

Climate change and climate science

A basic reader

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This book is based on material published by the Baltic University Programme and the project UZWATER, a TEMPUS-financed project conducted in a team of 5 BUP universities and 8 Uzbek universities. The text has been edited, updated and expanded in 2019 by Lars Rydén, former Director of the Baltic University Programme, in particular using the reports of the Intergovernmental Panel of Climate Change, IPCC, and national reports from the Baltic Sea region countries and European Union data. New data and updated statistics is, however, constantly provided by various authorities, research institutions etc and searching this information is needed for keeping the text up-to-date. The links provided here can often be used for this purpose. Updating is often a relevant task for students studying climate issues.

The book is meant to be basic reader and freely available resource for all universities in the region, which want to use it for teaching and learning. All illustrations and material shown can be downloaded from the internet using the links provided.

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Chapter 1 The Climate system

1.1 Factors of Earth's climate

The climate system is a complex, interactive system consisting of the atmosphere, land surface, snow and ice, oceans and other bodies of water, and living things. The atmospheric component of the climate system most obviously characterises climate; climate is often defined as 'average weather'. Climate is usually described in terms of the mean and variability of temperature, precipitation and wind over a period of time, ranging from months to millions of years (the classical period is 30 years). The climate system evolves in time under the influence of its own internal dynamics and due to changes in external factors that affect climate, called *forcings*. External forcings include natural phenomena such as volcanic eruptions and solar variations, as well as human-induced changes in atmospheric composition.

Solar radiation powers the climate system. There are three fundamental ways to change the radiation balance of the Earth:

- 1) by changing the incoming solar radiation (e.g., by changes in Earth's orbit or in the Sun itself);
- 2) by changing the fraction of solar radiation that is reflected (called 'albedo'; e.g., by changes in cloud cover, atmospheric particles or vegetation); and
- 3) by altering the long wave radiation from Earth back towards space (e.g., by changing greenhouse gas concentrations).

Climate, in turn, responds directly to such changes, as well as indirectly, through a variety of feedback mechanisms. The amount of energy reaching the top of Earth's atmosphere each second on a surface area of one square meter ($\text{W}/\text{m}^2\text{s}$) facing the Sun during daytime is about 1,370 Watts, and the amount of energy per square meter per second ($\text{W}/\text{m}^2\text{s}$) averaged over the entire planet is one-quarter of this (Fig. 1.1). About 30% of the sunlight that reaches the top of the atmosphere is reflected back to space. Roughly two-thirds of this reflectivity is due to clouds and small particles in the atmosphere known as 'aerosols'. Light-coloured areas of Earth's surface – mainly snow, ice and deserts – reflect the remaining one-third of the sunlight.

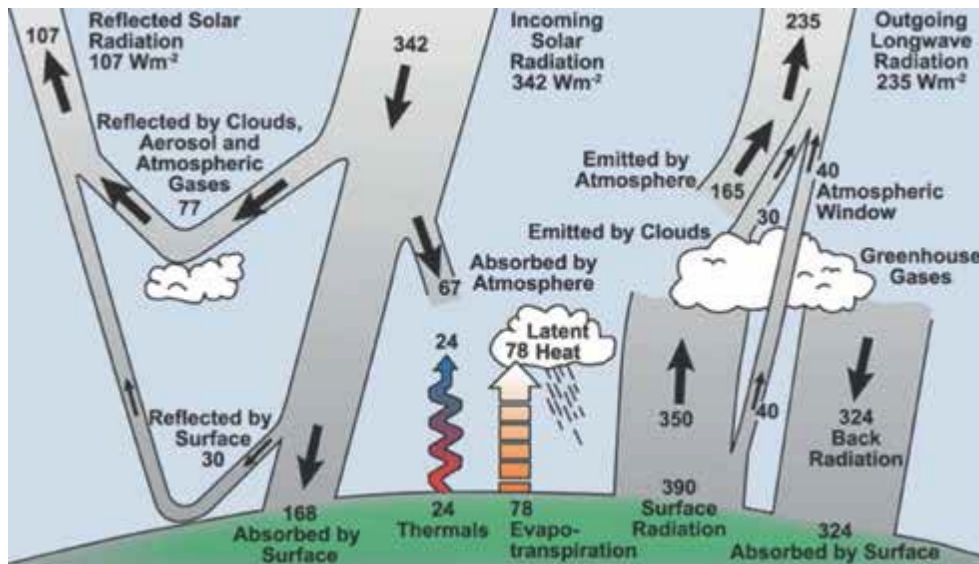


Figure 1.1. Estimate of the Earth's annual and global mean energy balance. Over the long term, the amount of incoming solar radiation absorbed by the Earth and atmosphere is balanced by the Earth and atmosphere releasing the same amount of outgoing long wave radiation. About half of the incoming solar radiation is absorbed by the Earth's surface. This energy is transferred to the atmosphere by warming the air in contact with the surface (thermals), by evapotranspiration and by long wave radiation that is absorbed by clouds and greenhouse gases. The atmosphere in turn radiates long wave energy back to Earth as well as out to space. Source: Kiehl and Trenberth (1997).

The most dramatic change in aerosol-produced reflectivity comes when major volcanic eruptions eject material very high into the atmosphere. Rain typically clears aerosols out of the atmosphere in a week or two, but when material from a violent volcanic eruption is projected far above the highest clouds, these aerosols typically influence the climate for about a year or two before falling into the troposphere and being carried to the surface by precipitation. Major volcanic eruptions can thus cause a drop in mean global surface temperature of about half a degree Celsius that can last for months or even years. Some manmade aerosols also significantly reflect sunlight. The energy that is not reflected back to space is absorbed by the Earth's surface and atmosphere. This amount is approximately 240 Watts per square metre (W/m²). To balance the incoming energy, the Earth itself must radiate, on average, the same amount of energy back to space. The Earth does this by emitting outgoing long wave radiation.

Everything on Earth emits long wave radiation continuously. That is the heat energy one feels radiating out from a fire; the warmer an object, the more heat energy it radiates.

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important greenhouse gases are water vapour and carbon dioxide. The two most abundant constituents of the atmosphere – nitrogen and oxygen – have no such effect. Clouds, on the other hand, do exert a blanketing effect similar to that of the greenhouse gases; however, this effect is offset by their reflectivity, such that on average, clouds tend to have a cooling effect on climate (although locally one can feel the warming effect: cloudy nights tend to remain warmer than clear nights because the clouds radiate long wave energy back down to the surface).

Human activities intensify the blanketing effect through the release of greenhouse gases. For instance, the amount of carbon dioxide in the atmosphere has increased by about 45% in the industrial era, and this increase is known to be due to human activities, primarily the combustion of fossil fuels and removal of forests. Thus, humankind has dramatically altered the chemical composition of the global atmosphere with substantial implications for climate.

Because the Earth is a sphere, more solar energy arrives for a given surface area in the tropics than at higher latitudes, where sunlight strikes the atmosphere at a lower angle. Energy is transported from the equatorial areas to higher latitudes via atmospheric and oceanic circulations, including storm systems. Energy is also required to evaporate water from the sea or land surface, and this energy, called latent heat, is released when water vapour condenses in clouds (Fig. 1.1). Atmospheric circulation is primarily driven by the release of this latent heat. Atmospheric circulation in turn drives much of the ocean circulation through the action of winds on the surface waters of the ocean, and through changes in the ocean's surface temperature and salinity through precipitation and evaporation.

Due to the rotation of the Earth, the atmospheric circulation patterns tend to be more east-west than north-south. Embedded in the mid-latitude westerly winds are large-scale weather systems that act to transport heat toward the poles. These weather systems are the familiar migrating low- and high-pressure systems and their associated cold and warm fronts. Because of land-ocean temperature contrasts and obstacles such as mountain ranges and ice sheets, the circulation system's planetary-scale atmospheric waves tend to be geographically anchored by continents and mountains although their amplitude can change with time. Because of the wave patterns, a particularly cold winter over North America may be associated with a particularly warm winter elsewhere in the hemisphere.

1.2 Changes in the climate system

Changes in various aspects of the climate system, such as the size of ice sheets, the type and distribution of vegetation or the temperature of the atmosphere or ocean will influence the large-scale circulation features of the atmosphere and oceans. There are many feedback mechanisms in the climate system that can either amplify ('positive feedback') or diminish ('negative feedback') the effects of a change in climate forcing. For example, as rising concentrations of greenhouse gases warm Earth's climate, snow and ice begin to melt. This melting reveals darker land and water surfaces that were beneath the snow and ice, and these darker surfaces absorb more of the Sun's heat, causing more warming, which causes more melting, and so on, in a self-reinforcing cycle. This feedback loop, known as the 'ice-albedo feedback', amplifies the initial warming caused by rising levels of greenhouse gases. Detecting, understanding and accurately quantifying climate feedbacks have been the focus of a great deal of research by scientists unravelling the complexities of Earth's climate.

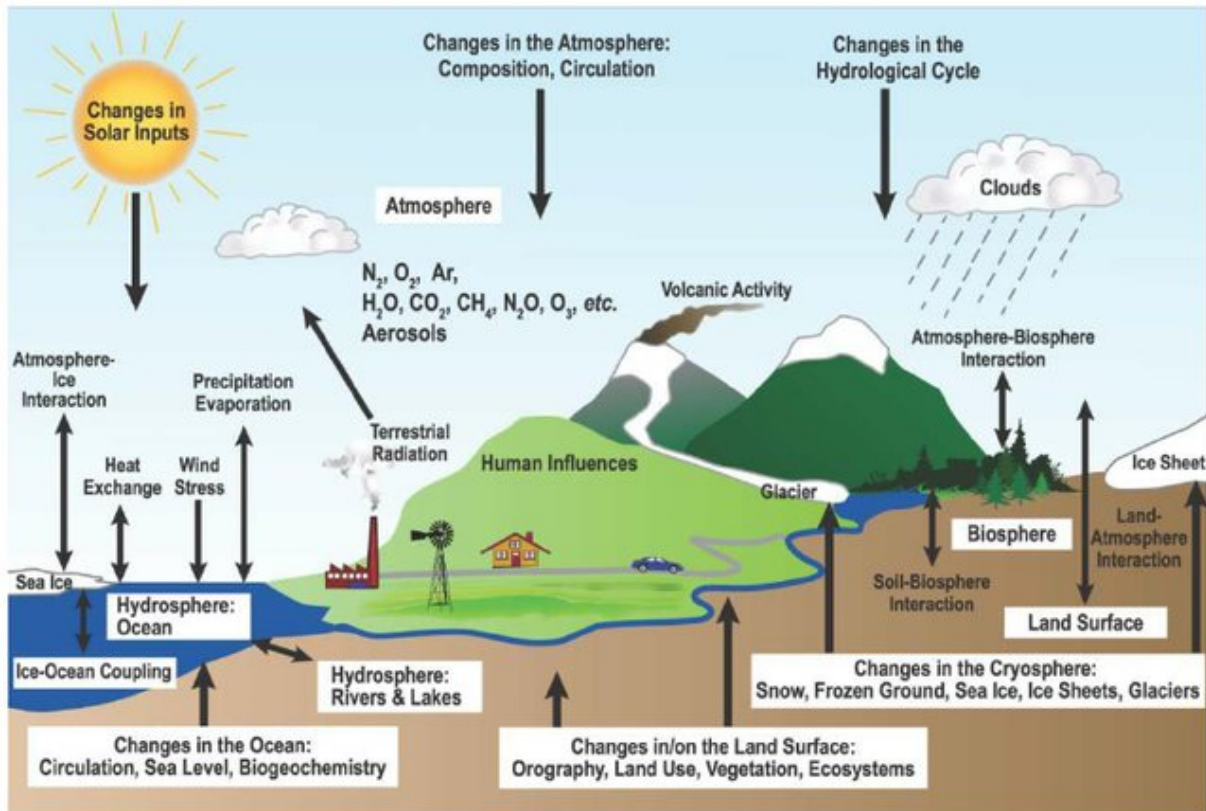


Figure 1.2. Schematic view of the components of the climate system, their processes and interactions (source: Treut et al., 2007; https://www.researchgate.net/publication/267784058_Coupled_Terrestrial_Carbon_and_Water_Dynamics_in_Terrestrial_Ecosystems_Contributions_of_Remote_Sensing/figures?lo=1)

Climate can be viewed as concerning the status of the entire Earth system, including the atmosphere, land, oceans, snow, ice and living things (Fig. 1.2) that serve as the global background conditions that determine weather patterns. An example of this would be an El Niño affecting the weather in coastal Peru (See Section 1.6 below on the large ocean currents). The El Niño sets limits on the probable evolution of weather patterns that random effects can produce. A La Niña would set different limits.

