice | Read and respond

One scenario in "The Great Climate Migration" reflects the likely outcomes if the United States pursues a policy of closed borders and national self-interest, seeking to obstruct rather than facilitate the regional migration triggered by climate change. This projection invites us to consider: What does environmental justice mean in the context of global climate migration?

Instructions

Read the article excerpt and the attached article from *Climatic Change*. Also explore the following datasets through the Our World In Data online tool.

Using these sources, and supplementing with additional research as necessary, write a persuasive essay in response to the following questions:

> **What is "climate debt"? How should it relate to the funding and facilitation of climate mitigation, adaptation, and migration?**
>
> **What is the role of national borders in creating and maintaining environmental justice or injustice? What should the role of global entities like the United Nations be?**
>
> **What needs to change to facilitate global environmental justice?**

Sources

"The Great Climate Migration" Abrahm Lustgarten and Meridith Kohut, July 23, 2020, co-published by ProPublica and The New York Times | Excerpt and data visualization

www.features.propublica.org/climate-migration/model-how-climate-refugees-move-across-continents/

Our World in Data | Emissions by country and by sector; emissions drivers

www.ourworldindata.org/co2-and-other-greenhouse-gas-emissions

www.ourworldindata.org/emissions-drivers

Khan, M., Robinson, Sa., Weikmans, R. et al. "Twenty-five years of adaptation finance through a climate justice lens." *Climatic Change* 161, 251–269 (2020).

Excerpt from "The Great Climate Migration" by Abrahm Lustgarten, Pro Publica, July 23, 2020

To better understand the forces and scale of climate migration over a broader area, The New York Times Magazine and ProPublica joined with the Pulitzer Center in an effort to model, for the first time, how people will move across borders.

We focused on changes in Central America and used climate and economic-development data to examine a range of scenarios. Our model projects that migration will rise every year regardless of climate, but that the amount of migration increases substantially as the climate changes. In the most extreme climate scenarios, more than 30 million migrants would head toward the U.S. border over the course of the next 30 years.

Migrants move for many reasons, of course. The model helps us see which migrants are driven primarily by climate, finding that they would make up as much as 5% of the total. If governments take modest action to reduce climate emissions, about 680,000 climate migrants might move from Central America and Mexico to the United States between now and 2050. If emissions continue unabated, leading to more extreme warming, that number jumps to more than a million people. (None of these figures include undocumented immigrants, whose numbers could be twice as high.)

The model shows that the political responses to both climate change and migration can lead to drastically different futures.

In one scenario, globalization — with its relatively open borders — continues. As the climate changes, drought and food insecurity drive rural residents in Mexico and Central America out of the countryside. Millions seek relief, first in big cities, spurring a rapid and increasingly overwhelming urbanization. Then they move farther north, pushing the largest number of migrants toward the United States. The projected number of migrants arriving from Central America and Mexico rises to 1.5 million a year by 2050, from about 700,000 a year in 2025.

We modeled another scenario in which the United States hardens its borders. People are turned back, and economic growth in Central America slows, as does urbanization. In this case, Central America's population surges, and the rural hollowing reverses as the birthrate rises, poverty deepens and hunger grows — all with hotter weather and less water. That version of the world leaves tens of millions of people more desperate and with fewer options. Misery reigns, and large populations become trapped.

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Twenty-five years of adaptation finance through a climate justice lens

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Abstract
How much finance should be provided to support climate change adaptation and by whom? How should it be allocated, and on what basis? Over the years, various actors have expressed different normative expectations on climate finance. Which of these expectations are being met and which are not; why, and with what consequences? Have new norms and rules emerged, which remain contested? This article takes stock of the first 25+ years of adaptation finance under the United Nations Framework Convention on Climate Change (UNFCCC) and seeks to understand whether adaptation finance has become more justly governed and delivered over the past quarter century. We distinguish among three "eras" of adaptation finance: (1) the early years under the UNFCCC (1992–2008); (2) the Copenhagen shift (2009–2015); and (3) the post-Paris era (2016–2018). For each era, we systematically review the justice issues raised by evolving expectations and rules over the provision, distribution, and governance of adaptation finance. We conclude by outlining future perspectives for adaptation finance and their implications for climate justice.

Keywords Adaptation finance · Climate justice · United Nations Framework Convention on Climate Change (UNFCCC)

1 Introduction

> It is about power politics, and the rich and the powerful never, ever voluntarily give up their power and their wealth. And so it has to be extracted like teeth in a dentist chair. – Saleemul Huq, Director of the International Centre for Climate Change and Development (ICCCAD), Dhaka, 2014.

The original version of this article was revised. Unfortunately the uncorrected version of the article was published online. This has been corrected.

This article is part of a Special Issue, *"Climate Finance Justice: International Perspectives on Climate Policy, Social Justice, and Capital," edited by Lauren Gifford and Chris Knudson*

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These words of Saleemul Huq, from a Guardian newspaper podcast, reflect his lifetime of experience of the intense power struggles over international climate adaptation finance. These struggles have involved conflicts related to several key questions: How much finance should be provided to support climate adaptation? Who should provide adaptation finance? Through which channels should adaptation finance be delivered to developing countries? How should it be allocated? Should some countries be prioritized? Which, and on what basis? Does adaptation finance represent a form of compensation from "polluting" countries to "victims" of climate change? Such questions on the norms and rules that guide adaptation finance are at the core of climate justice. Over the years, various actors have expressed different normative expectations about adaptation finance. Which of these expectations are being met and which are not; why, and with what consequences? Have new norms and rules emerged, which remain contested?

