Guide to the Science of Climate Change in the 21st Century

Chapter 20
AR5 - Mitigation

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20.1 Introduction

The most serious impacts of climate change can be avoided by implementing mitigation initiatives. (Mitigation is defined as 'the action of reducing the severity, seriousness, or painfulness of something'.) We are talking about mitigating 'climate change'.

IPPC AR5 Working Group Three in their report states: 'Mitigation is a human intervention to reduce the sources or enhance the sinks of greenhouse gases.' They continue 'Mitigation, together with adaptation to climate change, contributes to the objective expressed in Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC): *The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.* Climate policies can be informed by the findings of science, and systematic methods from other disciplines.'

Pivotal to the success of mitigation initiatives is a clear understanding of what is being attempted and communicating it to those who must implement it or are affected by it. There must be 'buy-in' or even the best strategies will not gain support. Inclusivity in the decision-making process is important.

20.2 The science.

The starting point is a close examination of the energy budget discussed in Chapter 4 reproduced here as Figure 20.1. The energy budget provides an intuitive model which puts human impacts and mitigation initiatives into context. It connects the objective to the science. The initiatives can then be promoted to a knowledgeable community including the policy makers and their constituency. From Figure 20.1 it is clear that there is human influence on the energy budget in a variety of ways including but not limited to:

1. The concentration of greenhouse gases and the amount of long-wave radiation that is radiated from the Earth's surface that is absorbed, warms the atmosphere and radiated back to Earth and space.
2. Aerosols such as oxides of sulfur and nitrogen that will absorb both short-wave and long-wave radiation and warm the atmosphere.
3. Atmospheric particulate matter such as carbon black and dust that will absorb both short-wave and long-wave radiation and warm the atmosphere.

4. Land surface modification which then affects amount of short-wave radiation reflected by surface, amount of short-wave radiation absorbed by surface and long-wave surface radiation emitted. Warmer land surface will affect cryosphere resulting in increased glacier melt, melt of Greenland and Antarctic ice sheets (increased sea level) and disappearance of sea ice (profound ecological effects).
5. Warmer land surface (including ocean surface) will impact the hydrological cycle which is discussed in Chapter 6. The hydrological cycle is shown in Figure 6.1 reproduced here as Figure 20.2. The result of a warmer land (and ocean) surface is greater evapotranspiration (evaporation and transpiration from plants), increased concentration of water vapour in atmosphere (water vapour is a greenhouse gas) and cloud formation (reflects short-wave radiation). Warmer land surface will also result in increased air circulation from lower troposphere to near the stratosphere where water vapour will be condensed to form precipitation events (some of which might be cyclonic in nature).