Another example is found in the familiar contrast between summer and winter. The march of the seasons is due to changes in the geographical patterns of energy absorbed and radiated away by the Earth system.

Likewise, projections of future climate are shaped by fundamental changes in heat energy in the Earth system, in particular the increasing intensity of the greenhouse effect that traps heat near Earth's surface, determined by the amount of carbon dioxide and other greenhouse gases in the atmosphere. Projecting changes in climate due to changes in greenhouse gases 50 years from now is a very different and much more easily solved problem than forecasting weather patterns just weeks from now. To put it another way, long-term variations brought about by changes in the composition of the atmosphere are much more predictable than individual weather events. As an example, while we cannot predict the outcome of a single coin toss or roll of the dice, we can predict the statistical behaviour of a large number of such trials.

While many factors continue to influence climate, scientists have determined that human activities have become a dominant force, and are responsible for most of the warming observed over the past 50 years. Human-caused climate change has resulted primarily from changes in the amounts of greenhouse gases in the atmosphere, but also from changes in small particles (aerosols), as well as from changes in land use, for example. As climate changes, the probabilities of certain types of weather events are affected. For example, as Earth's average temperature has increased, some weather phenomena have become more frequent and intense (e.g., heat waves and heavy downpours), while others have become less frequent and intense (e.g., extreme cold events).

1.3 Solar radiation and the global heat balance

The sun shines on the planet with an intensity of about 1,330 Watts per square metre at the outer reaches of the atmosphere, and varies according to location and time of year. How much of this reaches the surface of the planet? Reflectivity, or the so called *albedo*, is an important phenomenon. About 25% of incoming solar radiation is reflected by the clouds and the atmosphere and does not contribute to the heat balance of the planet. The atmosphere and clouds absorb another 25%.

Only half of the solar radiation thus reaches the surface of the Earth, some being again reflected, or backscattered. If the surface is covered by clean snow the albedo is very high, about 90%, while black soil, which hardly reflects light at all, has an albedo close to 0%. The Earth on average has a 5% albedo – mostly since the oceans, which cover large areas, absorb much of the sunlight. The 25% reflected by clouds in the atmosphere should be added, to make up a total albedo of 30% for Earth as a whole. About 45% of incoming radiation is finally absorbed by the surface of the planet. This energy is used for e.g. evaporation of water. All of it is, however, in the end radiated back to maintain heat balance. However, since the outgoing radiation comes from the colder Earth it is very different from the incoming radiation. It is mostly low energy, longer infrared wavelength radiation (heat radiation).

The atmosphere is much less transparent to outgoing heat radiation than it is to the incoming solar light. Thus, much of the energy is used to heat up the lower atmosphere and indirectly the surface of the Earth. This effect contributes to the heat balance of the planet with about 35 °C. Without this effect, the Earth would not harbour life as we know it. The heating through absorption of infrared back radiation is called the “greenhouse effect,” comparing the atmosphere to the glass in a greenhouse that makes the inside warmer by absorbing outgoing radiation.

Table 1.1 Solar radiation

Incoming solar radiation	%
Reflected by clouds and the atmosphere	25
Absorbed by the atmosphere and clouds	25
Reflected by the surface	5
Absorbed by the surface	45
Use of solar input	%
Heating the surface	50
Evaporation of water from the surface running the hydrological cycle	23
Convection in the oceans, currents	20
Winds	7
Photosynthesis	0.1
Human energy turnover	0.01

The most important component in the Earth's atmosphere that absorbs the infrared light from the Earth is water vapour. However, any gas that absorbs infrared light contributes. Most important are carbon dioxide and methane. The concentrations of each of these gases are decisive for the heat balance of the planet.

The present dramatic increase of carbon dioxide and other greenhouse gases is obviously influencing this balance and causes a shift towards a warmer climate. The energy available for processes on the surface of the Earth, such as the hydrologic cycle, photosynthesis and heating of soil layers and vegetation, is called the net radiation. This is the net income of energy to the Earth's systems. Net radiation consists of the nets of long-wave and short-wave radiation. In the energy balance of the Earth's surface the net radiation is distributed between sensible heat flux (heating air and vegetation), latent heat (evapotranspiration) and ground heat flux (heating the ground).

1.4 The water cycle

The third crucial component, after the soil and the atmosphere, of the planet is water, or the *hydrosphere*. Water is a very special substance. Water constitutes a liquid in a temperature range that is perfect for life, and in fact is the only substance with such properties. When it solidifies to ice it becomes slightly lighter and thus floats on liquid water, a behaviour which is also quite unique. It takes a considerable amount of energy to vaporise water, and thus it stays liquid over an unusually wide temperature range.

There is about 1,403 million km³ of water on the Earth. If this was evenly spread out over the planet, and if the surface was smooth, it would cover the whole Earth in a layer about 3 km deep. The surface is of course not smooth and about 70% of the surface of the planet is covered by water. Most water on Earth is not immediately useful to us. Ocean and saline water accounts for about 97.6% of all water on Earth. The rest, 33,400 km³, is fresh water. Most of this is bound in ice and glaciers. Liquid fresh water makes up 4,400 km³. It is distributed between about 4,000 km³ of ground water and smaller amounts of surface water. Lakes, rivers and brooks, wetlands, etc., contain about 130 km³ on the Earth as a whole, and the atmosphere holds about 13 km³. Considerable amounts are contained in biota (65 km³) and soil moisture (65 km³). Surface water is constantly re-circulated in what is called a natural *hydrological cycle*. Water evaporates from land, surface water and organisms. It enters the atmosphere and forms clouds as it condenses. It is transported by the winds and as it cools, especially at higher altitudes over mountains, it precipitates as rain and snow. Back on the ground it flows by gravity, coming back to the sea.

The water flow described involves a considerable amount of energy. Mass (here water) present at higher altitudes contains potential energy, i.e., the flow down to lower levels represents an enormous amount of energy, which is used in e.g. hydropower plants.

Evaporation of water from land surfaces and transpiration from plants, called evapotranspiration, constitutes a considerable flow of water. Sublimation should also be included here. Sublimation is evaporation directly from the solid form of the substance without becoming a liquid first, e.g. snow, can sublimate on sunny winter days. Water as vapour, in a gaseous form in air, constitutes the humidity of the air. In the reverse process, condensation, water vapour forms droplets of liquid water. Most often, condensation leads to cloud formation. When it occurs on ground or plant surfaces the water that appears is called dew. Some plants get all their water from dew.

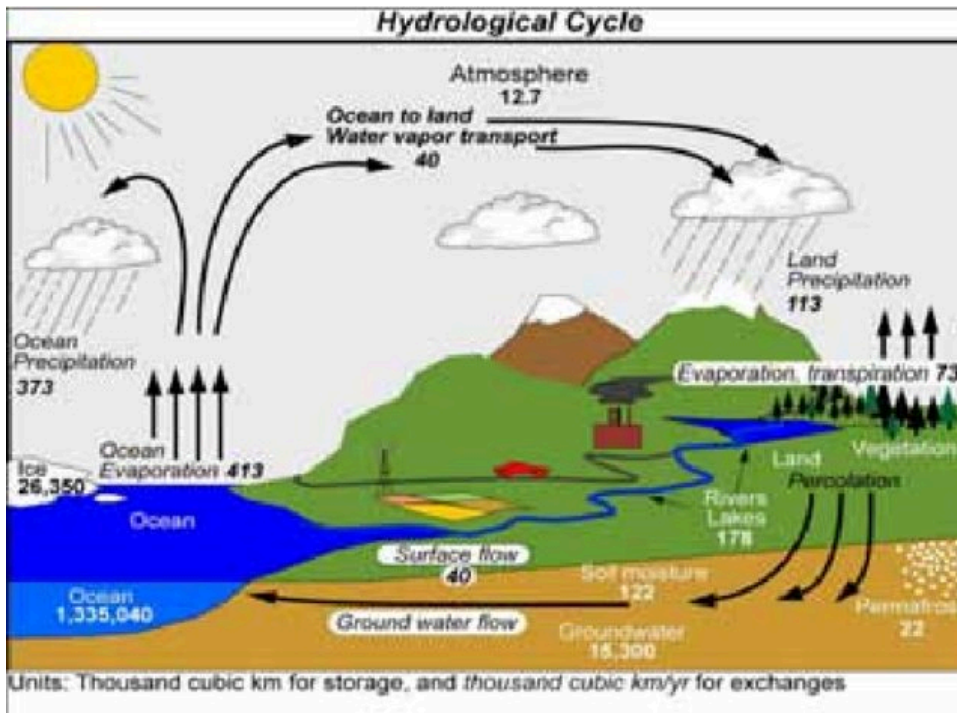


Figure 1.3. The hydrological cycle. Water evaporates from the oceans and land, is transported in the atmosphere, condenses as clouds and finally precipitates and runs through rivers, back to the oceans. The numbers in the Figure are millions of Mtonnes of water per year globally. (Source: Yves Birot, Carlos Gracia, Marc Palahí, 2011; https://www.researchgate.net/publication/304998682_Towards_Integrated_Ecological_Socio-Economic_and_Hydrological_Management)

Precipitation is the general term for rainfall, snowfall and other forms of frozen or liquid water falling from clouds. Precipitation is intermittent, and the character of the precipitation when it occurs depends greatly on temperature and the weather situation. The latter determines the supply of moisture through winds and surface evaporation, and how it is gathered together in storms as clouds. Precipitation forms as water vapour condenses, usually in rising air that expands and hence cools. The upward motion comes from air rising over mountains, warm air riding over cooler air (warm front), colder air pushing under warmer air (cold front), convection from local heating of the surface, and other weather and cloud systems. Hence, changes in any of these aspects alter precipitation.

As precipitation maps tend to be spotty, overall trends in precipitation are indicated by the Palmer Drought Severity Index (Fig. 1.4), which is a measure of soil moisture using precipitation and crude estimates of changes in evaporation. Observations show that *changes are occurring in the amount, intensity, frequency and type of precipitation*. These aspects of precipitation generally exhibit large natural variability, and El Niño and changes in atmospheric circulation patterns such as the North Atlantic Oscillation have a substantial influence. Pronounced long-term trends from 1900 to 2005 have been observed in precipitation amount in some places: significantly wetter in eastern North and South America, northern Europe and northern and central Asia, but drier in the Sahel, southern Africa, the Mediterranean and southern Asia. More precipitation now falls as rain rather than snow in northern regions. Widespread increases in heavy precipitation events have been observed, even in places where total amounts have decreased. These changes are associated with

increased water vapour in the atmosphere arising from the warming of the world's oceans, especially at lower latitudes. There are also increases in some regions in the occurrences of both droughts and floods.