This article takes stock of the first 25+ years of adaptation finance under the United Nations Framework Convention on Climate Change (UNFCCC or "the Convention") and seeks to understand whether adaptation finance has become more justly governed and delivered over this past quarter century. Following Grasso (2010, p. 53), we define adaptation finance justice as a "[...] fair process, that involves all relevant Parties, of raising adaptation funds according to the responsibility for climate impacts, and of allocating raised funds putting the most vulnerable first." In doing so, we distinguish among three "eras": (1) the early years of adaptation finance under the UNFCCC (1992–2008), (2) the Copenhagen shift (2009–2015), and (3) the post-Paris era (2016–2018). For each era, we systematically review the justice issues raised by evolving expectations and rules over the provision, distribution, and governance of adaptation finance. Based on our observation of multiple UNFCCC negotiations and on interviews with negotiators and observers, we also analyze whether these expectations and rules are reflected in the actual, behaviors of actors and reflect on the impacts of potential disconnections between expectations, rules, and behaviors on climate justice. We conclude by outlining future perspectives for adaptation finance in the contemporary period of neoliberal climate governance.

2 Climate justice as it relates to climate finance

There are several types of justice—distributive, procedural, recognition, compensatory, restitutive, corrective, or neoliberal justice (e.g., see Ciplet and Roberts 2017; Fraser 1998; Ikeme 2003; Klinsky and Dowlatabadi 2009; Rawls 1971; Young 1990). The concept of distributive justice refers to a situation where all primary social goods, e.g., opportunity, income, and wealth, are distributed equally unless an unequal distribution of any or all of these goods is to the advantage of the least favored, which guarantees a fair deal for the most disadvantaged (Rawls 1971). Equity and fairness are key concepts of distributive justice.

Distributive justice, however, usually cannot be ensured without investigating the structural elements that cause injustices, e.g., social structures, power relations, and institutional contexts, which may cause oppression and domination (Young 1990). Therefore, procedural justice refers to the representation of all who have a stake in the outcomes of decision-making processes (Klinsky and Dowlatabadi 2009). "Recognition" is another distinct concept concerned with "making visible histories of discrimination and disrespect" (Hobson 2003, p. 5) and challenging the norms, values, and meanings that legitimize inequality (Fraser and Honneth 2004, p. 29). Distributive and procedural justice and recognition are interdependent; they consider the resources that should be redistributed, to whom, and the norms guiding decision-making processes. With compensatory, restitutive and corrective justice, people's rights are to be respected, not violated or harmed through others' actions; if not done, compensation must be paid to those harmed. Compensatory justice calls for providing the equivalent of that which the harm has caused (Goodin 1989). In practice, there are other ways to provide compensation; however, what constitutes a just approach is subjective (see Goodin 1989).

Despite repeated calls from developing countries and civil society actors for distributive, procedural, and compensatory justice for harm caused, wealthy countries have avoided measures that would evoke responsibility and incur liability. Neoliberal justice, which promotes libertarian principles of "justice as mutual advantage" and "justice as private property," has often been favored by wealthy countries, and has been reflected in more recent UNFCCC texts (see Ciplet and Roberts 2017). Justice as mutual advantage speaks to "rational agreement of agents to cooperate with one another to further their self-interest" (cited in Ciplet and Roberts 2017, p. 150). As private property, it emphasizes the importance of property rights over all others. Institutions, it is argued, should protect the freedom of actors to exploit their natural advantages. Together, these principles allow for culpable Parties to avoid legal liability and for the framing of climate adaptation finance provision as goodwill or subject to market forces, rather than preconditions for establishing responsibility for creating the problem in the first place.

As it relates to climate adaptation, justice should be contextualized within the normative, institutional, and political realities of the process from which concerns have emerged (Ciplet et al. 2013). Shue (1992, p. 386) argues that questions of justice are not external to international climate negotiations on three grounds: (1) "background injustice" is not lost sight of by the Parties involved in the negotiations, which, over time, give rise to what others call "principled beliefs"; (2) the harm caused by the rich nations, though done unintentionally, is the subject of negotiation and cooperation; and (3) avoiding the issue of justice would ultimately condemn the poor nations to sacrificing their "vital" interests, namely survival, in order for the rich nations to avoid sacrificing their "trivial" interests (also see Roberts and Parks 2006; Vanderheiden 2011, p. 65).

Considering this context of governance and the numerous conceptions of justice, this article raises the following queries, as it relates to adaptation finance: Who should provide adaptation finance, how much, and to whom? On what basis and through what mechanisms should it be delivered? How should those mechanisms be governed? In the next three sections, we identify three "eras" of adaptation finance and review the evolution of climate regime provisions and actual behaviors of actors according to these guiding justice issues. In our conclusion, we argue that emerging neoliberal characteristics and the guiding principles of the contemporary climate regime present distinct challenges to advancing justice related to adaptation finance.

3 The early years of adaptation finance under the UNFCCC (1992–2008)

3.1 The emergence of the climate debt frame

The concepts of carbon debt, climate debt, and ecological debt were introduced into international climate politics in the late 1990s by non-governmental organizations (NGOs) such as Acción Ecológica and Christian Aid (see Roberts and Parks 2006; Simms et al. 1999). The specific networks that pushed for gains in this area were broad-based, loosely tied, and often involved developing country State and non-State actors in the Global South and North working in tandem. Climate debt advocates purport that the Global North owes the Global South a climate debt, which is far greater than the Third World financial debt due to its disproportionate use of atmospheric space without payment (Martinez-Alier 2002). The concept evolved to have two main components. First, because wealthy countries have utilized most of the atmospheric space for storing carbon emissions, developing countries should be paid an "emissions debt" to account for their fair share of atmospheric space. Second, wealthy countries owe an "adaptation debt" which represents compensation owed to enable developing countries to adapt and respond to climate impacts that are not of their own making (see Government of Bolivia 2009b).