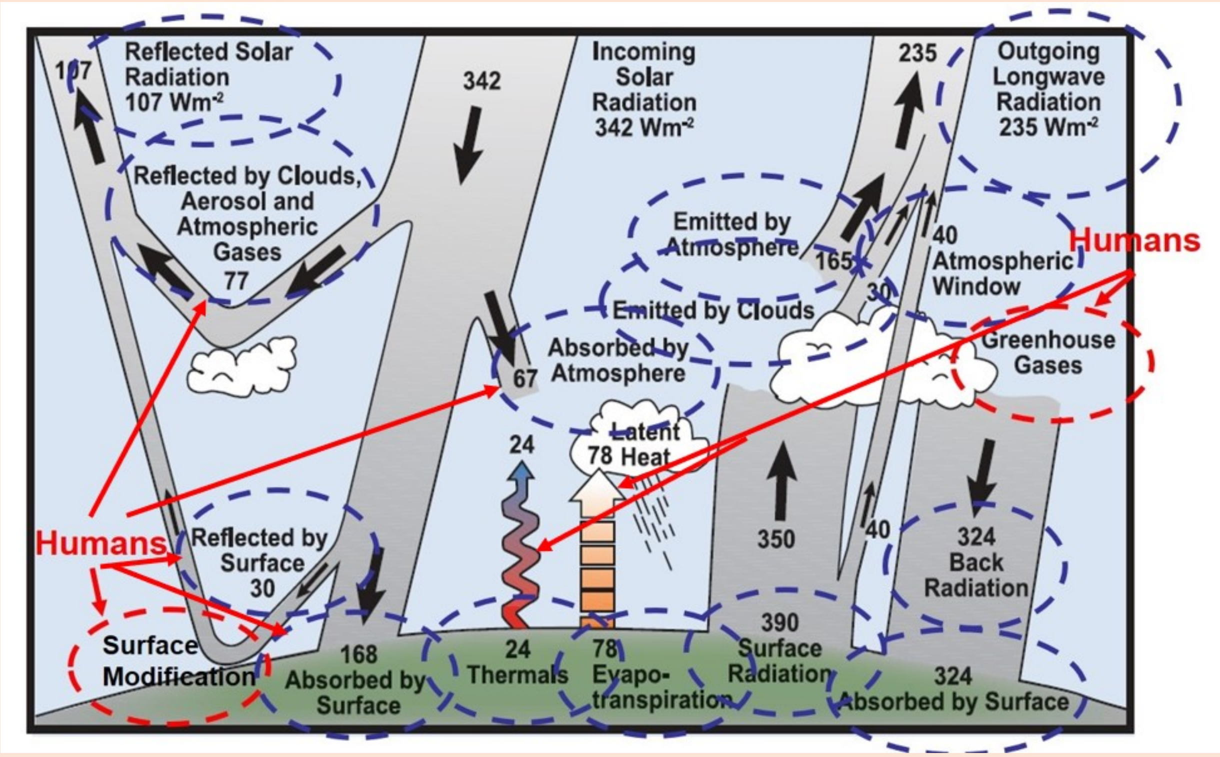

Figure 20.1 Energy budget as affected by humans.

6. The concentration of greenhouse gases and the amount of long-wave radiation that is radiated from the Earth's surface and is absorbed, warms the atmosphere and radiated back to Earth and space.
7. Aerosols such as oxides of sulfur and nitrogen that will absorb both short-wave and long-wave radiation and warm the atmosphere.
8. Atmospheric particulate matter such as carbon black and dust that will absorb both short-wave and long-wave radiation and warm the atmosphere and land.
9. Land surface modification which then affects the amount of short-wave radiation reflected by surface, amount of short-wave radiation absorbed by surface and long-wave surface radiation emitted. Warmer land surface will affect cryosphere resulting in increased glacier melt, melt of Greenland and Antarctic ice sheets (increased sea level) and disappearance of sea ice (profound ecological effects).
10. Warmer land surface (including ocean surface) will impact the hydrological cycle which is discussed in Chapter 6. The hydrological cycle is shown in Figure 6.1 reproduced here as Figure 20.2. The result of a warmer land (and ocean) surface is greater evapotranspiration (evaporation and transpiration from plants), increased concentration of water vapour in atmosphere (water vapour is a greenhouse gas) and cloud formation (reflects short-wave radiation). Warmer land surface will also result in increased air circulation from lower troposphere to near the stratosphere where water vapour will be condensed to form precipitation events (some of which might be cyclonic in nature). Less precipitation in the form snow. Smaller accumulations of snow. Earlier snow melt.

