2 The Issue of Climate Change

Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems.

The 5th Report of the IPCC (2014)

2.1 The Carbon - Temperature Conundrum

According to the Intergovernmental Panel on Climate Change (IPCC) which aggregates international research efforts on climate change, "global atmospheric concentrations of CO_2, CH_4 and N_2O have increased markedly as a result of human activities since 1750 and in 2005 exceeded by far the natural range of the last 650,000 years" (IPCC 2007), with an increase of 70 % of global greenhouse gas (GHG) emissions due to human activities between the two periods.[1]

The parts-per-million metric (ppm) that describes the concentration of carbon dioxide (CO_2) in the atmosphere, went from 280 ppm at the early stages of the Industrial Revolution (around 1750) to above 380 ppm in 2010 (as shown in Fig. 2.1). In 2014, the average atmospheric concentration surpassed the 400 ppm level.

In the meantime, the average global temperature has followed a strikingly similar pattern of increasing and accelerating warming. Eleven of the last 15 years (2000–2014) were among the warmest years on the instrumental record of global surface temperature (since 1850) with almost permanent occurrences of positive

[1]The recognized GHGs are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydroflurocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6). Despite its influence on climate, water vapor is not listed among the GHG gases, due to its ability to absorb infrared radiation.

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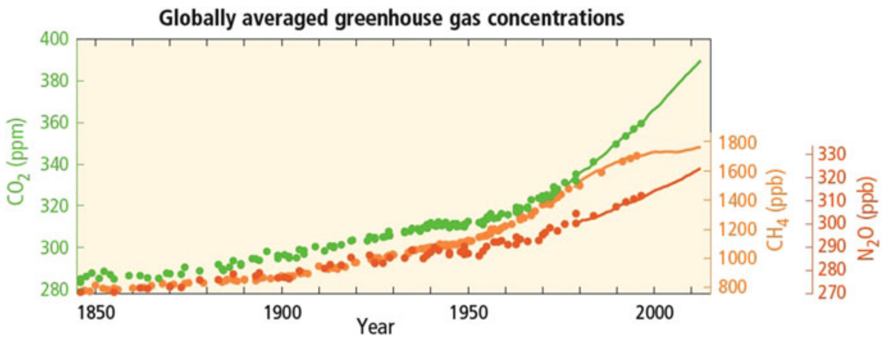

Fig. 2.1 Globally averaged greenhouse gas concentrations (Source: IPCC 2014)

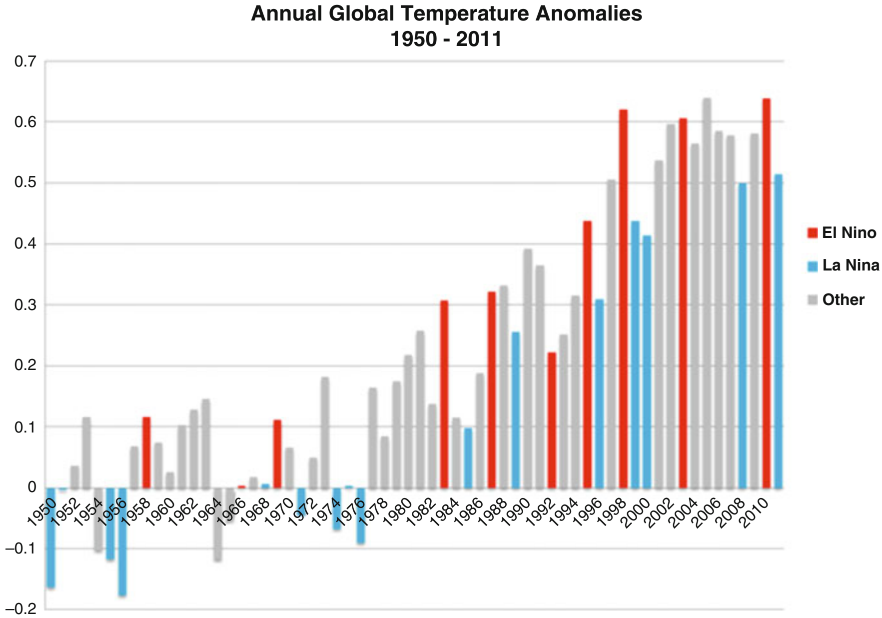

Fig. 2.2 Global Temperature Anomalies compared to long-term average (1950–2012) (Source: NOAA.gov)

temperature anomalies since 1980. Temperature anomalies since 1950 are presented in Fig. 2.2.