Around the same time, States in the Global South began expressing demands in this area. This message was galvanized in the statement released by the Heads of State and Government at the Group of 77 (G77) and China's South Summit in Havana in 2000 (see G77 and China 2000, online). In subsequent years, the least developed countries (LDCs), Alliance of Small Island States (AOSIS), G77, and a coalition of more than 30 Western NGOs, policy institutes, and think tanks began to aggressively push for remuneration of the ecological and climate debts (Roberts and Parks 2009), in addition to calling for wealthy States to take the lead on cutting emissions. While this was a core demand of the LDCs since their founding as a negotiating group in 2002 and a full decade earlier by AOSIS, adaptation was still not widely viewed as a core issue in the negotiations.

The concept of climate debt is closely associated with the emergence of the global climate justice movement. The Eighth Conference of the Parties (COP) to the UNFCCC in New Delhi in 2002 signaled the emergence of the climate justice movement: a coalition of fishers from the Indian States of Kerala and West Bengal representing the National Fishworkers' Forum, farmers from the Agricultural Workers and Marginal Farmers Union, and a delegation of Indigenous peoples from the mining-impacted areas of Orissa and threatened by the massive Narmada Dam marched in the streets. Delegates of NGOs from 20 other countries also participated in the march (Khastagir 2002). In the same year, an international coalition of groups gathered in Johannesburg for the World Summit on Sustainable Development and released a formative statement for the climate justice movement called the "Bali Principles of Climate Justice." Ecological debt was a key tenet of this document. For example, it called for, "Affirming the principle of ecological debt, climate justice protects the rights of victims of climate change and associated injustices to receive full compensation, restoration, and reparation for loss of land, livelihood, and other damages" (CorpWatch 2002, online).

It was not until COP13 in Bali in 2007 that developing countries made adaptation a core demand at the negotiations. Arguing that adaptation in the UNFCCC documents and discussions was "piecemeal," Tuvalu, on behalf of the LDCs and AOSIS, introduced the so-called International Blueprint on Adaptation (see Government of Tuvalu 2007). This document would largely set the agenda on adaptation politics for the next five years (though crucial elements were watered down). In addition to calling for predictable and adequate funding and a coordinated international response to adaptation, the blueprint introduced a novel demand for a "burden sharing mechanism." This included a proposal for an international levy on international aviation and maritime transport to fund adaptation in vulnerable countries.

3.2 UNFCCC provisions on adaptation/adaptation finance

During the first decade and a half of negotiations, the concept of justice was not explicitly defined in the UNFCCC. However, other provisions in the Convention implied the meaning of justice (Okereke 2008). For example, Paragraph 3 of the Convention's Preamble refers to disproportionate "per capita" and "historical emissions" of developed countries. The

Convention's basic principles also guide the global community on addressing climate change, particularly the cardinal principle of "common but differentiated responsibilities and respective capabilities" (CBDR+RC). In view of developed countries having the largest share of historical and present-day emissions, they were to lead on mitigating greenhouse gas emissions (Article 3.1) and on supporting adaptation in vulnerable countries (Article 4.4), including providing financial assistance with "new and additional" monies (Article 4.3). The CBDR+RC principle also implicitly refers to the polluter pays principle (i.e., those who produce pollution should bear the costs of managing it so as to prevent damage to the environment or human health). The provisions of the Convention such as Article 4.3 and Article 4.4, which highlight "the need for adequacy and predictability in the flow of funds and the importance of appropriate burden sharing among the developed country Parties" and which calls on Annex II Parties [developed country Member States of the Organisation for Economic Co-operation and Development (OECD)] to "assist the developing country Parties that are particularly vulnerable to the adverse effects of climate change in meeting costs of adaptation," respectively, are a clear recognition and acceptance of developed country responsibilities. Further, special consideration is directed to the needs and concerns of specific categories of developing countries and LDCs through the provision of finance, technology, and insurance mechanisms (Articles 4.8 and 4.9). These provisions indicate an implied acceptance that the Annex II Parties should provide compensation to the developing countries, as subject to availability (Article 11 para. 3(d)).

Having been drafted in 1991 and 1992, however, the Convention focused mostly on mitigation as the ultimate solution to climate change, though there are five references to adaptation. In the initial years, adaptation was overlooked in part because of the apprehension that it might lead Parties to underemphasize mitigation (Ciplet et al. 2015). Moreover, while AOSIS raised the issue of compensation for climate impacts suffered, compensatory justice was largely neglected by the COP, and relegated to a decision on the provision of insurance (see Article 4.8) (Khan 2014). This was, in part, due to the fact that the climate regime has often narrowly reflected market-based solutions of both economic growth and climate change within the framework of neoliberal, market economics (Ciplet and Roberts 2017). This placed adaptation on the back burner in terms of the developed countries taking responsibility for climate change.

On the one hand, with the publication of the Third and Fourth Assessment Reports of the Intergovernmental Panel on Climate Change (IPCC) in 2001 and 2007, respectively, climate change issues began to be seen as development issues that required the mainstreaming of adaptation. On the other hand, mitigation was not being taken seriously by the developed countries. As a result, COP7 adopted the Marrakesh Accords in 2001, which, among other things, contained the first substantial package on adaptation. There, three Funds were established—the Least Developed Countries Fund (LDCF) and the Special Climate Change Fund (SCCF) under the Convention and the Adaptation Fund under its 1997 Kyoto Protocol (Decisions 5/CP.7, 6/CP.7 and 10/CP.7).

In terms of adaptation finance, this period witnessed the laying out of infrastructures and the operationalization of the newly established Funds under the UNFCCC regime. The Global Environment Facility (GEF), since its inception in 1993, began to fund adaptation projects. But developing countries were skeptical of the Facility because it is donor-controlled, based at the World Bank in Washington, D.C., and requires that all spending result in global public goods benefits, including in the case of adaptation projects (Khan 2014; Khan and Roberts 2013). Gradually, this policy was relaxed, and the Facility began accommodating a broader approach to adaptation funding.