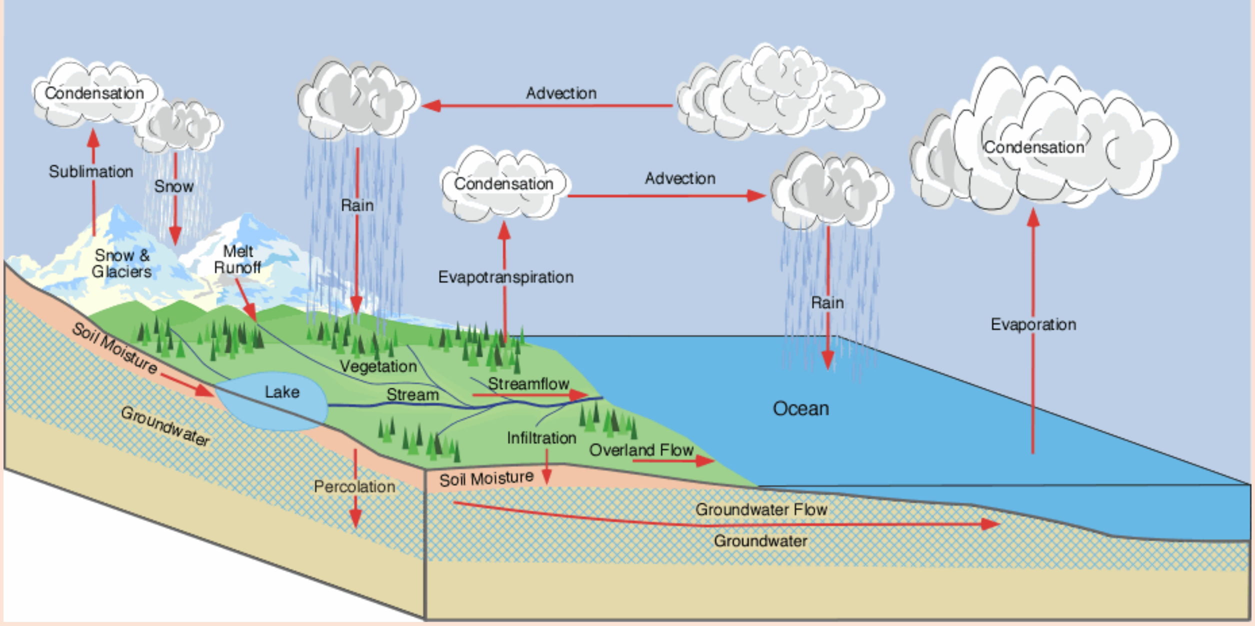

Figure 20.2 Hydrological cycle. http://www.physicalgeography.net/fundamentals/5c_1.html

The carbon cycle is also affected by human activities which in turn impact the energy cycle. The carbon cycle is discussed Chapter 5. The carbon cycle shown in Figure 5.1 is reproduced here as Figure 20.3.

Humans affect:

1. Production of greenhouse gases through mining and burning of fossil fuels.
2. Release of greenhouse gases through land use change, particularly the release of stored carbon from the soil and from the biomass destroyed as a result of deforestation.
3. Decrease in carbon storage as a result of deforestation (removal of carbon by photosynthesis and storage in plant biomass and soil).
4. Decrease in carbon sequestration by ocean uptake by reactive sediments (consequence of ocean acidification). Reactive sediments would ultimately settle to ocean floor.

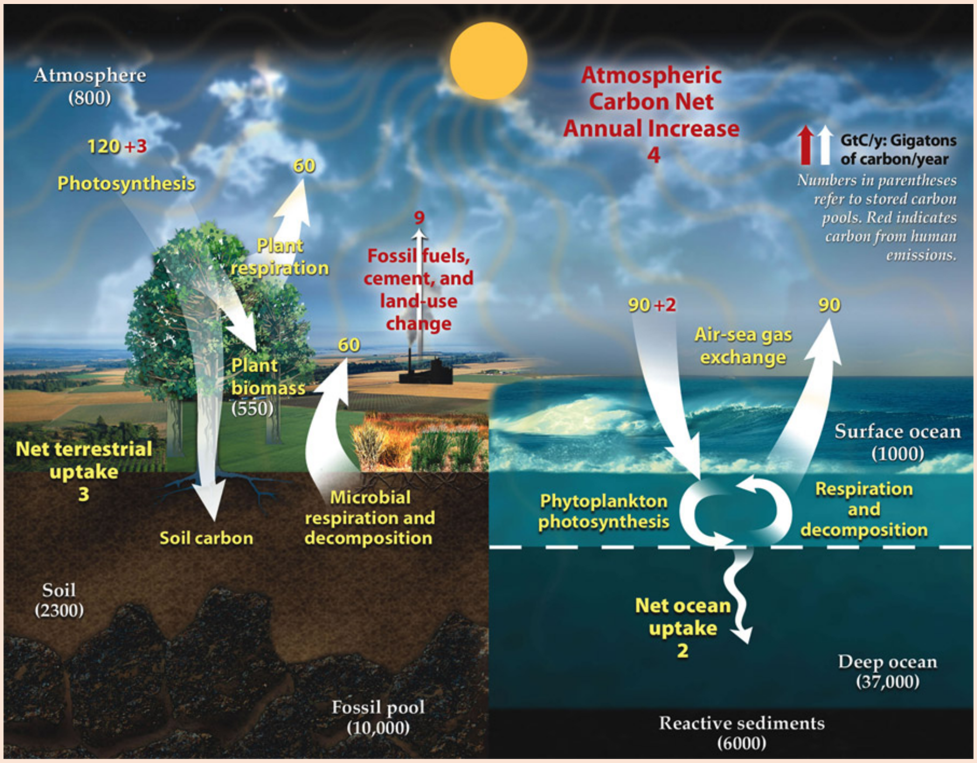

Figure 20.3 Carbon Cycle. (Office of Biological and Environmental Research of the U.S. Department of Energy Office of Science)