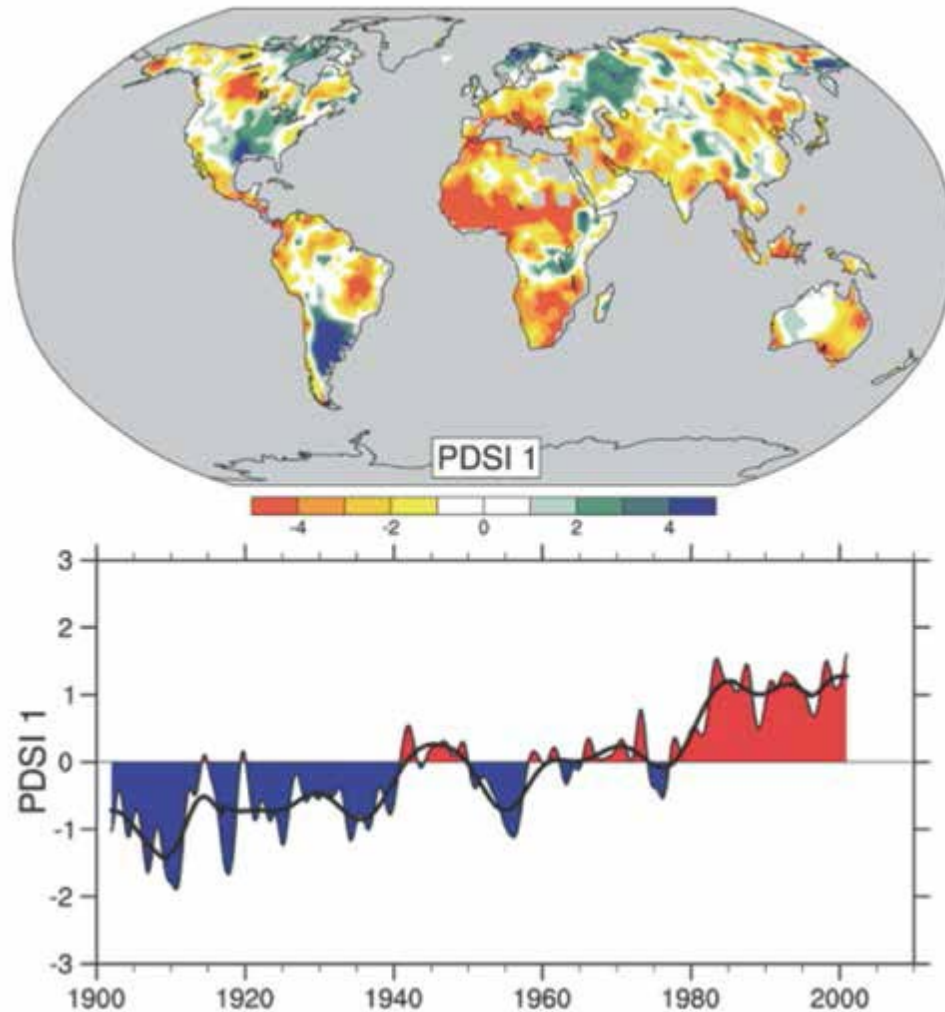


Figure 1.4. Palmer Drought Severity Index (PDSI) The most important spatial pattern (top) of the monthly index (PDSI) for 1900 to 2002. The PDSI is a prominent index of drought and measures the cumulative deficit (relative to local mean conditions) in surface land moisture by incorporating previous precipitation and estimates of moisture drawn into the atmosphere (based on atmospheric temperatures) into a hydrological accounting system. The lower panel shows how the sign and strength of this pattern has changed since 1900. Red and orange areas are drier (wetter) than average and blue and green areas are wetter (drier) than average when the values shown in the lower plot are positive (negative). The smooth black curve shows decadal variations. The time series approximately corresponds to a trend, and this pattern and its variations account for 67% of the linear trend of PDSI from 1900 to 2002 over the global land area. It therefore features widespread increasing African drought, especially in the Sahel, for instance. Note also the wetter areas, especially in eastern North and South America and northern Eurasia. Adapted from Dai et al. (2004b).

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Precipitation occurs when water condensed in clouds forms large enough water droplets. Precipitation varies over the globe from several thousand millimetres per year down to almost zero. The main Uzbek River Armu Darya, which flows into the Aral Sea, receives most of its water, about 78 km^3 , from the glacier and snow melt in the Pamir Mountains. The steppes in the drainage basin have an annual precipitation of about 300 mm per year. Much of this evaporates. The runoff equals precipitation minus evapotranspiration.

The hydrologic cycle includes the slow movement of ground and soil water. Here, movement is typically in the order of metres per year, as compared to metres per second for streams and metres per days for lakes. The storage of water in the ground and soil functions to even out water supply in nature. Even after prolonged draughts, some water is left in the soil and as ground water. There are two implications of these aspects of water storage. First, seasonal water balances must include changes in the amount of water stored in the ground and soil. Second, polluted ground water moves slowly and may remain a problem even for future generations.

The water balance is connected to the heat balance by evapotranspiration. Net radiation is the driving force and sets the limit for evapotranspiration. In this way, the hydrological cycle is powered by precipitation which is the mass income, and net radiation is the power source. The hydrological cycle thus constitutes a large solar powered pump that moves water and substances carried by water. Water evaporates in warmer areas, is transported by weather systems and precipitates in other colder areas.

1.5 The global carbon cycle

The carbon of the planet is found in the atmosphere as carbon dioxide, dissolved in ocean water, bound in biomass, and stored in the lithosphere as carbonate minerals. Although the atmosphere holds only 0.036% of CO_2 this substance is a key component in the physics of the planet since it interacts, as explained above, with the heat balance. It is also essential to all living cells as it is used when new biomass is built up in carbon dioxide fixation.

The carbon cycle starts when carbon dioxide in the atmosphere is formed from carbonates in the lithosphere. Carbon has been added to the atmosphere, through volcanic activities, throughout the history of the planet. An important part of the carbon flow is the formation of calcium carbonate in the seas especially as shells in marine organisms. As these die and their shells sink to the bottom, carbonate is transferred from the atmosphere to the sediments which finally become limestone rock, and thus return to the lithosphere. This slow, but in the history of the planet, major part of the carbon cycle, is estimated to have taken care of some 60 entire atmospheres of carbon dioxide, and that each carbon atom has made about 30 such round trips.

The absorption of carbon dioxide in ocean water is slow however, and in addition, limited by the slow mixing of the upper layer with the rest of the water in the oceans. An immediate component is the fixation of carbon dioxide to organic substances by living organisms during photosynthesis. As the biosphere builds up to considerable amounts of biomass, this constitutes a major carbon sink, not the least in the forests of the planet, but also organic material in soil.

Carbon dioxide fixation removes carbon from the atmosphere and respiration returns it back. In respiration organic molecules are oxidised with oxygen to provide energy to living cells. The by-products are water and carbon dioxide. All kinds of combustion and decay processes add to this flow. Today, the comparatively immense utilisation of fossil fuels

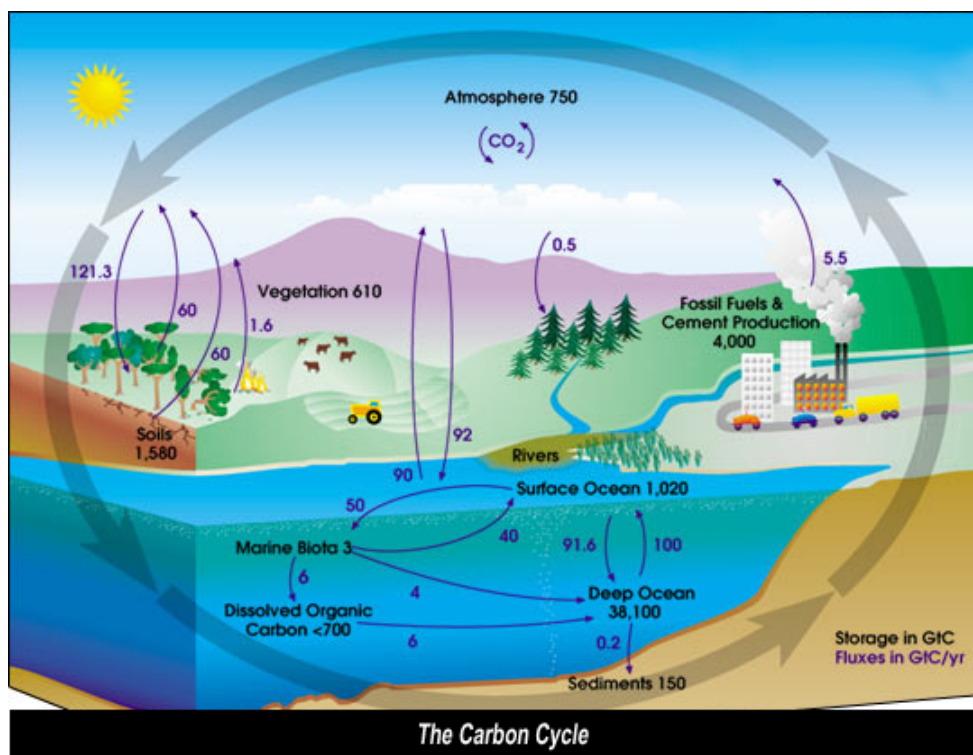


Figure 1.5. The natural carbon cycle. Carbon is available in the ecosphere as carbon dioxide in the atmosphere or dissolved in sea water as carbonates. A large amount is also present in organic form in living organisms or in dead organic matter in the soil and the sea. A rapid turnover between these two pools occurs through photosynthesis and respiration. The inorganic and organic pools correspond to around 400 and 20 years of photosynthesis, respectively. The carbon in fossil fuels, if used, is enough to significantly change the carbon concentrations in the atmosphere. The numbers denote for flows gigatonnes per year globally and for storages gigatonnes. (Source: Global Greenhouse Warming. <http://www.global-greenhouse-warming.com/global-carbon-cycle.html>)

seriously disturbs the balance between natural processes. Modern combustion practices cause the concentration of carbon dioxide to increase. This increase is the key factor behind the enhanced greenhouse effect. The people of the Earth now consume 6 gigatonnes carbon/year, a mass that exceeds the mass of all the metals used by mankind during the period of time by a factor of ten! In addition, the handling of many fossil fuels involves flows of other matter than pure carbon, particularly sulphur (see below), which adds to the turnover of matter and many profound environmental stresses.

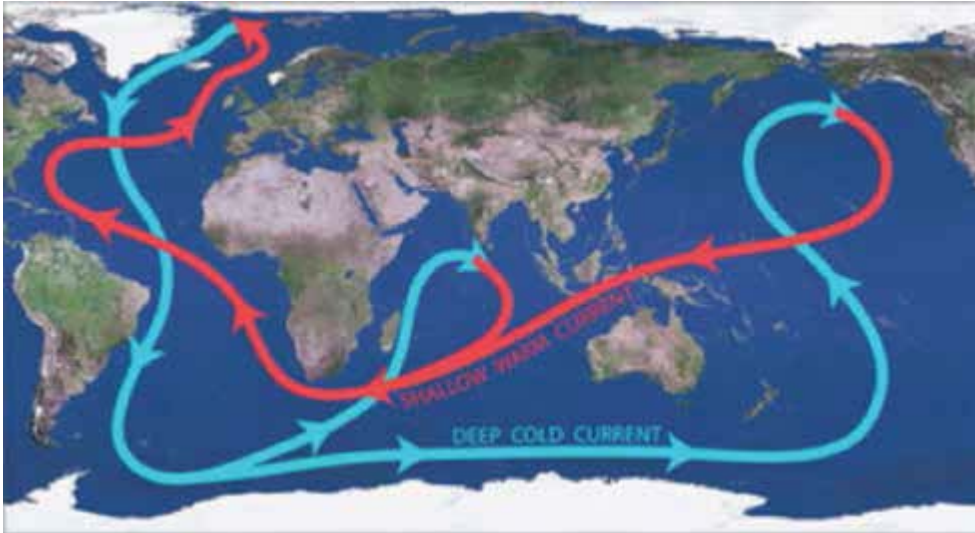


Figure 1.6 Ocean Conveyor Belt. Source:

http://cmore.soest.hawaii.edu/education/teachers/science_kits/ocean_conveyor_kit.htm

1.6 The large global ocean and atmospheric currents

In many parts of Earth the climate is strongly dependent on the large ocean or atmospheric currents. An ocean current is a continuous, directed movement of seawater. It is influenced by forces such as waves, wind, the Coriolis effect, temperature and salinity differences. Ocean currents flow for great distances, and together, create *the global conveyor belt*. As ocean currents influence travel through a region warm currents increase the temperature of the coasts along which they move. The most striking example is the *Gulf Stream*, which makes northwest Europe much more temperate than any other region at the same latitude. A second important ocean current is the Humboldt Current which cools the western coast of South America along Peru.