According to the fifth Assessment Report of the IPCC, the globally averaged combined land and ocean surface temperature rose by approximately 0.85 °C between 1900 and 2012. Over the last 50 years, global temperature has risen at an average rate of approximately 0.13 °C per decade, almost twice as fast as the maximum 0.07 °C per decade increase observed over previous periods. This kind of development is extremely worrisome, since it has been estimated that 1000 years are needed to reach a decrease in global average temperature of 1 °C, in the hypothetical case where GHG emissions were to be fully stopped.

GHGs are naturally present in the atmosphere and are not solely the result of anthropogenic activities. In the climate – temperature cycle, they play a fundamental role by absorbing and re-emitting solar radiation and causing the necessary warming of the earth's temperature. In the pre-industrial era, GHG concentrations were stable, but rapidly increased thereafter (see Fig. 2.1).

As their concentration in the atmosphere intensifies, GHGs act as a radiation trap that forces more energy to stay on the surface and more heat to be produced, therefore causing global warming. Each type of GHG has a specific and complex cycle that involves interactions between the atmosphere, the terrestrial biosphere, the oceans, the sediments, and the earth's crust. CO_2 for instance is produced, captured, and dissolved through a short-to-medium-term carbon cycle involving carbon sources (such as fuel consumption, organic respiration, and volcanic eruptions) and sinks (forest uptake and sedimentation). Over the long term, CO_2 concentration in the atmosphere is subject to a decay rate permitted by the permanent sink role of oceans' sedimentation. Scientists tend to consider that it takes 55 years for emissions to be permanently removed from the atmosphere. Any attempt to reduce emissions has, therefore, to deal with the unavoidable inertia in the system and the existence of potential saturation limits of the natural sinks. It has been estimated that more than two thirds of the global carbon budget has already been used, leaving mankind with approximately 20 years until dangerous GHG concentrations are reached, if economic activity continues along the business-as-usual path.

In relative terms, gases do not have the same effect on radiation retention: compared to CO_2, CH_4 and N_2O are present in smaller quantities in the atmosphere, but have a greater capacity to create greenhouse effects. To compare their relative influence on global warming, scientists rely on the concept of *global warming potential* (GWP). The GWP is a relative scale that compares the greenhouse effect of a specific mass of gas to the same mass of CO_2 and is, therefore, unitless. The GWP measure accounts for the different decay rates of gases: a gas that generates relatively high greenhouse effect, but which is dissolved rapidly, has a high short-term GWP coefficient but a low long-term one. To account for this factor, GWP tables are given for specific time horizons (TH) (see Table 2.1).

While the relationship between carbon and temperature is no longer debated, it seems fair to acknowledge that the specific role of anthropogenic emissions for

Table 2.1 GWP values and lifetime (Source: IPCC 2013, Chapter 8)

Global Warming Potential (GWP)			
Gas	Lifetime	TH: 20 years	TH: 100 years
CH_4	12.4	84	28
N_2O	121	264	265
HFC-11	45	6,900	4,660
HFC-134a	13.4	3,710	1,300
SF_4	50,000	4,880	6,630

global warming is still the subject of specific scientific feuds, the most recent having occurred in November 2009.[2] The so-called *climate skeptics* represent disparate groups of ideas and interests, united by their disbelief that climate change is an important issue to tackle, either because they consider the scientific evidence to be weakened by too much uncertainty, or because they regard other issues as much more important, and therefore deserving priority. Proponents of the first line of argumentation suggest that data are not entirely reliable, incapacitating any meaningful comparison of past patterns into current trends, or that anthropogenic emissions are just a fraction of larger natural interactions not yet completely understood. A minority of scientists believe that climate change is not man-made. However uncertain some results might be, it seems clear that a scientific consensus has now formed (embodied by the IPCC and other scientific institutions) and is strongly backed by the most recent measurements. Worryingly, those measurements tend to support rather pessimistic predictions for the consequences of climate change on human and environmental systems.