20.3 Consequences of unconstrained continued emission of greenhouse gases

The IPCC (https://ar5-syr.ipcc.ch/ipcc/ipcc/resources/pdf/IPCC_SynthesisReport.pdf page 72) identify five reasons for concern which are:

1. Unique and threatened systems: Some unique and threatened systems, including ecosystems and cultures, are already at risk from climate change (high confidence). The number of such systems at risk of severe consequences is higher with additional warming of around 1°C. Many species and systems with limited adaptive capacity are subject to very high risks with additional warming of 2°C, particularly Arctic-sea-ice and coral-reef systems.
2. Extreme weather events: Climate change related risks from extreme events, such as heat waves, extreme precipitation, and coastal flooding, are already moderate (high confidence) and high with 1°C additional warming (medium confidence). Risks associated with some types of extreme events (e.g., extreme heat) increase further at higher temperatures (high confidence).
3. Distribution of impacts: Risks are unevenly distributed and are generally greater for disadvantaged people and communities in countries at all levels of development. Risks are already moderate because of regionally differentiated climate change impacts on crop production in particular (medium to high confidence). Based on projected decreases in regional crop yields and water availability, risks of unevenly distributed impacts are high for additional warming above 2°C (medium confidence).
4. Global aggregate impacts: Risks of global aggregate impacts are moderate for additional warming between 1–2°C, reflecting impacts to both Earth's biodiversity and the overall global economy (medium confidence). Extensive biodiversity loss with associated loss of ecosystem goods and services results in high risks around 3°C additional warming (high confidence). Aggregate economic damages accelerate with increasing temperature (limited evidence, high agreement), but few quantitative estimates have been completed for additional warming around 3°C or above.
5. Large-scale singular events: With increasing warming, some physical systems or ecosystems may be at risk of abrupt and irreversible changes. Risks associated with such tipping points become moderate between 0–1°C additional warming, due to early warning signs that both warm-water coral reef and Arctic ecosystems are already experiencing irreversible regime shifts (medium confidence). Risks increase disproportionately as temperature increases between 1–2°C additional warming and become high above 3°C, due to the potential for a large and irreversible sea level rise from ice sheet loss. For sustained warming greater than some threshold, greater than ~0.5°C additional warming (low confidence) but less than ~3.5°C (medium confidence), near-complete loss of the Greenland ice sheet would occur over a millennium or more, eventually contributing up to 7 m to global mean sea level rise.

Limiting temperature increases between 1-2°C above pre-industrial by 2100 are the objective.

20.4 Strategies for limiting temperature increases to between 1-2°C

The IPCC has identified four scenarios called representative concentration pathways, RCPs, that include time series of emissions and concentrations of greenhouse gases, aerosols, chemically active gases and changes in land cover to 2100. They are not the only options but they are representative of the sort of emission patterns that will lead to a specific outcome. These are shown in Figure 20.4 below taken directly from the IPCC report (also identified as Figure 18.3 in Chapter 18).

It is clear that only RCP2.6 leads to the temperature objective.

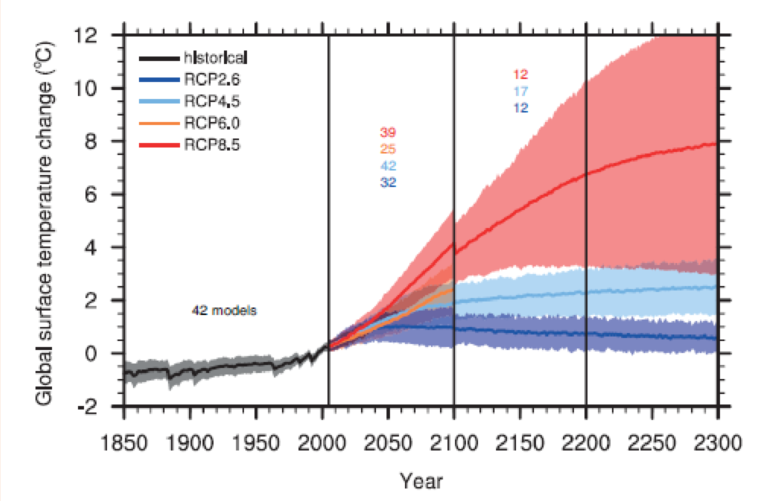

Figure 12.5 | Time series of global annual mean surface air temperature anomalies (relative to 1986–2005) from CMIP5 concentration-driven experiments. Projections are shown for each RCP for the multi-model mean (solid lines) and the 5 to 95% range (±1.64 standard deviation) across the distribution of individual models (shading). Discontinuities at 2100 are due to different numbers of models performing the extension runs beyond the 21st century and have no physical meaning. Only one ensemble member is used from each model and numbers in the figure indicate the number of different models contributing to the different time periods. No ranges are given for the RCP6.0 projections beyond 2100 as only two models are available.