The predominant driving force of the ocean currents is differences in density, caused by salinity and temperature variations. The density of ocean water is not globally homogeneous, but varies significantly and discretely. Sharply defined boundaries exist between water masses which form at the surface, and subsequently maintain their own identity within the ocean. Warm seawater expands and is thus less dense than cooler seawater. Lighter water masses float over denser ones, a phenomenon known as “stable stratification”. This thermohaline circulation is mainly triggered by the formation of deep water masses in the North Atlantic and the Southern Ocean caused by differences in temperature and salinity of the water. The great quantities of dense water sinking at polar ocean basin edges must be offset by equal quantities of water rising elsewhere. The cold water in polar zones sink relatively rapidly over a small area, while warm water in temperate and tropical zones rise more gradually across a much larger area. It then slowly returns pole-ward near the surface to repeat the cycle. In this way the ocean currents contribute to the distributions of heat over the planet. A threat against the Gulf Stream would be large scale melting of the Greenland ice cap which would reduce the salinity of sea water and thus inhibit the sinking of the water and thus arrest the stream.

El Niño is the warm phase of an ocean current called *El Niño Southern Oscillation* (commonly called ENSO) and is associated with a band of warm ocean water that develops in the central and east-central equatorial Pacific, including off the Pacific coast of South

America. El Niño Southern Oscillation refers to the cycle of warm and cold temperatures of the tropical central and eastern Pacific Ocean. El Niño is accompanied by high air pressure in the western Pacific and low air pressure in the eastern Pacific.

The cool phase of ENSO is called “La Niña” with surface temperatures in the eastern Pacific below average and air pressures high in the eastern and low in western Pacific. The ENSO cycle, both El Niño and La Niña, causes global changes of both temperatures and rainfall.

Developing countries dependent upon agriculture and fishing, particularly those bordering the Pacific Ocean, are the most affected. The name La Niña originates from Spanish, meaning “the girl”, analogous to El Niño meaning “the boy” (referring to the newborn Jesus, Christ Child, as it often begins in December). During a period of La Niña, the sea surface temperature across the equatorial Eastern Central Pacific Ocean will be lower than normal by 3-5 °C. It has extensive effects on the weather in North America, even affecting the Atlantic Hurricane Season. La Niña often, though not always, follows an El Niño.

An important atmospheric air current is originating over the Amazonas. This very unique part of our planet holds nearly 25% of all fresh water in the world. Part of this is transported to other regions of the world and thus contribute to their possibility for agriculture. A large scale deforestation of the Amazonas may have global consequences for the climate.

1.7 Regional climate

Climate varies from region to region. This variation is driven by the uneven distribution of solar heating, the individual responses of the atmosphere, oceans and land surface, the interactions between these, and the physical characteristics of the regions. The perturbations of the atmospheric constituents that lead to global changes affect certain aspects of these complex interactions.

Some human-induced factors that affect climate (‘forcings’) are global in nature, while others differ from one region to another. For example, carbon dioxide, which causes warming, is distributed evenly around the globe, regardless of where the emissions originate, whereas sulphate aerosols (small particles) that offset some of the warming tend to be regional in their distribution. Furthermore, the response to forcings is partly governed by feedback processes that may operate in different regions from those in which the forcing is greatest. Thus, the projected changes in climate will also vary from region to region.

1.8 Climate science

Research to understand climate in all its variability has a very long history. In recent years this research has increased dramatically as a consequence of the climate change and a wish to understand and predict future climate changes. The development of computer tools and modeling have been important in this development. The Intergovernmental Panel on Climate Change (IPCC), initiated by the World Meteorological Association in 1988, is a global cooperation between climate scientist with the intention to define, for political purposes, the best understanding of present changes in climate. It recruits several thousand researchers all over the world.

Climate science is an atmospheric science and belongs to physical geography and thus the Earth sciences. It most often also cooperate with oceanography and the study of the large biogeochemical flows, that is, biogeochemistry. The study of contemporary climates

Box 1.1 The Intergovernmental Panel on Climate Change (IPCC)

The Intergovernmental Panel on Climate Change (IPCC) is the leading international body for the assessment of climate change. It was established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) in 1988 to provide the world with a clear scientific view on the current state of knowledge in climate change and its potential environmental and socio-economic impacts. In the same year, the UN General Assembly endorsed the action by WMO and UNEP in jointly establishing the IPCC.

The IPCC is a scientific body under the auspices of the United Nations (UN). It reviews and assesses the most recent scientific, technical and socio-economic information produced worldwide relevant to the understanding of climate change. It does not conduct any research nor does it monitor climate related data or parameters.

Thousands of scientists from all over the world contribute to the work of the IPCC on a voluntary basis. Review is an essential part of the IPCC process, to ensure an objective and complete assessment of current information. IPCC aims to reflect a range of views and expertise. The Secretariat coordinates all the IPCC work and liaises with Governments. It is supported by WMO and UNEP and hosted at WMO headquarters in Geneva. *Source:*

<http://www.ipcc.ch/organization/organization.shtml>

incorporates meteorological data accumulated over many years: this includes records of precipitation, temperature and atmospheric pressure and composition. Basic knowledge of climate can be used for weather forecasting, which covers days or weeks.

A region's climate is generated by the *climate system*. The basic components of the climate system are the atmosphere, the hydrosphere, the cryosphere (snow and ice), the lithosphere, and the biosphere. Climatologists thus study the atmospheric and ocean circulation patterns and boundary layers, heat transfer (radiative, convective and latent), the interactions between the atmosphere and the oceans and land surface (particularly vegetation, land use and topography). The chemical and physical composition of the atmosphere are important parts of climate science. It is a difficult and complex because of the large scale, the long time periods, and the complex processes which govern climate.

Climate is governed by physical laws which can be expressed as differential equations in mathematical climate models. The equations are coupled and nonlinear, so that approximate solutions are obtained by using numerical methods to create global climate models. Statistical climate models integrate different observations and test how they fit together. Modeling is used for understanding past, present and potential future climates. In the models the atmosphere and the earth are divided into small interacting elements (pixels), and the development of a number of parameters (such as temperature) in these are studied over a time period which in turn is divided into parts.

Running climate models require supercomputers. A more detailed study requires smaller elements and then becomes more complex and requires longer computational time. In this way regional and global climate change have been studied.

All climate models balance, or very nearly balance, incoming energy as short wave (including visible) electromagnetic radiation to the earth with outgoing energy as long wave (infrared) electromagnetic radiation from the earth. Any unbalance results in a change in the average temperature of the earth. The most talked- about models of recent years have been

those relating temperature to emissions of carbon dioxide and other greenhouse gases. These models predict an upward trend in the surface temperature record, as well as a more rapid increase in temperature at higher latitudes.

Chapter 1 sources:

Sections 1.1 Factors of Earth's climate and 1.2 Changes in the climate system:

IPCC Fourth Assessment Report: Climate Change 2007 (AR4) <http://ipcc.ch/report/ar4/>

IPCC Fifth Assessment Report: Climate Change 2013 (AR5) <http://ipcc.ch/report/ar5/>

Contribution of Working Groups I, II and III to AR4 of the IPCC

http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_synthesis_report.htm. Contribution of Working Group I to the AR4 of IPCC. Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.) Cambridge University Press. 996 pp. http://ipcc.ch/publications_and_data/ar4/wg1/en/contents.html

Sections 1.3 Solar radiation and the global heat balance, 1.4 The water cycle and 1.5 The global carbon cycle:

BUP Environmental Science, Lars-Christer Lundin and Lars Rydén Chapter 2 How the Environment Works - Turnover of Matter and Energy. <http://www.balticuniv.uu.se/index.php/boll-online-library/834-es-environmental-science>

Section 1.6 The large global ocean and atmospheric currents and Section 5.7 Climate science

Basic information from Wikipedia and other Internet resources.

Chapter 2

Climate Change – causes and consequences

2.1 Observed Changes in the Climate System – Global warming

Observations of the climate system are based on direct measurements and remote sensing from satellites and other platforms. Global-scale observations from the instrumental era began in the mid-19th century for temperature and other variables, with more comprehensive and diverse sets of observations available for the period 1950 onwards. Paleoclimate reconstructions extend some records back hundreds to millions of years. Together, they provide a comprehensive view of the variability and long-term changes in the atmosphere, the ocean, the cryosphere, and the land surface.

The data in this chapter is mainly based on the 5th assessment report (AR5) from the Intergovernmental Panel on Climate Change, IPCC (See Box 2.1) and updates.

Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia and even millions of years. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased. Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850. In the Northern Hemisphere, 1983-2012 was likely the warmest 30-year period of the last 1400 years. The globally averaged combined land and ocean surface temperature data as calculated by a linear trend, show a warming of 1.1 °C, over the period 1880 to 2017, when multiple independently produced datasets exist. The total increase between the average of the 1850-1900 period and the 2003-2012 period is 0.78 °C, based on the single longest dataset available.

The degree of certainty in key findings in this assessment is based on the author teams' evaluations of underlying scientific understanding and is expressed as a qualitative level of confidence (from very low to very high) and, when possible, probabilistically with a quantified likelihood (from exceptionally unlikely to virtually certain). Confidence in the validity of a finding is based on the type, amount, quality, and consistency of evidence (e.g., data, mechanistic understanding, theory, models, and expert judgment) and the degree of agreement. Probabilistic estimates of quantified measures of uncertainty in a finding are based on statistical analysis of observations or model results, or both, and expert judgment. Where appropriate, findings are also formulated as statements of fact without using uncertainty qualifiers. The data on uncertainty and variation have not been included in these chapters but can be found in the original reports, here as summaries for policy makers.

A long term temperature curve is shown in Fig. 2.1. The data are from NASA Goddard Institute. In a recent report Goddard Institute says that the year 2016 ranks as Earth's warmest since 1880, according to two separate analyses by NASA and National Oceanic and Atmospheric Administration (NOAA) scientists. The 10 warmest years in the instrumental record, with the exception of 1998, have now occurred since 2000. This trend continues as a long-term warming of the planet, according to an analysis of surface temperature measurements by scientists at NASA's Goddard Institute of Space Studies (GISS). Since 1880, Earth's average surface temperature has warmed by about 1.1 degrees Celsius, a trend that is largely driven by the increase in carbon dioxide and other human emissions into the planet's atmosphere. The majority of that warming has occurred in the past three decades. A short film showing the temperature increase as distributed of the planet is available as seen in Fig. 2.2.

Box 1.1 Intergovernmental Panel on Climate Change, IPCC, 5th report, AR5

The Intergovernmental Panel on Climate Change, IPCC releases its assessment reports (AR) each 5 years. The reports are consensus documents meaning that everyone in the network have accepted the statements. Thus the reported conclusions tend to be conservative. They are also several years old since research results take much time to be reviewed by the panel and incorporated in the common conclusions. The most recent reports, No 5, was released in 2013 and 2014 by the three working groups of IPCC. More recent data have been taken from several of the large institutions working with climate science in the world. Important institutions include the NASA Goddard Institution (USA) the Potsdam Institute for Climate Impact Research (Germany) and the The Grantham Research Institute on Climate Change (UK).

The IPCC Working Group I contribution to the IPCC's Fifth Assessment Report (AR5) considers new evidence of climate change based on many independent scientific analyses from observations of the climate system, paleo-climate archives, theoretical studies of climate processes and simulations using climate models. It builds upon the Working Group I contribution to the IPCC's Fourth Assessment Report (AR4), and incorporates subsequent new findings of research. As a component of the fifth assessment cycle, the IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) is an important basis for information on changing weather and climate extremes.

The degree of certainty in key findings in this assessment is based on the author teams' evaluations of underlying scientific understanding and is expressed as a qualitative level of confidence (from very low to very high) and, when possible, probabilistically with a quantified likelihood (from exceptionally unlikely to virtually certain). Confidence in the validity of a finding is based on the type, amount, quality, and consistency of evidence (e.g., data, mechanistic understanding, theory, models, and expert judgment) and the degree of agreement. Probabilistic estimates of quantified measures of uncertainty in a finding are based on statistical analysis of observations or model results, or both, and expert judgment. Where appropriate, findings are also formulated as statements of fact without using uncertainty qualifiers. The data on uncertainty and variation have not been included in these chapters but can be found in the original reports, here as summaries for policy makers.