3.3 Who should get adaptation finance?

In terms of distributive justice, there were numerous provisions on burden sharing among industrialized countries (Decision 10/CP7; Articles 4.3 and 11.2 of the Convention and Kyoto Protocol, respectively). The Convention obligates that Annex I [or developed] countries "shall" "meet the costs of adaptation" in particularly vulnerable countries (Article 4.4). Moreover, it implies a commitment to distributive justice where particularly vulnerable countries should be prioritized (Decision 5/CMP2; Decision 1/CMP3). The Convention, however, never defined the term "particularly vulnerable." For setting a list of criteria of vulnerability, an assessment process was approved in 1995, with the first decision on guidance for financial mechanisms. Although there is a broad understanding of the need for the prioritization of eligible countries based on vulnerability, the G77, the largest negotiating bloc of developing countries, never pursued this issue further because of political sensitivities. At COP13 in Bali in 2007, the Bali Action Plan was adopted, which put adaptation as one of the four pillars, together with mitigation, technology transfer, and finance. The Adaptation Fund was operationalized, with the GEF working as the Trustee, which it also did for the other two Funds—the LDCF and the SCCF. African countries were subsequently included in the Bali Action Plan alongside the LDCs and the small island developing States (SIDS) by virtue of also being "particularly vulnerable to the adverse effects of climate change" (para. 1(c)(i)).

But there remained the issue that funds may not be allocated in a way that prioritized the most vulnerable groups; instead, some funding allocation formulae reflected donor interests more than the needs of vulnerable countries; others distributed funds by a quota system with flat amounts across groups of nations (Ciplet et al. 2013). This puzzle raised the question: how can "fair" funding allocation criteria be developed without disrupting developing country solidarity? As Jagers and Duus-Otterström (2008, p. 577) argue, adaptation poses distributive justice-related questions that are "not only between burden-takers (i.e., those who take adaptive or mitigating action) but also between recipients of benefits." Some of the associated ethical issues have been directly addressed in the literature, for example, through the definition of burden sharing rules for allocating the cost of adaptation (e.g., see Baer et al. 2009; Dellink et al. 2009; Jagers and Duus-Otterström 2008), or indirectly through the individuation of responsibility for climate cost burdens (e.g., see Caney 2005; Paavola and Adger 2006; Page 2008).

3.4 Procedural justice—governance of financial mechanisms

Grasso (2010, p. 53) argues that both procedural and distributive justice in adaptation financing can be ensured through a "fair process which involves all relevant Parties, of raising adaptation funds according to responsibility for climate impacts, and of allocating the funds raised in a manner that puts the most vulnerable first." Accordingly, there have been major struggles over who should oversee climate Funds and how the Funds should be structured. Developing countries and civil society groups, often critiquing international aid practices as extending the neo-colonial interests of wealthy countries, pushed for the COP to oversee the Funds with "equitable and balanced representation" (Articles 11 and 11.2). Notably, the guiding principles of the Adaptation Fund include "access to the Fund in a balanced and equitable manner" (Decision 5/CMP.2 para. 1(b)) and "transparency and openness in the governance of the Fund" (para. 1(c)). The governing body is also to be constituted by Parties in the Kyoto Protocol, based on the one country–one vote rule, which should ensure strong representation by developing countries (para. 5 and 6); projects financed through the Adaptation Fund are to be "country driven" and "based on needs, views, and priorities of eligible parties […]" (Decision 5/CMP.2 para. 2(c)).

Developed countries preferred that the GEF oversee the Funds. Since major donors have near veto power at the World Bank, where the Facility is based, developing countries objected to the GEF having administrative power over UN Funds. Further controversy was added by the GEF's earlier Resource Allocation Framework, which was based on two criteria—global benefits from projects and country performance (GEF 2010). The criterion of "global benefits" is seen by the LDCs as a way of diverting most of the GEF resources to mitigation, while leaving almost nothing for adaptation. Despite developing country opposition, the LDCF and SCCF continue to be administered by the GEF (Decision 1/CMP.4).

4 The shift in Copenhagen (2009–2015)

4.1 Adaptation finance justice demands

The Climate Action Network (CAN) International, Climate Justice Now!, a new climate justice network, and other civil society networks such as the Pan African Climate Justice Network, representing 63 NGOs from across Africa, attended COP15 in Copenhagen in record numbers in 2009. Many of these groups had adopted a justice message at the negotiations, focused on realizing a legally binding and enforceable treaty, and for wealthy countries to pay their climate debt, including the establishment of a Fund under the COP to administer such finance.

Civil society groups in both CAN International and the newly formed Climate Justice Now! network made calls during this period for innovative public finance mechanisms to fund adaptation. CAN International, while focusing most of its attention on mitigation, called for adaptation to have equal footing with mitigation in the Convention (e.g., see CAN International 2007). Many of the more radical groups demanded a "solidarity fund" or a "reparations fund" to administer climate debt to countries of the South. A sign-on letter was issued earlier in 2009 before the intersessional in Bonn by the Third World Network in order to "galvanize the members of the civil society and social movements globally to support the call for the repayment of the climate debt and to advance these calls in the climate negotiations" (cited in Raman and Lin 2009, online).

In Copenhagen, other civil society networks also called for repaying the climate debt and for displacing a growing focus on market mechanisms in favor of public support (developed country government-funded adaptation pledges and payments to developing countries). These included a statement by participants of the Indigenous Peoples' Global Summit on Climate Change held in Anchorage, Alaska, which was agreed by Indigenous representatives from the Arctic, North America, Asia, the Pacific, Latin America, Africa, the Caribbean, and Russia (see Inuit Circumpolar Council 2009), a statement by the Pan African Climate Justice Alliance, and a statement by the Trade Union Conference of the Americas, including people from across Latin America and the Caribbean (Third World Network 2009). The movement to get wealthy countries to pay their climate debt was gaining momentum, and upon entering the Bella Center in Copenhagen, it was hard to miss this message which decorated countless signs in the NGO display booths and buttons on backpacks and jackets of civil society members. For example, the Pan African Climate Justice Alliance declared:

> "For their disproportionate contribution to the effects of climate change—causing rising costs and damage in our countries that must now adapt to climate change—the developed countries have run up an "adaptation debt." Together the sum of these debts—emissions debt and adaptation debt—constitutes the climate debt. Proposals by developed countries in the climate negotiations, on both mitigation and adaptation, are inadequate. They seek to pass on the costs of adaptation and mitigation, avoiding their responsibility to finance climate change response efforts in Africa" (Pan African Climate Justice Alliance 2009, online).