2.2 Global Warming Scenarios and Mitigation Paths

According to the IPCC (2014), the magnitude of anthropogenic GHG emissions depends on several key factors: population size, economic activity, lifestyle, energy use, land use patterns, technology, and climate policy. These factors are used for predicting the future development of GHG concentrations and environmental consequences, which should stand at the basis of the decision-making process. The IPCC relies on the GHG driving factors and estimates possible twenty-first century pathways, called Representative Concentration Pathways (RCPs). In the fifth assessment of the IPCC, four main scenarios are in focus, which differ according to the chosen climate policy. These are: RCP8.5, RCP6.0, RCP4.5, and RCP2.6, see Fig. 2.3.

While the RCP8.5 scenario captures a situation of continued high GHG emissions, the RCP2.6 describes a GHG concentration path in which stringent mitigation efforts are undertaken. The RCP6.0 and RCP4.5 scenarios capture GHG developments in between these two extremes. Business-as-usual economic development, without any additional efforts of reducing emissions, would lead to paths ranging between RCP6.0 and RCP8.5.

The changes in atmospheric temperature can also be predicted based on the different GHG concentration pathways (see Fig. 2.4). Worryingly, only very low

[2] On November 19th, 2009 the email server of the Climate Research Unit at the University of East Anglia (one of the most prominent research outlets on the issue of climate change) was hacked and email correspondences among its researchers were publicly disseminated. Dubbed “Climategate” by the press, the incident has revealed the bitter acrimony among most of the climate scientists and the climate skeptics, and has forced additional statements to reaffirm the existence of uncertainty in scientific evidence and results.

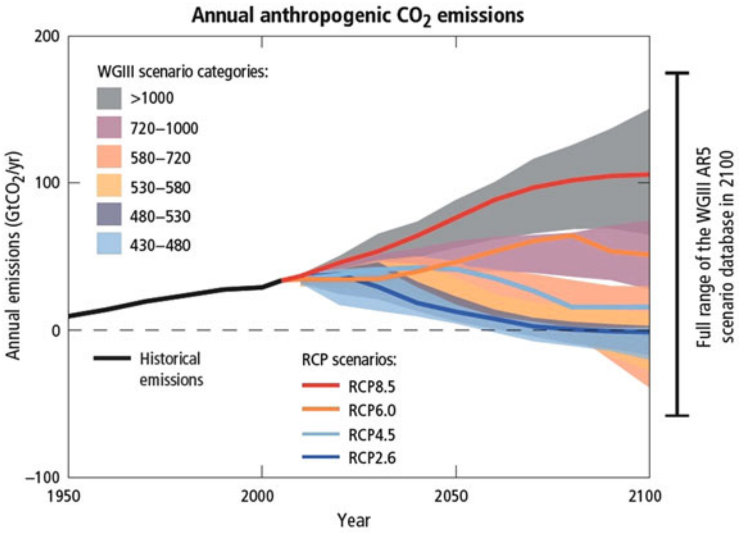

Fig. 2.3 Current and predicted scenarios of annual anthropogenic GHG emissions (Source: IPCC 2014)

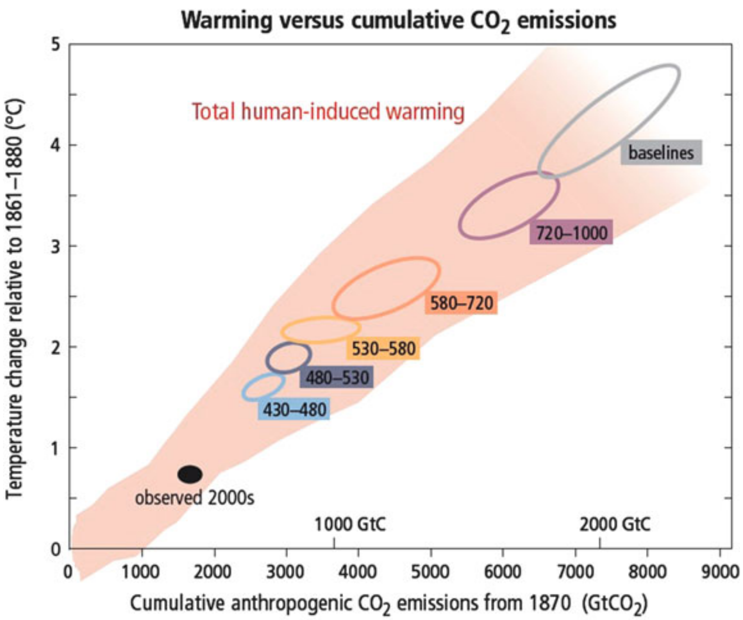

Fig. 2.4 Increases in atmospheric temperature from pre-industrial levels based on scenarios of GHG emissions (Source: IPCC 2014)