In Summary the climate change looks like this: 2016 was the warmest year since measurements began; 2017 the second warmest and 2017-2018 the warmest for a La Nina year. 2018 was particularly dramatic with record warm in the arctic area with some 6 °C warmer spring in Svalbard, and record heat in the summer in Northern Europe, North America and Australia. Climate variability is increasing, e.g. 2010 was warm in Russia, 2012 in North America, while winter was strong in Europe. Present warming is very fast: 0.16 °C per decade; this is about 16 times faster than the warming after the last ice age, which was 0.1 °C per century. Climate sensitivity according to IPCC is around 3.7 watts per m² (W/m²). This means that there is a 3 °C increase for a doubling of CO₂ levels. Studying the long term changes in atmospheric carbon dioxide concentrations we notice that during previous warming events CO₂ levels started to increase after an increase in temperature. Now it is the opposite. We do not know what it will lead to.

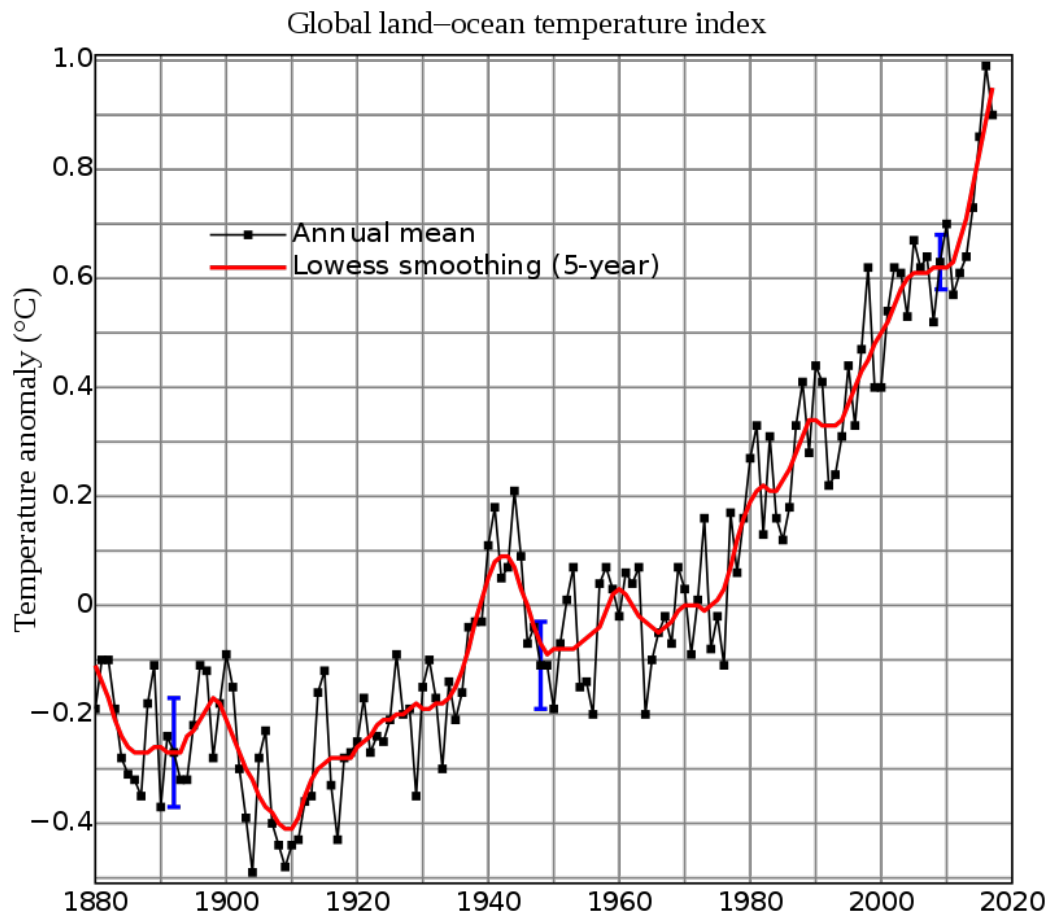


Figure 2.1 Global Land Ocean Temperature index. Data source: NASA Goddard Institute for Space Studies NASA [Goddard Institute for Space Studies - http://data.giss.nasa.gov/gistemp/graphs/](http://data.giss.nasa.gov/gistemp/graphs/)

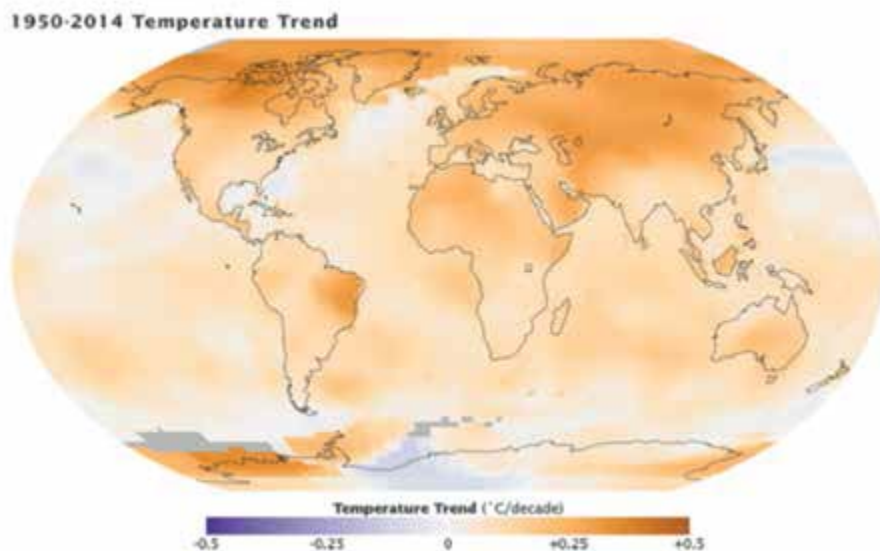


Figure 2.2 Regional temperature trends. This color-coded map in Robinson projection displays a progression of changing global surface temperature anomalies from 1880 through 2014. Higher than normal temperatures are shown in red and lower than normal temperatures are shown in blue. The final frame represents the global temperatures 5-year averaged from 2010 through 2014. Source: NASA Goddard Institute <http://svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=4252&button=recent>.

2.2 Declining ice and glaciers – the Arctic

The most rapid warming has occurred in the Arctic. The most visible change in the Arctic region in recent years has been the rapid decline of the perennial ice cover, the arctic summer ice. The perennial ice is the portion of the sea ice floating on the surface of the ocean that survives the summer. This ice which spans multiple years represents the thickest component of the sea ice cover. It is illustrated in Fig. 2.3 showing the 2012 minimum. It was 760,000 square kilometres below the previous record minimum extent in the satellite record, which occurred on September, 2007. This is an area about the size of Germany and Poland together. The September 2012 minimum was in turn 3.29 million square kilometres below the 1979 to 2000 average minimum, representing an area nearly twice the size of the state of Alaska. A short film showing the declining ice is available (Fig. 2.3).

The Arctic summer ice may be gone by 2035, and the Canadian Arctic Ocean coast, the Northwest Passage, start to be used for ship transport. This is in fact already the case. The rapid melting of the Arctic ice has so far not been predicted by global climate models. There may be at least two factors which have been difficult to include in the models, both contributing to making the temperature increase rapid. One is that the exposure of sea surface as the ice melts changes the *albedo* (reflectivity) drastically. Thus the black water surface absorbs sunlight much more efficient than the white ice. Secondly the *permafrost* in the Arctic area is melting and thereby releasing enormous amounts of methane which so far has remained frozen in the tundra. Methane is a very strong greenhouse gas. As it tends to remain in the atmosphere above the Arctic the concentration of methane is large and it contributes to a strong greenhouse effect. This is thus a strong self-reinforcing mechanism.

Another effect of global warming is the melting of glaciers (ice on a land surface) all over the world. An illustration is provided by the Upsala glacier in South America shown in 1928 and 2004 illustrating how the glacier has turned into a lake (Fig. 2.5).

Most far reaching has the consequences been for the Greenland ice sheet. Over the last two decades, the Greenland and Antarctic ice sheets have been losing mass, glaciers have continued to shrink almost worldwide, and Arctic sea ice and Northern Hemisphere spring snow cover have continued to decrease in extent. Greenland's 2012 melt season started early, surpassing the 30-year average for melt-covered area in mid-May, and remaining far in excess of typical conditions for June, July, and through mid-August (Fig. 2.6). On 6 August, 2012 updated compilation of NASA MODIS observations of Greenland ice sheet reflectivity (albedo) indicate that through the 2012 melt season, beginning ~28 May, the ice sheet has remained in a darkened state as in 2011 and 2010. Remaining in this condition, the ice sheet has absorbed ~200 Exajoules more solar energy for June-July, more than twice the US annual energy consumption, in a self-reinforcing feedback loop. For July, the 100 Exajoules more energy absorption is sufficient, for example to melt 136 Gt of ice at a temperature of 0 °C. (http://bprc.osu.edu/wiki/Greenland_Ice_Albedo_Monitoring).



Figure 2.4 The Arctic sea ice cover at its minimum measured on September 6, 2013. A film showing the perennial Arctic sea ice from 1979 to 2014 is available at <http://svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=4251&button=recent>. It has a graph overlay which shows the area's size measured in million square kilometres for each year. Credit: National Snow and Ice Data Center.



Figure 2.5 The Upsala Glacier, Patagonia, Argentina. Original photograph taken in 1928, ©Archivo Museo Salesiano / De Agostini. Comparison image taken in 2004, © Greenpeace/Daniel Beltrá 02/06/2004. Courtesy Greenpeace Argentina.

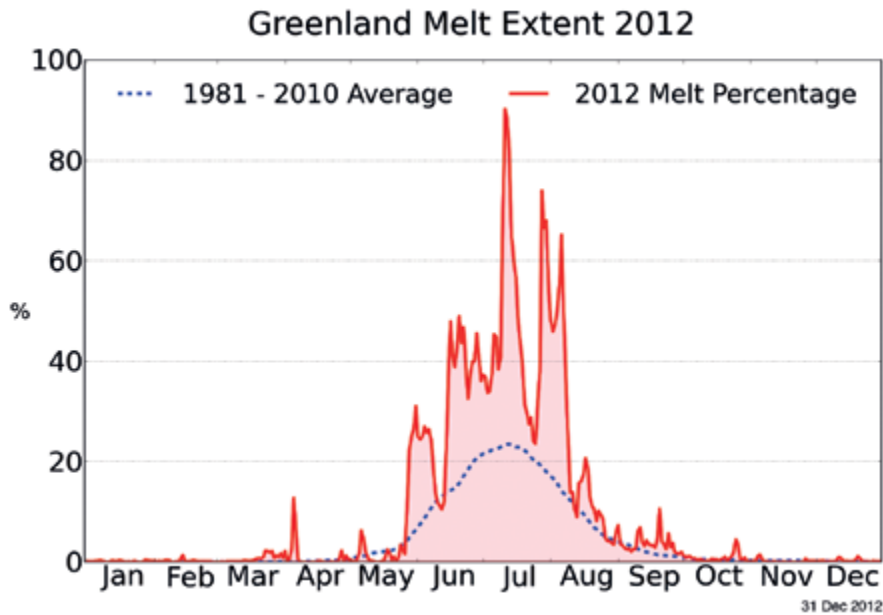


Figure 2.6 Melting of Greenland ice. For the peak melt days in early July and again in early August, more than 70% of the surface of the ice sheet experienced some melt, and the peak melt event on July 10 to 11 occurred over 97% of the ice sheet. Source: National Snow and Ice Data Center (<http://nsidc.org/>).

2.3 Rising sea levels

Another effect of global warming is the increased level of the surface of the oceans, *sea level rise*. It should be noted that the melting of the Arctic Sea ice does not contribute to sea level rise since it is a sea ice, while the melting of the Greenland and Antarctic ice does contribute since they are on land. Another factor is the increased temperature of the ocean water, since it leads to volume increase of the water. Ocean warming dominates the increase in energy stored in the climate system, accounting for more than 90% of the energy accumulated between 1971 and 2010. The upper ocean (0-700 m) warmed from 1971 to 2010 and it likely warmed between the 1870s and 1971. On a global scale, ocean warming is largest near the surface, and the upper 75 m warmed by 0.11 °C per decade over the period 1971 to 2010.