This statement sought to stand in support of States in the negotiations that made similar official statements on climate debt in the UNFCCC process, including a Declaration by Bolivia, Cuba, Dominica, Honduras, Nicaragua, and Venezuela, a speech by the Sri Lankan Environment Minister, and a statement by the Lesotho delegate on behalf of the LDC negotiating group (Third World Network 2010). For example, the Latin American countries above declared that:

> As for climate change, developed countries are in an environmental debt to the world because they are responsible for 70% of historical carbon emissions into the atmosphere since 1750. Developed countries should pay off their debt to humankind and the planet; they should provide significant resources to a fund so that developing countries can embark upon a growth model which does not repeat the serious impacts of the capitalist industrialization (cited in Rabble News 2009, online).

Likewise, the Sri Lankan Environment Minister explained: "If we adopt [the] scientific criteria of [the] IPCC, these so-called developed countries should cut their emission level by at least 70–90% by 2020. On the other hand, they owe environmental debt to other countries and should compensate them by establishing an adaptation fund" (cited in Nizam 2009, online).

Low-income States including the LDCs, AOSIS Members, and Bolivia came into the pivotal negotiations in Copenhagen with other ambitious demands. These included a legally binding treaty that would keep average global temperature rise below 1.5°C, US$400 billion of "fast-start finance" from wealthy countries to enable those hardest hit by climate change to adapt to its impacts, and an equitable share of the atmosphere to ensure adequate "development rights" (see AOSIS 2009; Government of Bolivia 2009a; Ourbak and Magnan 2017). Tuvalu's blueprint, which it had tabled at COP13 in Bali in 2007, called for an International Climate Insurance Pool that included internationally-agreed threshold triggers such as wind speed, flood levels, sea-level rise, drought indices, and inundation levels due to storm surge for payouts to communities. This would largely be a precursor to demands beginning in 2010 for a loss and damage mechanism[1].

The leadership and capacity of the LDCs grew stronger over the years.[2] This, combined with the adept legal skills and ambitious demands of AOSIS, meant that the presence of the

[1] It is likely that the term "loss and damage" originated from this document. Page 15 reads "A template for assessing damage, losses, and needs after a disaster could be drafted to ensure rapid compensation for those affected."

[2] The LDCs have grown more forceful and organized, and there was over a decade of support from the European Capacity Building Initiative, directed by the Oxford Institute of Energy Policy, for developing its demands. This support included one- to two-week workshops on climate science, policy, and strategy development for LDC representatives.

low-income States in the negotiations had become highly visible since the pivotal conference in Bali in 2007. On the eve of the negotiations in Copenhagen in 2009, the G77, despite major shifts in broader geopolitical relations, seemed as strong and capable as ever in challenging the interests of the Global North.

A central focus of the more radical civil society groups was pushing the World Bank and other major multilateral banks to get out of climate finance, something that was backed by numerous developing countries. To this end, during the first week of negotiations in Copenhagen, a mobilization took place outside the Bella Center calling for reparations and addressing the climate debt. Bolivian Ambassador to the UN, Pablo Solon-Romero, speaking at the Bolivia and Jubilee South Press Conference on December 14, joined in this call saying, "The first element we are speaking about is a debt of emissions, second we are speaking about a debt in adaptation, and third we are speaking about a debt to mother earth" (pers comm).

Other organizations, as part of the more moderate Climate Action Network, also took strong positions on climate finance for developing countries, a notable shift from the level of attention that they gave the issue just two years prior in Bali. These calls echoed the climate finance demands of low-income countries, and in some cases, sought to preempt what they saw as strategies of co-option for a weak political agreement on mitigation that were yet to come.

4.2 Provision of adaptation finance

The Copenhagen negotiations, dubbed by critics as "Brokenhagen," were a turning point in global climate politics. Expectations were high for a new agreement on climate action and support that finally addressed the injustices. Even after almost two decades, there were wide differences among groups of countries in the negotiations about how climate finance should be mobilized (Ciplet et al. 2015). There was a yawning gap in the amount of adaptation funds available to developing nations, compared with any assessment of adaptation needs. The Copenhagen Accord and the 2010 Cancun Agreements promised developing countries US$30 billion in short-term "fast-start finance" for the period 2010 to 2012 and a "scaling up" to US$100 billion per year by 2020. However, the true meaning of these numbers depended on the interpretation of key phrases in the text, many of which were loosely defined or not defined at all (Roberts and Weikmans 2017). In our interviews with delegates from different blocs during these negotiations, widely different interpretations were derived.

First, the texts promised "adequate funding" yet developed countries fell short in this area. Donor countries did not make it clear how they would determine their financial contributions for adaptation. In order to know if the pledges and delivered funds are truly adequate, "we would need updated and best-knowledge estimates of need for mitigation and adaptation funding" (Ciplet et al. 2013, p. 58). Such estimates are very difficult to establish but the UN Environment Programme estimated that adaptation costs could range from US$140 billion to US$300 billion per year by 2030, and between US$280 billion and US$500 billion per year by 2050 (UNEP 2016). The mobilization of US$100 billion a year both for mitigation and adaptation by 2020 was clearly not in line with these cost estimates.