Table 2.2 Concentration stabilization scenarios and impact on temperature increase and sea level rise (Source: IPCC 2007). CO_{2e} stands for CO_2 equivalent, as described below

Scenario	CO_2 concentration at stabilization	CO_{2e} concentration at stabilization	Change in global CO_2 emissions in 2050 (% of 2000 emissions)	Global average temperature increase (in °C)	Global average sea level rise (in m)
I	350–400	445–490	−85 to −50	**2.0–2.4**	0.4–1.4
II	400–440	490–535	−60 to −30	**2.4–2.8**	0.5–1.7
III	440–485	535–590	−30 to +5	**2.8–3.2**	0.6–1.9
IV	485–570	590–710	+10 to +60	**3.2–4.0**	0.6–2.4
V	570–660	710–855	+25 to +85	**4.0–4.9**	0.8–2.9
VI	660–790	855–1130	+90 to +140	**4.9–6.1**	1.0–3.7

concentration pathways, such as the RCP2.6 scenario, are consistent with a temperature increase from pre-industrial levels below 2 °C by the end of the century.

In order to assess mitigation costs, the IPCC has computed simulations for stabilization scenarios around six specific carbon dioxide equivalent (CO_2e)[3] concentration levels in the atmosphere, acknowledging that attempts to reduce concentration to 445–490 ppm would require negative emissions for several decades (that is, higher uptakes than emissions). The different scenarios are presented in Table 2.2.

According to the sensitivity projections of the IPCC, any commitment to limit the global average temperature increase within a +2 °C limit would force CO_2 concentration to be stabilized at around 350–400 ppm. In December 2014, the concentration passed the 400 ppm level. A targeted concentration of 445–490 ppm would represent an increase in temperature of around +2–2.4 °C above pre-industrial levels. In the current context of increasing emissions, achieving a 400 ppm stabilization level would require a set of strong mitigation measures with various costs, areas of applicability and timing. The IPCC has introduced in the stabilization scenarios a set of usable mitigation strategies with increasing marginal cost: technology efficiency improvement, source of energy switching (e.g. from coal to natural gas), development of renewable energies, demand reduction, and carbon capture and storage.

[3]Carbon dioxide equivalence is a quantity that describes, for a given mixture and amount of greenhouse gas, the amount of CO_2 that would have the same global warming potential. It is measured over a specified timescale, generally 100 years.

2.3 Environmental and Economic Impacts

Until damages are elicited and adaptation costs monetized, the urgency of taking measures against climate change remains elusive for many. In a traditional cost-benefit analysis, investing in mitigation (i.e. emission reductions) makes sense only if it reduces damages and impacts up to a point where the local marginal costs of abatement and local marginal damages are equal. However, the issue of attaching costs to global warming and assessing impacts is a complex task that needs to overcome several hurdles, such as: (i) regional and sectoral implications of a global problem (the atmosphere is a common good), (ii) presence of high degrees of uncertainty, (iii) dynamic aspects, and (iv) ethical issues.

Climate change damages are difficult to accurately assess in a cost-benefit analysis, as the main causes of the damages are not generated locally, but are instead the result of collective externalities. In broad terms, the climate is a public good. Since some countries or regions will disproportionately suffer from the impacts in comparison with their emissions, it may prove difficult for them to define mitigation and adaptation strategies and to accurately adjust to the damages, given that they control only a limited share of the collective responsibility. This aspect leads to the second main difficulty, the importance of uncertainties in impact valuation.

Damages and costs are highly regional (or sectoral) and require long-term and costly bottom-up studies, which are difficult to compare across regions. A robust global cost-benefit analysis would require a concerted effort under the supervision of a centralized body, which has been the role played by the IPCC so far. However, its current assessment procedure does not provide clear monetized impacts, forcing further studies to rely on disconnected regional and sectoral assessments, or to come up with ad hoc assumptions.