Global sea level gradually rose in the 20th century and is currently rising at an increased rate, after a period of little change between the years AD 0 and AD 1900. Sea level is projected to rise at an even greater rate in this century (see Figure 2.7). The two major causes of global sea level rise are thermal expansion of the oceans (water expands as it warms) and the loss of land-based ice due to increased melting. Global sea level rose by about 120 m during the several millennia that followed the end of the last ice age (approximately 21,000 years ago), and stabilised between 3,000 and 2,000 years ago. Sea level indicators suggest that global sea level did not change significantly from then until the late 19th century. The instrumental record of modern sea level change shows evidence for onset of sea level rise during the 19th century. Estimates for the 20th century show that global average sea level rose at a rate of about 1.7 mm/year.

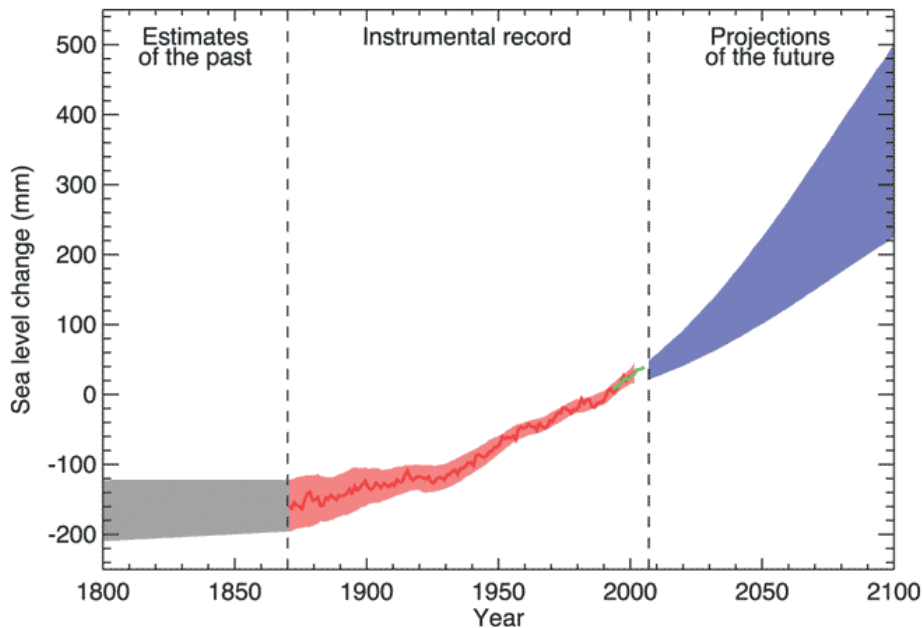


Figure 2.7 Time series of global mean sea level (deviation from the 1980-1999 mean) in the past and as projected for the future. For the period before 1870, global measurements of sea level are not available. The grey shading shows the uncertainty in the estimated long-term rate of sea level change. The red line is a reconstruction of global mean sea level from tide gauges, and the red shading denotes the range of variations from a smooth curve. The green line shows global mean sea level observed from satellite altimetry. The blue shading represents the range of model projections for the SRES A1B scenario for the 21st century, relative to the 1980 to 1999 mean, and has been calculated independently from the observations. Beyond 2100, the projections are increasingly dependent on the emissions scenario. Over many centuries or millennia, sea level could rise by several metres.

The global sea level is projected to rise during the 21st century at a greater rate than during 1961 to 2003. Under the IPCC Special Report on Emission Scenarios (SRES) A1B scenario by the mid-2090s, for instance, global sea level reaches 0.22 to 0.44 m above 1990 levels, and is rising at about 4 mm/year. As in the past, sea level change in the future will not be geographically uniform, with regional sea level change varying within about ± 0.15 m of the mean in a typical model projection. Thermal expansion is projected to contribute more than half of the average rise, but land ice will lose mass increasingly rapidly as the century progresses. An important uncertainty relates to whether discharge of ice from the ice sheets will continue to increase as a consequence of accelerated ice flow, as has been observed in recent years. This would add to the amount of sea level rise, but quantitative projections of how much it would add cannot be made with confidence, owing to limited understanding of the relevant processes.

2.4 Extreme weather events

A most serious effect of global warming are the extreme weather events. These are predicted to be stronger and come more often. This includes heat waves, tornados, hurricanes, storm, floods and draughts. A study of extreme temperatures show that these occur more often (Fig. 2.8).

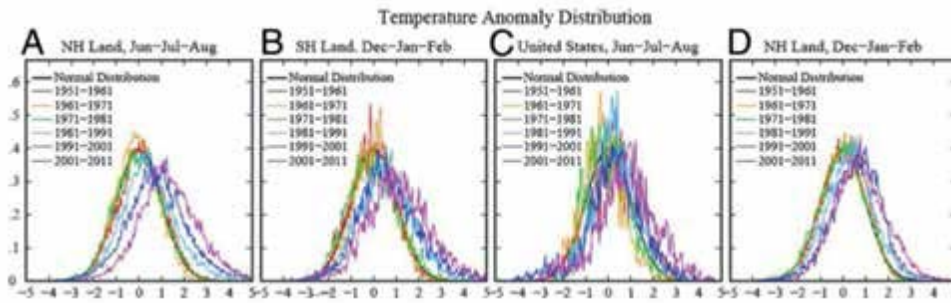


Figure 2.8 Frequency of occurrence of local temperature anomalies (relative to 1951–1980 mean) divided by local standard deviation obtained by counting gridboxes with anomalies in each 0.05 interval of the standard deviation (x axis). (Source: Hansen J et al. PNAS 2012;109:14726-14727).

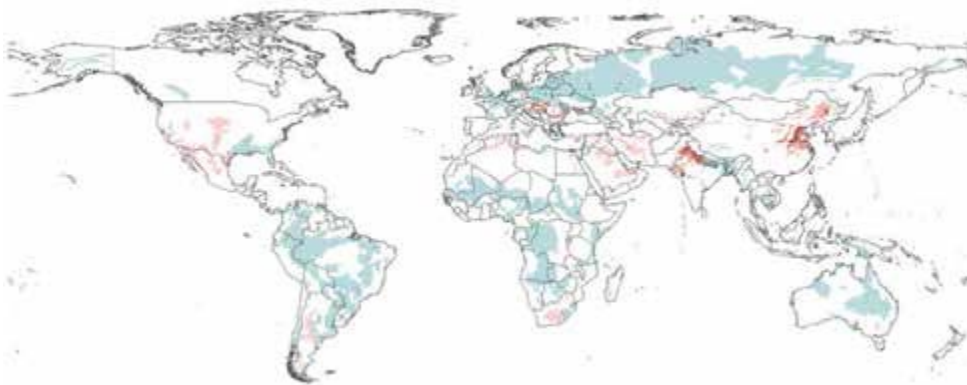


Figure 2.9 Groundwater stress may be affecting 1.7 billion people and could limit the potential to increase agricultural production in the world. Blue: Population density in areas with less stressed regional aquifers (km²). Red: Population density in areas with more stressed regional aquifers (km²). Source: Tom Gleeson, Yoshihide Wada, Marc F. P. Bierkens & Ludovicus P. H. van Beek, Nature Vol 488, August 9, 2012.

The higher temperature of ocean surfaces will lead to stronger storms and tornadoes. This has occurred already many times by increased incidence on the USA east coast, and in south-east Asia. The number of serious floods are also increasing, especially in areas which already previously had regular flooding. There are also increased droughts. For example in 2012 the USA had a very serious drought which destroyed some 30% of food production. 2018 has also be a year of severe droughts in norther Europe and the USA. The general patter is that wet areas will be wetter and dry areas drier.

The social, economic and environmental consequences of these extreme weather events are serious. Thus the particularly hot year of 2003 in Europe had an additional 30,000 casualties due to heat. Agriculture will change and harvests decrease in some areas (and increase in others). Hurricanes, storm, and floods in densely inhabited areas destroy infrastructure and property for immense values. A general trend is that ground water levels are decreasing all over the world. In some areas it is more serious (Fig. 2.9). This may lead to a water crisis in the near future.

There will also be large consequences for ecosystems which all are very climate dependent. Thus warmth-craving southern species (including insects being vectors for diseases) will move north while northern species (e.g. polar bears) become marginalised or

disappear. Some of these effects are already painful. Crops have to be adapted to a different climate and in some areas irrigation will be problematic.



Figure 2.10. The effects of climate change are already serious for the civil society in many parts of the world, especially in the poorer countries (courtesy of picture World Bank).

2.5 Increased greenhouse gases concentrations

The large scale combustion of fossil fuels, which have been going on since the beginning of industrialisation around 1750, has led to massive emissions of carbon dioxide into the atmosphere. In addition changes in land use, especially deforestation, have also contributed to large emissions of carbon dioxide. Estimations are that 1,200 Gigatonnes of CO₂ have entered the atmosphere in this way, almost all of it since 1900, and at a rate which is still increasing. About 40 Gt (billion tonnes) was emitted in 2017, the great part of this, 36 Gt, from fossil fuels and industry, the rest from land use, in particular deforestation. During 2014-2016 the emissions were levelling off at 35 Gt from fossil fuels and industry but it has since increased in parallel with increased world economy and is still increasing in 2018.

Emitted carbon dioxide is partly dissolved in the world's oceans. This reduces the content in atmosphere but also makes the ocean water more acidic. This is a threat to the world's coral reefs and much marine biodiversity.

Atmospheric carbon dioxide concentration has been carefully monitored since 1958 at a research station in Hawaii (Fig. 2.11). The concentration has increased from pre-industrial levels of about 280 ppm. The first values of 400 ppm was measured during 2014, and 410 ppm in 2018. The contribution from fossil fuel combustion can be estimated from the ¹⁴C content of atmospheric CO₂, since there is no ¹⁴C in the fossil carbon. Through measurements of ice cores from the Antarctica and other data, we have estimations of carbon dioxide concentrations in the atmosphere since about 800,000 years. At no time during this period it was as high as it is today (Fig.2.12). A steady increase is seen, and still going on.

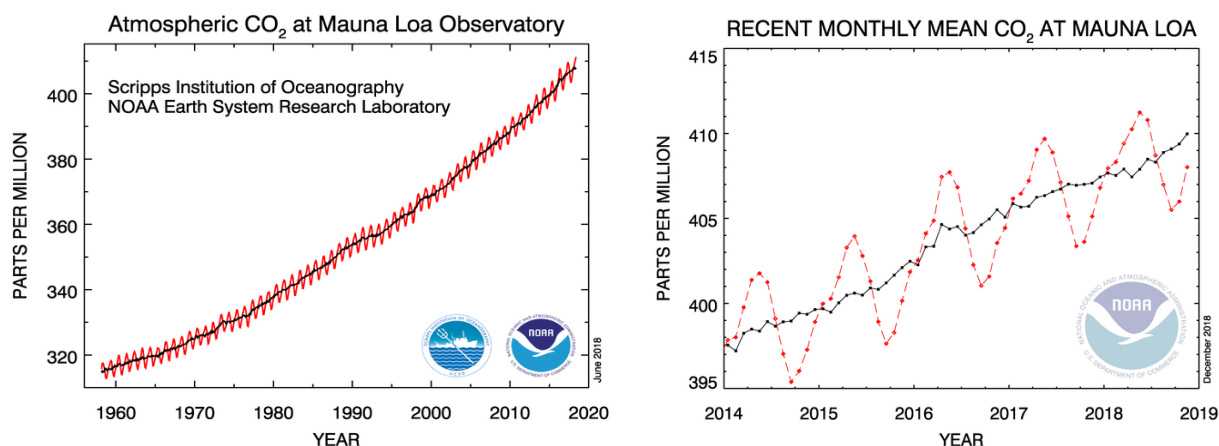


Figure 2.11. Monitoring of the atmospheric CO₂ at the Mauna Loa Observatory on Hawaii. The variation over the year is due to the large land mass on the northern hemisphere gives a lower atmospheric CO₂ level during the northern summer as more photosynthesis is then occurring.