The proportion of the funding that would be in the form of pure grants, partial grants, or purely market rate loans was also not made clear. The Copenhagen Accord states that, "This funding will come from a wide variety of sources, public and private, bilateral, and multilateral, including alternative sources of finance." Despite repeated complaints about this mixing of two very different types of finance, during this period, there was no improved clarity regarding the proportion of funding that should or must be publicly raised in the agreements that followed, i.e., the Cancun Agreements of 2010, the Durban Platform of 2011, or the Doha or Warsaw Agreements of 2012 and 2013, respectively. The 2015 Paris Agreement avoids mentioning specifics, indicating that funds will be mobilized "from a wide variety of sources, instruments, and channels, noting the significant role of public funds […]" (Article 9.3). But contributor nations are protecting their right to channel climate finance through their own bilateral agencies (and not just through the multilateral climate Funds established under the UNFCCC) and to provide loans and export credits, instead of grants-based assistance. While the United States (USA) allocated no money to the UNFCCC or the Green Climate Fund (GCF) in its Appropriations Bill for the 2018 Financial Year, for example, it has been channeling a larger amount of its climate finance support through its State Department, its Agency for International Development, and its Treasury (Thwaites 2018; United States Government 2018). This preference for prioritizing bilateral transfers is in no way surprising—the Paris Agreement avoids directly referencing some of the key principles of climate finance relating to funds mobilization, administration, governance, disbursement, and implementation (Schalatek and Bird 2015). And unlike the Convention, the Copenhagen Accord and the Cancun Agreements, the Paris Agreement also does not mention "alternative/innovative" sources of finance, such as funds that could be generated through a tax on international financial transactions or international air travel. These funds are critical for scaling up commitments from developed countries such as the USA.

The Copenhagen and Cancun texts as well as the Paris Agreement promise "predictable" funds, which is essential for developing countries to establish their own budgets and to plan for adaptation responsibly, but predictability did not increase in this period. Some quite developed proposals were put forward to levy international air passengers a small flat fee or to finally tax bunker fuels used in international shipping, instituting a tiny international transaction tax, or a tax on carbon, or even a tax on arms trade (see Gewirtzman et al. 2018; Richards and Boom 2014). However, none of these proposals were advanced and climate finance remained voluntary, depending most apparently on political expediency in the wealthy countries (Khan 2015).

Another issue impacting the predictability of funding during this period was the extreme fragmentation of climate finance (see Caravani et al. 2012). There were almost 100 dedicated funding channels, both bilateral and multilateral, with private foundations also actively mobilizing funds (OECD 2015). With so many funding channels, and sometimes little transparency regarding what is being funded, it was difficult for both contributors and recipients to adequately assess where money was going (Roberts and Weikmans 2017; Weikmans and Roberts 2019).

The phrase "scaled up" is another aspect that was not adequately addressed during this era. After years of the wealthy nations putting only token amounts of voluntary funding into the UN climate Funds, developing nations pushed for real, "scaled up" funding after Copenhagen. This phrase came to stand for the post- "fast-start finance" period, from 2013 to 2020, when the Cancun Agreements specified a tenfold "scale up" of funding per year. Yet, there was no language in the associated UNFCCC decisions indicating a plan for the "scaling up" period. In 2013, only US$25 billion (7% of total flows) of public funds supported adaptation, despite previous agreements on maintaining a balance between funding adaptation and mitigation (Buchner et al. 2014; Ciplet et al. 2013). More recent years have seen small improvements in the imbalance (Carty and Comte 2018). Also disquieting is that the overwhelming share of climate finance (76–80%) is actually official development assistance, defined as "government aid that promotes and specifically targets the economic development and welfare of developing countries" (OECD 2018b, p. 1). This suggests that climate funds are not additional to what would have been delivered anyway

(Nakhooda et al. 2013). In the Paris talks in 2015, the OECD published a report claiming that developed countries provided US$62 billion in climate finance in 2014 (OECD and CPI, 2015). The Indian delegation, based on their analysis, responded that only US$2.2 billion could be regarded as credible new and additional climate support (Government of India 2015).

Overall, the above issues suggest that while low-income States succeeded in some ways in their efforts during this period to have adaptation finance scaled up, large gaps in justice remained. Never were fair shares or carbon debt–based approaches seriously considered in the formal negotiations. Moreover, it seemed unlikely that the emerging "loss and damage" agenda, focused on those climate impacts that cannot be readily adapted to, would result in a rebalancing of this power dynamic.

4.3 Who should get adaptation finance?

During this second era, there was no formalization of which countries should be prioritized for receiving adaptation funding. Though the Copenhagen Accord, and the Cancun and Paris Agreements recognize that preference should be given to the particularly vulnerable countries, the Paris Agreement avoids mentioning those countries in Africa as part of the particularly vulnerable countries group. The Copenhagen Accord had the expression of "the most vulnerable countries." The Africa Group, led by Egypt and South Africa, was very active in the negotiations and continues to lobby for such recognition. Some other developing countries also floated the idea of "highly vulnerable countries." This effort has been referred to as something of a "beauty contest" to identify those countries that are the most vulnerable (CAN International, 2010, online). While the proposal for "highly vulnerable countries" was rejected by the G77, it indicates the perceived benefits that gaining specific vulnerability status might have for certain poor and vulnerable countries in the UNFCCC. This process also indicates the risk that concessions based on special status can have on disrupting solidarity among developing countries (Ciplet et al. 2013). However, after Copenhagen, disunity among the G77 intensified (Khan et al. 2013). Some activists from the Global South even called for the dismantling of the bloc (Narain et al. 2011).

Studies on the distribution of adaptation finance did not concretely establish that money was directed to the most vulnerable countries (Betzold and Weiler 2017 is an exception). In the case of SIDS, for example, more adaptation finance went to countries with good governance quality and low per capita incomes (Robinson 2018a, 2018b; Robinson and Dornan 2017). The Maldives, which ranked first of all SIDS on an average of the University of Notre Dame's Global Adaptation Index for exposure between 2010 and 2014, received the 18th largest commitment of approximately US$23 million (Robinson and Dornan 2017). These studies should, however, be considered with caution, given the poor quality of adaptation finance data (e.g., see Kono and Montinola 2019; Weikmans et al. 2017), and the lack of reliable vulnerability indicators (e.g., see Füssel 2010; Klein 2009).