Figure 20.4 Observed and projected global surface temperature change 1850 – 2300.
https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter12_FINAL.pdf

20.5 Mitigation strategies

The different representative concentration pathways are shown in Figure 20.5 (also identified as Figure 18.1 in Chapter 18). The names of the different pathways are derived from the resulting radiative forcing in the year 2100. For example, RCP6 will result in a radiative forcing of 6 Wm^{-2}, RCP2.6 will result in a radiative forcing of 2.6 Wm^{-2} and so on.

The pathway of interest is RCP2.6 since it is the only one of the four that will meet the temperature increase objective. It may be possible to follow one of the other pathways for a period of time and then abruptly adjust the emissions very low and realize the same objective but this is not considered likely.

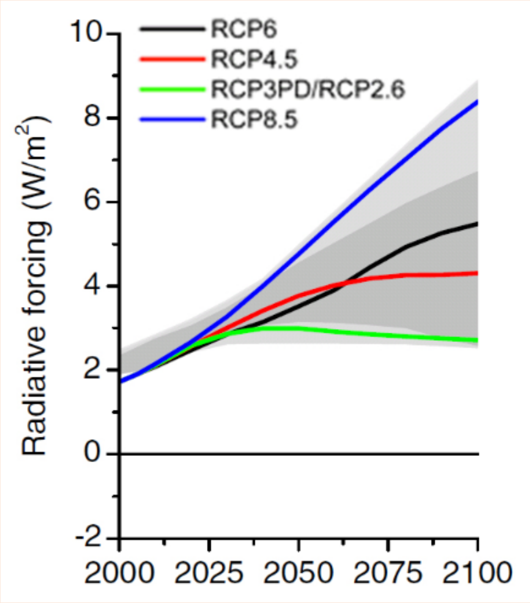

Figure 20.5 Representative concentration pathways or RPC's. Note that the name of the RPC; for example, RPC 8.5 refers to the radiative forcing in the year 2100. (See Strategies for mitigation of climate change: a review
https://link.springer.com/article/10.1007/s10584-011-0148-z)

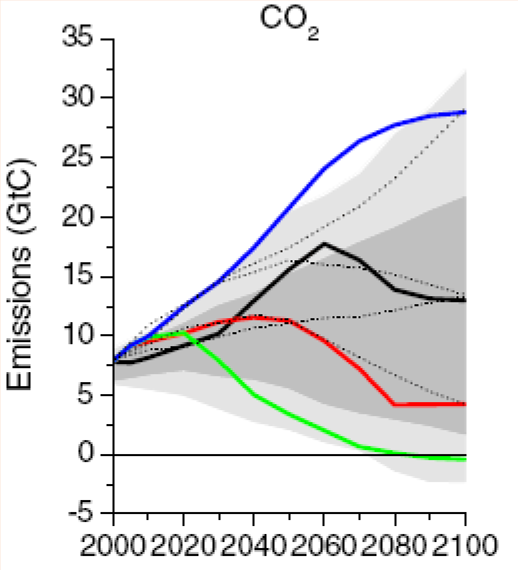

Figure 20.6 Greenhouse gas emissions to achieve the RCP outcomes.
https://www.climatechangeinaustralia.gov.au/en/climate-campus/modelling-and-projections/projecting-future-climate/greenhouse-gas-scenarios/

Consideration of the energy budget, carbon cycle and hydrological cycle suggest several mitigation strategies. These include:

1. Limiting the GHG emission from use of fossil fuels by
   a. Restricting use of fossil fuels.
   b. Capturing GHGs, particularly carbon dioxide, resulting from use of fossil fuels before it can enter the atmosphere and permanently store it.
   c. Decreasing demand for fossil fuels.
   d. More efficient use of fossil fuels.
   e. Use of alternative sources of energy.
2. Reducing energy demand.
3. Producing energy from renewable sources.
4. Stopping deforestation.
5. Starting reforestation.
6. Starting agricultural practices that preserve the soil as a place to store carbon and limit need for synthetic fertilizers and crop management chemicals.
7. Limiting the use of land for urban communities.
8. Removing carbon from the atmosphere and permanently store it.
9. Reducing consumption of food and other products whose production results in significant greenhouse gas production.
10. Modification of life-style to a 'low carbon footprint'.