Damages and impacts are also dynamic in nature and susceptible to reinforcing loops or switching periods of positive and negative effects. In order to compare across periods, a sound cost assessment requires the definition of a reliable and sensible discount rate. If the assumed discount rate is low, that is close to zero, the model implies equal impacts across periods and generations, supporting the view of the proponents of intergenerational equity. Conversely, if the discount rate is high, the damage assessment would limit itself to the view of the current generation.

Many studies conduct impact analysis on a subset of the global regional/sectoral matrix, with extensive research focusing on agriculture, forestry, and coastal economics. In a comprehensive effort, Tol (2005) summed up the results of different studies (see Table 2.3 where the estimates are expressed as percentages of the Gross Domestic Product).

According to these estimates, it is apparent that the burden of climate change will not be borne equally across regions. On one hand, some countries could benefit (over the estimated horizon) from a temperature increase which will positively reduce the harsh conditions of their winters and increase economic outputs (for instance, Russia

Table 2.3 Estimates of the regional impacts of climate change in percentage of GDP (Source: Tol 2005)

Estimates of the regional impacts of climate change in percentage of GDP (Horizon: 2100)				
	Pearce et al. (1996)	Mendelsohn et al. (1998)	Nordhaus and Boyer (2000)	Tol (1999)
	Temperature increase (°C)			
	2.5 °C	2.5 °C	2.5 °C	1 °C
North America	−1.5 %			+3.4 %
USA	−1 % to −1.5 %	+0.3 %	−0.5 %	
OCDE Europe	−1.3 %			+3.7 %
EU	−1.4 %		−2.8 %	
OCDE Pacific	−1.4 % to −1.8 %			+1 %
Japan		−0.1 %	−0.5 %	
Eastern Europe/Former USSR	+0.3 %			+2 %
Eastern Europe			−0.7 %	
Former USSR	−0.7 %			
Middle East	−4.1 %		−2 %	+1.1 %
Latin America	−4.3 %			−0.1 %
Brazil		−1.4 %		
South and Southeast Asia	−8.6 %			−1.7 %
India		−2 %	−4.9 %	
China	−4.7 % to −5.2 %	+1.8 %	−0.2 %	+2.1 %
Africa	−8.7 %		−3.9 %	−4.1 %

and Canada may experience positive economic growth). Unfortunately, on the other hand, the least developed countries in Africa and Southeast Asia are predicted to suffer the most from climate change, with an anticipated impact on GDP ranging from −3.9 % to −8.6 %.

Why is the developing world particularly affected?

- The livelihood of the poor is known to be significantly dependent on natural resources.
- When natural disasters destroy capital (be it machinery, cattle, or other), the poor typically lack access to financial resources to restore the level of capital to its pre-disaster level.
- Areas of poverty are often located in places that are more susceptible to high variability in temperature and rainfall, such as hilly areas, or those with steep slopes, and flood plains.

(continued)

- Richer societies are more resilient societies as a result of the positive correlation between income and education, openness, financial development, and greater institutional capacity.
- In the words of the World Bank (Margulis and Narain 2009): *"developing countries face not only a deficit in adapting to current climate variation, let alone future climate change, but also deficits in providing education, housing, health, and other services. Thus, many countries face a more general* development deficit, *of which the part related to climate events is termed the* adaptation deficit".

Recognition of the partial ineluctability of global warming combined with the slow deployment of mitigation strategies have forced economists and policy makers to reconsider the importance of adaptation as a complementary measure to climate mitigation.

While mitigation covers the strategies to *reduce* the amount of GHG emissions that cause climate change, adaptation encompasses the set of activities conducted to *offset* partially or in totality the adverse impacts of climate change. Adaptation can be divided between anticipative (*ex ante*) and reactive (*ex post*) strategies. For instance, the selection (and R&D) of drought-resistant crops prior to explicit climatic changes can be considered a proactive measure, while emergency vaccinations in the case of climate-related pandemics belong to reactive adaptation. In practice however, *"the distinction between anticipative and reactive adaptation is intuitively clear, but difficult to delineate with precision in a dynamic setting"* (Lecocq and Shalizi 2007).