The atmospheric concentrations of the greenhouse gases methane (CH₄) and nitrous oxide (N₂O) have also increased since 1750 due to human activity. In 2016 atmospheric methane level reached 1 853 parts per billion (ppb), which was 157% above the pre-industrial level and nitrous oxide 329 parts per billion, 22% above pre-industrial levels.

Concentrations of CO₂, CH₄, and N₂O now substantially exceed the highest concentrations recorded in ice cores during the past 800,000 years (Fig. 2.12). The mean rates of increase in atmospheric concentrations over the past century are, with very high confidence, unprecedented in the last 22,000 years.

The increased concentrations of carbon dioxide and the other greenhouse gases (GHG) contributes to the so-called *enhanced greenhouse effect* of the atmosphere. Carbon dioxide absorbs heat and radiates it back, and thus increases the temperature of the planet. The *natural* greenhouse effect, which was there before human impact has occurred, increases the planet's temperature by some 35 degrees due to already present GHGs (mostly water). That is why the effect caused by increased CO₂ concentrations is called "enhanced".

Other greenhouse gases which contribute to the enhanced greenhouse effect, include methane with 21 times higher radiative forcing than CO₂, nitrous oxide N₂O, and CFCs also called freons. Even if these three GHGs, also emitted from society, have a much larger effect, they are emitted in smaller volumes and have a shorter half-life in the atmosphere (they are broken down to CO₂ and other components). Thus CO₂ with a very long half-life is the most serious one. If all GHGs are included according to their contributions recalculated as CO₂ equivalents, we have today about 445 ppm CO₂eq, where eq stands for equivalent.

Table 2.1 Greenhouse gases in the atmosphere; preindustrial levels and today.
ppm = parts per million, ppb = parts per billion

Gas	Conc in 1750	Conc in 2016	Increase (%)
CO ₂	279 ppm	403 ppm	44
CH ₄	721 ppb	1,853 ppb	157
N ₂ O	270 ppb	329 ppb	22

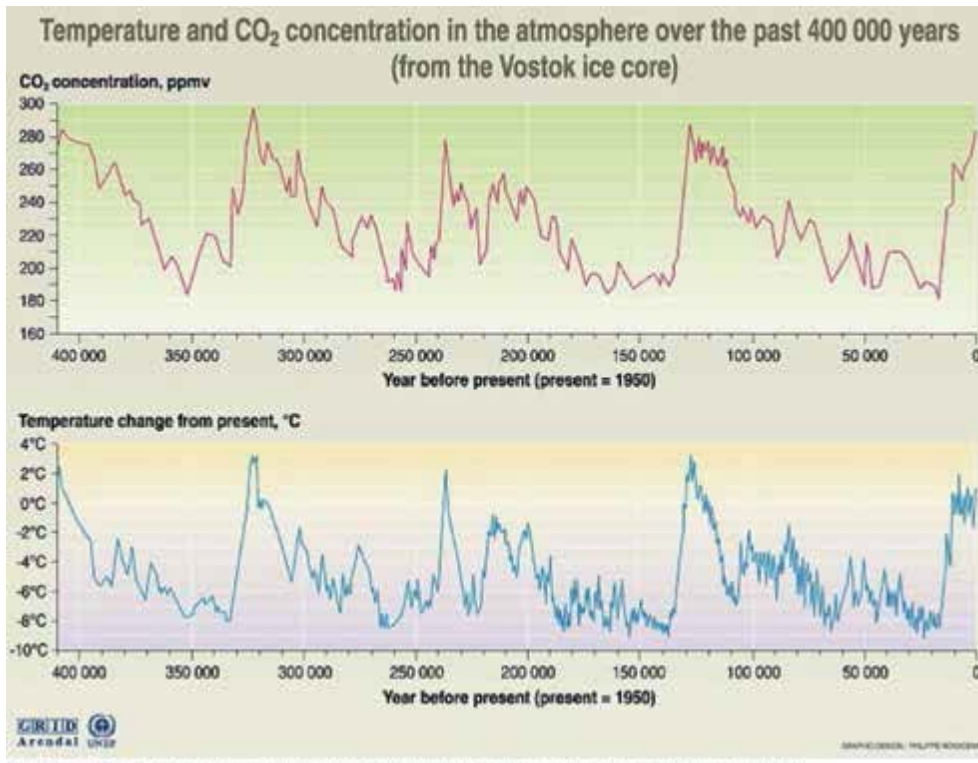


Figure 2.12 Variations in concentration of carbon dioxide (CO₂) and temperature in the atmosphere during the last 400 thousand years. Data from the Vostok ice core. www.grida.no/climate/vital/02.htm.

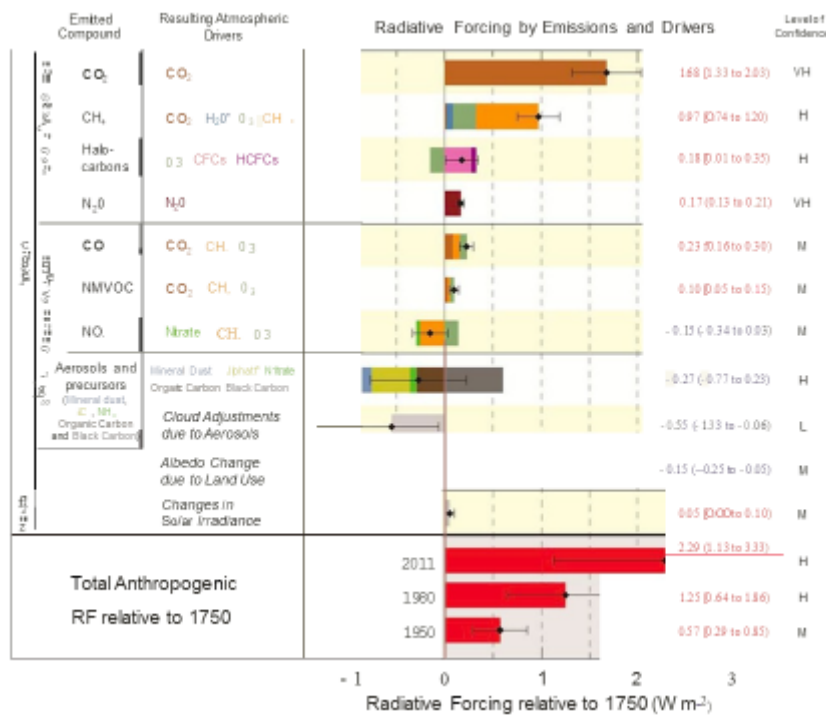


Figure 2.13 Radiative forcings as drivers of climate change. Source: Pär Holmgren.

The effect of the greenhouse gases on the climate is quantified in terms as radiative forcing. Natural and anthropogenic substances and processes that alter the Earth's energy budget are drivers of climate change (Fig. 2.13). Radiative forcing (RF) quantifies the change in energy fluxes caused by changes in these drivers relative to 1750, unless otherwise indicated. Positive RF leads to surface warming, negative RF leads to surface cooling. RF is estimated based on in-situ and remote observations, properties of greenhouse gases and aerosols, and calculations using numerical models representing observed processes. Some emitted compounds affect the atmospheric concentration of other substances. The RF can be reported based on the concentration changes of each substance. Alternatively, the emission-based RF of a compound can be reported, which provides a more direct link to human activities. It includes contributions from all substances affected by that emission. The total anthropogenic RF of the two approaches are identical when considering all drivers.

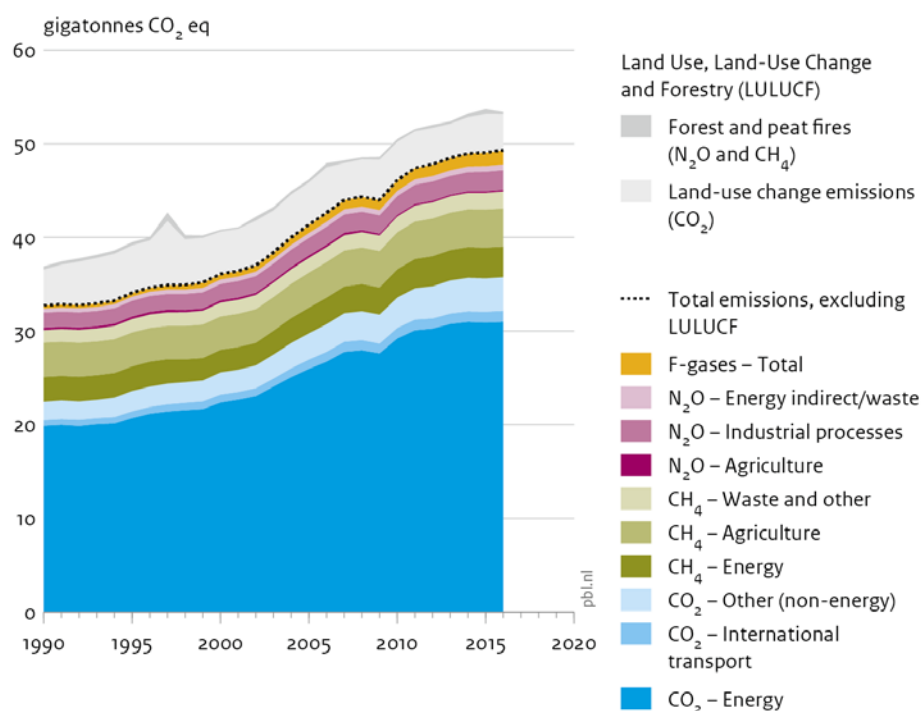
Total radiative forcing is positive, and has led to an uptake of energy by the climate system. The largest contribution to total radiative forcing is caused by the increase in the atmospheric concentration of CO₂ since 1750.

The total anthropogenic RF for 2011 relative to 1750 (Fig. 2.13) is 2.29 W/m², and it has increased more rapidly since 1970 than during prior decades. The total anthropogenic RF best estimate for 2011 is 43% higher than that for the year 2005. This is caused by a combination of continued growth in most greenhouse gas concentrations and improved estimates of RF by aerosols indicating a weaker net cooling effect (negative RF). The RF from emissions of well-mixed greenhouse gases (CO₂, CH₄, N₂O, and Halocarbons) for 2011 relative to 1750 is 3.00 W/m². The RF from changes in concentrations in these gases is 2.83 W/m². Emissions of CO₂ alone have caused an RF of 1.68 W/m². Including emissions of other carbon-containing gases, which also contributed to the increase in CO₂ concentrations, the RF of CO₂ is 1.82 W/m².

Globally, economic and population growth continue to be the most important drivers of increases in CO₂ emissions from fossil fuel combustion (Fig. 2.15). The contribution of population growth between 2000 and 2010 remained roughly identical to the previous three decades, while the contribution of economic growth has risen sharply. Between 2000 and 2010, both drivers outpaced emission reductions from improvements in energy intensity. Increased use of coal relative to other energy sources has reversed the long-standing trend of gradual decarbonisation of the world's energy supply.

Without additional efforts to reduce GHG emissions beyond those in place today, emissions growth is expected to persist driven by growth in global population and economic activities. Baseline scenarios, those without additional mitigation, result in global mean surface temperature increases in 2100 from 3.7 to 4.8 °C compared to pre-industrial levels. Baseline scenarios (scenarios without additional efforts to constrain emissions) exceed 450 parts per million (ppm) CO₂eq by 2030 and reach CO₂eq concentration levels between 750 and more than 1,300 ppm CO₂eq by 2100.

Global greenhouse gas emissions, per type of gas and source, including LULUCF



Source: EDGAR v4.3.2 (EC-JRC/PBL 2017); Houghton and Nassikas (2017); GFED 4.1s (2017)

Fig. 2.14. Global Greenhouse gas (GHG) emissions per type of gas and source, including LULUCF (Land Use, Land Use Change and Forestry) for 1990-2016. Source: Edgar v4.3.2 (EC-JRC/PBL 2017); Houghton and Nassikas (2017); and GFED 4.15 (2017).