Some of these will be positive (for example, burning less fossil fuels but not as much) and others will be negative (for example, reforestation). The radiative forcing associated with each act of mitigation needs to be quantified and all of the contributions summed.

IPCC identifies strategies called 'mitigation pathways' which would limit the temperature increase in 2100 to 2°C above pre-industrial levels or an atmospheric concentration of in the range 430 to 530 ppm CO_2 equivalent (See Chapter 15). The IPCC AR5 WG3 report provides a discussion on this concept. Quantification of the various mitigation activities is necessary and performed using accepted methods.

A review of mitigation strategies is reported by Fawzy, Osman, Doran and Rooney (https://link.springer.com/article/10.1007/s10311-020-01059-w). This paper was published in July, 2020. It provides an update of what the IPCC AR5 considers.

Information on annual greenhouse gas inventories on a country-by-country basis is available. All countries prepare reports on their greenhouse gas inventories according to guidelines prepared by the IPCC Task Force on National Greenhouse Gas Inventories, https://www.ipcc-nggip.iges.or.jp/index.html.

The IPCC bases their mitigation strategy on the major economic sectors contributing to greenhouse gas emissions as recently updated as shown in Figure 15.10. The report considers each of the sectors and how emissions might be reduced.

It is intuitively clear that those countries that produce the most emissions have the greatest opportunity and responsibility to reduce global emissions. However, each country develops and manages their own policies for emission reduction and choose strategies to meet their unique challenges and take advantage of their unique opportunities.

Operational mitigation plans require detailed knowledge of GHG emissions originating from individuals, events, organizations, services and product expressed in carbon dioxide equivalent as discussed in Chapter 15.

20.6 Paris Agreement

At COP 21 in Paris on 12 December 2015, Parties to the UNFCCC reached a landmark agreement to combat climate change and to accelerate and intensify the actions and investments needed for a low carbon future. The Paris agreement builds upon the Convention (https://unfccc.int/process-and-meetings/the-convention/what-is-the-united-nations-framework-convention-on-climate-change) and – for the first time – brings all nations into a common cause to undertake ambitious efforts to combat climate change and adapt to its effects, with enhanced support to assist developing countries to do so. As such, it charts a new course in the global climate effort.

The Paris Agreement, https://www.unep.org/resources/adaptation-gap-report-2020 , is a legally binding international treaty on climate change adopted at COP 21 in Paris on 12 December 2015 and entered into force on 4 November 2016. Its goal is to limit global warming to well below 2 and preferably 1.5 degrees Celsius compared to pre-industrial levels. Countries submit their plans for climate action known as nationally determined contributions (NDCs) which includes long-term low greenhouse gas emission development strategies. Additionally, the agreement aims to increase the ability of countries to deal with the impacts of climate change, and at making finance flows consistent with a low GHG emissions and climate-resilient pathway https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement/key-aspects-of-the-paris-agreement.

Countries make their own commitments and clearly state how these will be fulfilled. Starting with 2023 and every five years thereafter the collective progress is evaluated. This is called the Global Stocktake. The process is repeated.

20.7 Information support

Key web sites:

1. IPCC AR5 Working Group Three: Mitigation of Climate Change. https://www.ipcc.ch/report/ar5/wg3/

2. Representative concentration pathways: an overview, van Vuuren, et al. https://link.springer.com/article/10.1007/s10584-011-0148-z

3. IPCC Task Force on National Greenhouse Gas Inventories, https://www.ipcc-nggip.iges.or.jp/index.html.

4. Global emissions by sector. https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_chapter1.pdf

5. Strategies for mitigation of climate change: a review by Fawzy, S., Osman, A. I., Doran, J., and Rooney, D. W. https://link.springer.com/article/10.1007/s10311-020-01059-w

6. Greenhouse gas emission to meet RCP outcomes. https://www.climatechangeinaustralia.gov.au/en/climate-campus/modelling-and-projections/projecting-future-climate/greenhouse-gas-scenarios/

7. Paris Agreement. https://www.unep.org/resources/adaptation-gap-report-2020 and https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement/key-aspects-of-the-paris-agreement

8. United Nations Framework Convention on Climate Change. https://unfccc.int/process-and-meetings/the-convention/what-is-the-united-nations-framework-convention-on-climate-change