4.4 Governance of climate finance/procedural issues

During this era, the World Bank continued to serve as the Trustee of the LDCF and SCCF, while the Adaptation Fund was administered by a 16-member board, with 10 representatives from developing countries, and the remaining six from developed countries. The newly established GCF was operationalized and administered by a 24-member board, with equal representation from the developed and developing world. At COP18 in Doha in 2012, however, some developed countries unsuccessfully made efforts to dilute the accountability of the GCF to the COP, and thus weaken developing country decision-making over the Fund (Article 11.1 of the Convention plus Decision 3/COP17). Also, a 20-member Standing Committee on Finance with equal representation from developed and developing countries was operationalized to oversee the coordination, rationalization, mobilization, and the measurement, reporting, and verification of finance. As the financial architecture of the climate regime remained extremely fragmented, this high-level committee, with direct accountability to the COP, was tasked with rationalizing and making the whole process of raising and distributing climate finance more coherent. The committee was, however, given no power to force nations to behave differently—instead, it assumes the role of assessor of the Biennial Reports submitted by developed countries every two years.

In terms of concretizing compensatory justice, not much progress was made during this era. While the Paris Agreement recognizes the importance of "averting, minimizing, and addressing loss and damage associated with the adverse effects of climate change" (Article 8), it avoids tackling the dual issue of liability and compensation by explicitly stating that the Article "does not involve or provide a basis for any liability or compensation." Key Parties such as the USA opposed arguments for liability and compensation (Vanhala and Hestbaek 2016). As a result, the Article promotes sustainable development as a way of reducing the risk of loss and damage, which does not provide a concrete pathway for particularly vulnerable countries to be financially compensated.

5 The post-Paris era (2015–2018)

5.1 Adaptation finance justice demands

Both civil society and developing countries came into the Paris negotiations with many similar demands: a dramatic scaling up of public finance through innovative strategies, the paying of climate debt, a robust mechanism to address loss and damage, and equitable governance structures. Much attention was directed toward scaling up finance commitments to support initiatives outlined by developing countries as part of their new "Nationally Determined Contributions" plans. Moreover, many called on wealthy States to meet their Copenhagen commitments for the annual US$100 billion mobilization goal to equally target mitigation and adaptation, and for up-scaled post-2020 commitments commensurate with the escalating needs on the ground. Many criticized a growing focus on private finance in institutions such as the GCF in lieu of public funds and governance forms that reflected business as usual, rather than the "transformative" approach outlined in the Fund's mission statement. Civil society groups such as Jubilee South and Oxfam also critiqued the ways in which climate finance was further indebting LDCs such as Mozambique and causing increased dependency when primarily provided as loans as opposed to grants.

5.2 Provision of adaptation finance

The preamble of the Paris Agreement notes the importance of the concept of "climate justice" with respect to climate action. The principle of equity and CBDR+RC was revised, and the words "in the light of different national circumstances" added to the preamble. This is a weakening of the cardinal principle as the justice elements were restricted to the non-binding section of the Agreement.

The Paris Agreement reiterates the obligation for developed countries to provide climate finance to developing countries for mitigation and adaptation, while developing countries may voluntarily contribute to financing efforts (Article 9.2). It pushed the annual goal of US$100 billion forward, to be sustained from 2020 to 2025, prior to which a new target will be agreed. Though it stipulates a global goal on adaptation, recognizing the international dimension of adaptation, the pronouncements remained vague, but one positive aspect of the Agreement is that it links adaptation needs with the level of mitigation (Article 9.4) and urges Parties to make finance flows consistent with low-carbon climate resilient development (Article 2.1c). However, Article 8 on loss and damage does not bear any liability and compensation claims.

The post-Paris developments, however, do not paint a bright picture. In 2016, just before the start of COP22 in Marrakech, developed countries floated a new Roadmap on climate finance. However, the Roadmap lacked clarity on core issues, including additionality and predictability (Roberts and Weikmans 2016). Intensive negotiations that year failed to produce an agreed framework on long-term finance. This ultimately was salvaged by the Moroccan COP Presidency, adopting an innocuous and anodyne text, just urging the developed countries to “scale up” the pledged mobilization of US$100 billion a year by 2020.

The Paris outcome was also not encouraging in the two years that followed. The most anticipated negotiations were COP24 in Katowice in 2018. During these negotiations, the COP adopted a Rulebook, which requires Parties to report on support provided and mobilized through public interventions (Annex of Decision 18/CMA.1, para. 118–129). Parties are further required to provide more information than before on several key aspects of their accounting methodologies. However, the new accounting modalities for financial resources provided and mobilized still leave considerable discretion to Parties (van Asselt et al. 2018). The language is relatively permissive, which allows countries to report the full value of loans, rather than their “grant equivalent” share (Annex of Decision 18/CMA.1, para. 118-129). In the absence of an agreed understanding of what climate finance is, developed countries will continue to have wiggle room for creative accounting.

The persistent issue of double or even triple counting of the same money provided through the UNFCCC and non-UNFCCC delivery channels has not been resolved. The developed countries have been allowed to report on their own about how they count “new and additional” climate finance. This subjective fixing of accounting methodologies by finance providers hardly allows any comparability. An additional prick is the extreme fragmentation of climate finance delivery with the total number of public and private channels currently ranging from 99 to over 500, including over 22 multilateral climate finance Funds (NDC Partnership 2018; OECD 2015). There are too many overlaps involving huge transaction costs, which generate frustrations both for contributors who are duplicating efforts and recipients who have mountains of tedious paperwork to file in order to access these Funds (Robinson and Dornan 2017; Robinson and Gilfillan 2017). This plainly warrants a “thinning out” of climate finance agencies. One positive decision at COP24, however, was for the organizing of a workshop before COP25 in Santiago de Chile on the “effectiveness” of climate finance on the ground.