Strengths and weaknesses of adaptation measures

Strengths

1. Adaptation is by definition local (regional or sector-based). In fact, adaptation measures privatize policies tackling climate change by largely limiting the benefits of adaptation to those having invested in it.
2. Adaptation avoids the free-riding problem traditionally associated with mitigation and does not require concerted and simultaneous actions, fostering the advancement of regional or local projects.
3. Adaptation projects are often less costly and easier to set up.
4. Adaptation provides short-term protection against early damages.
5. For developing countries without mitigation issues, it represents the main set of strategies (e.g. Africa).
6. Adaptation should be able to deal with extreme events.

(continued)

Weaknesses

1. Larger uncertainties are faced when developing anticipative projects.
2. Defining a common performance indicator to compare the results of different adaptation projects remains an important challenge.
3. Relying on adaptation only could lure countries with large emissions to give up on their mitigation projects, especially those with short-term views (or equivalently, high discount rates).
4. Creating private goods and benefits, adaptation can foster or reinforce inequalities.
5. Adaptation projects can be easily mixed with development targets already in place, impeding access to additional resources (e.g. the Copenhagen Green Climate Fund).

Strengths and weaknesses of mitigation measures
Strengths

1. Mitigation is the only long-term solution to the tackle climate change problem at its root.
2. In general, the effectiveness and efficiency of mitigation strategies have been more extensively studied, thereby involving less uncertainty about the potential benefits. As the IPCC notes, uncertainties are much larger at the local/sectoral level than at the global level.
3. Mitigation will have global benefits that are non-excludable (i.e. equity value).
4. Mitigation strategies have the same performance metric which allows for comparisons and allocations.

Weaknesses

1. The atmosphere is a public good. Thus, mitigation projects are non-excludable and non-rivalrous. This creates agency problems, either through free-riders or barriers to collective action.
2. Mitigation requires international negotiations that are extremely difficult to manage in the search for an unequivocal consensus.
3. Mitigation is a long-term process that has no impact on short-term damages.
4. For numerous developing countries with few emissions but large exposure to impacts, mitigation does not represent an effective policy.

Table 2.4 Estimates of adaptation costs in developing countries for 2010–2050, 2005 USD, no discounting (Source: UNEP 2014)

Adaptation costs in developing countries regions and sectors for 2010–2050			
Region	USD billion per year	Sector	USD billion per year
East Asia and Pacific	17.9	Infrastructure	13.0
Central Asia	6.9	Coastal zones	27.6
Latin America and Caribbean	14.8	Water supply and flood protection	19.7
Middle East/North Africa	2.5	Agriculture, forestry, fisheries	3.0
South Asia	15.0	Human health	1.5
Sub-Saharan Africa	14.1	Extreme weather events	6.4

It is now clear that adaptation policies will have to be put in place, both as a way to cope with dramatic and extreme events and as a way to adapt to permanent changes in our environment. However, adaptation cost assessments are still lagging behind damage impact studies and still lack a homogenous corpus of evidence and measures.

Considering the still limited amount of research conducted on adaptation strategies, it remains unclear how and to what extent adaptation and mitigation strategies interact with each other in a dynamic setting. A classical example is air-conditioning (A/C). A/C systems represent adaptation measures that limit the impacts of climate change. Yet, they increase energy consumption and the release of GHGs. In this simple case, the correlation between the effects of adaptation and mitigation would be negative. In contrast, a positive correlation may be found with regard to projects targeting the Reduction in Emissions from Deforestation and forest Degradation (REDD), for which mitigation measures (lower deforestation) provide adaptive instruments against floods and landslides.

While adaptation is generally cheaper than the average range of available mitigation strategies in the short-term, it will nonetheless carry important costs. Table 2.4 presents a range of estimates covering adaptation costs in developing countries.

Most likely, an optimal policy to tackle climate change will have to combine both mitigation and adaptation measures. While adaptation is generally easier to implement, bears fewer uncertainties, and can be privatized (partially avoiding free-riding effects), only mitigation strategies are capable of reducing atmospheric GHGs in order to establish a viable long-term concentration. Simply relying on adaptation measures could increase the risk of reaching irreversible climate and environmental changes, while being more and more costly to keep up with increased damages.

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