Just weeks before COP24, the OECD published a report on climate finance, which showed that their Members had reported providing US$56.7 billion in climate finance to developing countries in 2017 (OECD 2018a). Such figures, however, have been met with great skepticism, given over-reporting and double-counting in earlier periods (see Weikmans and Roberts 2018). Overall, the large gap between the amount of finance that is claimed to be delivered as new and additional and the actual receipt of funds shows no sign of being bridged.

Another interesting dimension is that, though grants account for over a third of bilateral climate finance, they are a measly 10% of total multilateral funding (OECD 2018a, p. 5). The most vulnerable countries have persistently demanded adaptation funding in the form of grants to enhance their adaptive capacity and avoid greater indebtedness. Also, adaptation finance remains at one-fifth of total climate finance, though the often-repeated pledge has been to maintain a "balance" between mitigation and adaptation.

Amidst the clouds shrouding the skies of climate finance, it was announced in 2018 that the Adaptation Fund would be capitalized to the tune of US$129 million; and so too would the GCF—Germany pledged US$1.7 billion with France, Japan, Norway, Sweden, the United Kingdom, and others also making pledges. It is expected that the European Union may lead to fill the gap left by the USA, which had declared its withdrawal from the GCF as well as the Paris Agreement. Developed countries appear more interested in supporting capacity building for transparency in developing countries, than ensuring their own transparency of climate finance support. This is evident in the obligatory nature of funding for the former (Article 13 of the Paris Agreement), rather than for generic capacity building in the Global South (Article 11).

5.3 Who should get adaptation finance?

The problems of allocation remain much as they were in the previous period after the Paris negotiations. The Adaptation Fund, now serving the Paris Agreement, is likely to get richer, compared with the Funds explicitly designed to support the needs of the most vulnerable countries, including the LDCF and the SCCF. This was the first time that the Adaptation Fund garnered an amount higher than expected. Though the Adaptation Fund has prioritized the particularly vulnerable countries since its operationalization about a decade ago, the Africa Group at COP24 failed to be recognized by Parties as a priority constituency for climate action support.

5.4 Governance of financial mechanisms—the GCF and the Adaptation Fund

The period after Paris has also resulted in ongoing low-level struggles over the governance of climate finance. As mentioned before, only a small proportion of climate finance is channeled through the UNFCCC architecture, including the GCF, which began its journey with an initial capitalization of US$10.3 billion (initially planned to be spent over three to four years). Many developing country observers believed it would be handling the full US$100 billion a year commitment, but this is not the case. Over 60% of the US$10.3 billion has been deposited in the GCF's coffers, and over half of it has been delivered to around 75 projects. But there are several tensions. These include establishing criteria-based rationale for climate-related project proposals, enhancing access to the Fund, ensuring a level playing field for all Parties, making decisions according to consensus, and the reported politicization of the project approval process. Further, the USA had announced it would not deliver US$2 billion of the US$3 billion it had pledged.

6 Conclusion

This article sought to define the range of issues to be considered when evaluating the relationship between adaptation finance and climate justice; it also assessed what we know and do not know a quarter century into the process. How, finally, can a justice frame and criteria be deployed to influence behavior by big, wealthy nations and by international agencies and banks?

In the initial period from the drafting to the adoption of the UNFCCC in 1992, relatively abstract principles were translated into concrete institutional forms. The pivotal Copenhagen and Paris negotiations in 2009 and 2015, respectively, both saw adaptation finance as a core and contentious issue, especially from the perspective of particularly vulnerable countries. While Copenhagen saw some progress toward concrete commitments and institutional developments, the Paris Agreement, six years later, offered few gains in terms of justice. While the world has continued to warm, and climate impacts and costs increase exponentially, even the commitments made in Copenhagen show little promise of being honored. Ambiguity in key areas of climate finance governance related to distributive, procedural, recognition, and compensatory forms of justice still plague the UNFCCC regime. Moreover, where there is ambiguity, the history discussed here shows that powerful countries often creatively interpret expectations according to their own self-interests.

Looking at the broad sweep of whether "the arc of history" has bent towards climate justice (Roberts 2018, p. 163), we conclude that for adaptation finance, the answer is no. Several criteria laid out in our initial fundamental principles of climate adaptation justice have never been met, and in some ways, the international system seems farther than ever from meeting them, and less likely now to form a unified voice about this crucial issue. On the other hand, developing countries had to agree to forego any option of claiming compensation under the agenda of loss and damage.

The contemporary period of governance, rooted in neoliberal principles, presents distinct challenges for achieving justice related to adaptation finance. Specifically, the post-Paris context is characterized by a neglect of distributive justice as a guiding principle in favor of libertarian justice ideals, which emphasize the rational pursuit of self-interest, the de-emphasizing of public responsibility in favor of a focus on the market and private sector to solve collective problems, the sidelining of the "polluter pays" principle and command-and-control forms of governance in favor of a focus on transparency without robust systems of accountability (Ciplet et al. 2018), and exclusive decision-making processes in which core decisions are increasingly made bilaterally between powerful States outside of the consensus-based process of the UNFCCC (Ciplet and Roberts 2017). As such, the principles governing adaptation finance have largely reflected neoliberal justice. This has included a focus on voluntary action, a growing emphasis on leveraging private finance and market-based strategies, and a refusal by wealthy States to define commitments in relation to responsibility, developing country needs, liability, or historical debt.

We would argue that justice on climate finance is a bedrock issue to ambitious agreements on addressing this existential issue, and sadly, our review of the 25 + years of negotiations and fund provision does not paint a rosy picture. We, therefore, call for a turn towards centering finance justice issues of adequate and fair distribution of funds, of attention to governance, efficiency and accountability, and renewed dedication to collaboration across the North-South divide.

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