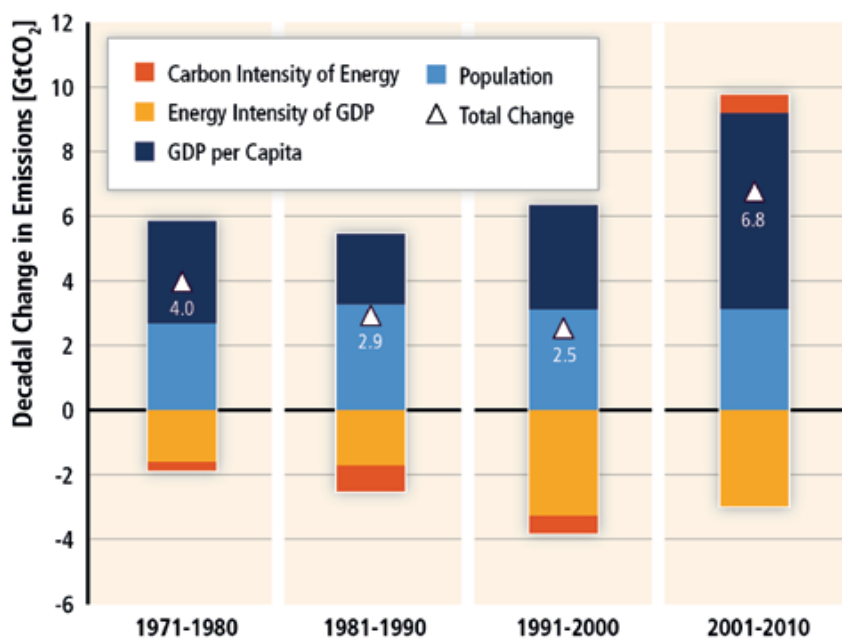


Figure 2.15 Decomposition of the decadal change in total global CO₂ emissions from fossil fuel combustion by four driving factors; population, income (GDP) per capita, energy intensity of GDP and carbon intensity of energy. The bar segments show the changes associated with each factor alone, holding the respective other factors constant. Total decadal changes are indicated by a triangle. Changes are measured in giga tonnes (Gt) of CO₂ emissions per decade; income is converted into common units using purchasing power parities.

2.6 Understanding the Climate System and its recent changes

Understanding recent changes in the climate system results from combining observations, studies of feedback processes, and model simulations. Evaluation of the ability of climate models to simulate recent changes requires consideration of the state of all modelled climate system components at the start of the simulation and the natural and anthropogenic forcing used to drive the models.

Human influence on the climate system is clear. This is evident from the increasing greenhouse gas concentrations in the atmosphere, positive radiative forcing, observed warming, and understanding of the climate system.

Box 6.2 Trends in stocks and flows of greenhouse gases

Total anthropogenic GHG emissions have continued to increase over 1970 to 2010 with larger absolute decadal increases toward the end of this period. Despite a growing number of climate change mitigation policies, annual GHG emissions grew on average by 1.0 gigatonne carbon dioxide equivalent (Gt CO₂eq), that is 2.2% per year from 2000 to 2010 compared to 0.4 Gt CO₂eq (1.3%) per year from 1970 to 2000.

Total anthropogenic GHG emissions were the highest in human history from 2000 to 2010 and reached 49 Gt CO₂eq/yr in 2010. The global economic crisis 2007/2008 only temporarily reduced emissions. CO₂ emissions from fossil fuel combustion and industrial processes contributed about 78% of the total GHG emission increase from 1970 to 2010, with a similar percentage contribution for the period 2000-2010. Fossil fuel-related CO₂ emissions reached 32 Gt CO₂/yr, in 2010, and grew further by about 3% between 2010 and 2011 and by about 1% between 2011 and 2012. Of the 49 Gt CO₂eq/yr in total anthropogenic GHG emissions in 2010, CO₂ remains the major anthropogenic GHG accounting for 76% (38 Gt CO₂eq/yr) of total anthropogenic GHG emissions in 2010. 16% (7.8 Gt CO₂eq/yr) come from methane (CH₄), 6.2% (3.1 Gt CO₂eq/yr) from nitrous oxide (N₂O), and 2.0% (1.0 Gt CO₂eq/yr) from fluorinated gases. Annually, since 1970, about 25% of anthropogenic GHG emissions have been in the form of non-CO₂ gases.

Table 6.2 Emissions of Greenhouse gases in 2010 (CO₂-eq)

Source	Emissions (Gt)	Emissions (%)
CO ₂	38.0	76
CH ₄	7.8	16
N ₂ O	3.1	6.2
fluorinated gases	1.0	2.0

About half of cumulative anthropogenic CO₂ emissions between 1750 and 2010 have occurred in the last 40 years. In 1970, cumulative CO₂ emissions from fossil fuel combustion, cement production and flaring since 1750 were 420 Gt CO₂; in 2010, that cumulative total had tripled to 1300 Gt CO₂. Annual anthropogenic GHG emissions have increased by 10 Gt CO₂eq between 2000 and 2010, with this increase directly coming from energy supply (47%), industry (30%), transport (11%) and buildings (3%) sectors (Fig. 2.16). Accounting for indirect emissions raises the contributions of the buildings and industry sectors. Since 2000, GHG emissions have been growing in all sectors, except AFOLU (Agriculture, Forestry and Other Land Use).

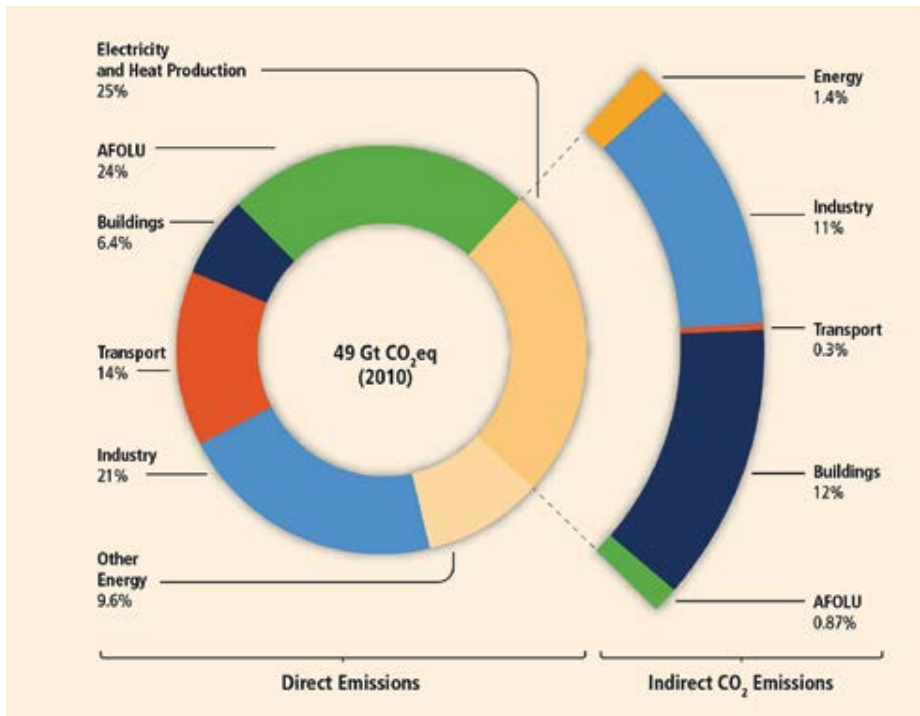


Figure 2.16 Total anthropogenic GHG emissions (Gt CO₂eq/yr) by economic sectors. Inner circle shows direct GHG emission shares (in% of total anthropogenic GHG emissions) of five economic sectors in 2010. Pull-out shows how indirect CO₂ emission shares (in % of total anthropogenic GHG emissions) from electricity and heat production are attributed to sectors of final energy use.

The today improved climate models reproduce observed continental-scale surface temperature patterns and trends over many decades, including the more rapid warming since the mid-20th century and the cooling immediately following large volcanic eruptions.

The long-term climate model simulations show a trend in global mean surface temperature from 1951 to 2012 that agrees with the observed trend. There are, however, differences between simulated and observed trends over periods as short as 10 to 15 years (e.g., 1998 to 2012). The observed reduction in surface warming trend over the period 1998 to 2012 as compared to the period 1951 to 2012, is due in roughly equal measure to a reduced trend in radiative forcing and a cooling contribution from natural internal variability, which includes a possible redistribution of heat within the ocean.

The reduced trend in radiative forcing is primarily due to volcanic eruptions and the timing of the downward phase of the 11-year solar cycle. The net feedback from the combined effect of changes in water vapour, and differences between atmospheric and surface warming amplifies changes in climate. Uncertainty in the sign and magnitude of the cloud feedback is due primarily to continuing uncertainty in the impact of warming on low clouds.

The equilibrium climate sensitivity quantifies the response of the climate system to constant radiative forcing on multi-century time scales. It is defined as the change in global mean surface temperature at equilibrium that is caused by a doubling of the atmospheric CO₂ concentration. Equilibrium climate sensitivity is in the range 1.5°C to 4.5°C. Estimates of these quantities for recent decades are consistent with the assessed range of the equilibrium climate sensitivity providing strong evidence for our understanding of anthropogenic climate change.

Human influence has been detected in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, in global mean sea level rise, and in changes in some climate extremes. Human influence has been the dominant cause of

the observed warming since the mid-20th century. The best estimate of the human-induced contribution to warming is similar to the observed warming over this period.

Greenhouse gases contributed a global mean surface warming is 0.5°C to 1.3°C over the period 1951 to 2010, with the contributions from other anthropogenic forcings, including the cooling effect of aerosols, -0.6°C to 0.1°C. The contribution from natural forcings is small. Together these assessed contributions are consistent with the observed warming of approximately 0.6°C to 0.7°C over this period.

Cumulative emissions of CO₂ largely determine global mean surface warming by the late 21st century and beyond. Most aspects of climate change will persist for many centuries even if emissions of CO₂ are stopped. This represents a substantial multi-century climate change commitment created by past, present and future emissions of CO₂.

2.7 The Climate sceptics – climate deniers

There is a considerable number of individuals – among the general public, politicians and even some researchers – who does not at all agree with the picture of climate change and the reasons for climate change which have been delineated in this chapter. These are commonly called climate sceptics or even climate deniers. Some of them disagree that we have climate change at all, for example by referring to the flattening of the temperature curve the first years of this century. Some also maintain that we are not measuring the temperature changes in a correct way, e.g. by not taking into account that measuring stations are located close to cities, and influenced by so-called “urban heat”. However it is more common to accept that there is a climate change but argue that this is perfectly normal and has happened many times before both in the recent history, for example by referring to the so-called small ice age (the 17th century) or earlier, for example during the much warmer conditions in the Palaeolithic period. It is of course true that there has been quite many periods of climate change in our more recent as well as older history. This group is also arguing that the warming we see today is not due to human intervention but has natural causes, just as during previous events.

The deniers have very many arguments. The most common seems to be “it is the sun, idiot!”. Now, this statement is very easy to check since the sun irradiance can be measured very precisely and it is certainly not increase of sun which is behind the present climate change. (Change in sun irradiance has been causing several of the earlier climate change events, as it does vary but has a very long periodicity.)

It is also possible to point to quite many differences between the present climate change and the changes in the previous periods. A most striking difference is that the warming now is much faster. It is about 16 times faster than the warming following the last glaciation. Carbon dioxide concentration in the atmosphere has also changed in connection with earlier climate change, but as far as it is possible to see it has happened as a consequence of increased temperature rather than causing warming.

The number of arguments from the climate deniers are, as mentioned, very many. Several are discussed in detail on the website called *Skeptical Science*. The link is <https://www.skepticalscience.com/argument.php>. In May 2015 there were 150 arguments discussed on both simple and more scientific level. Another site is <http://grist.org/series/skeptics/>.

Reasons for climate denial seem to be more on the personal than on the scientific level. Climate deniers are more common in the countries which are very dependent on fossil fuels, such as USA and Russia. Of course these countries have much to lose if we have to stop using fossil fuels. In addition many in the US have a tradition of forming their own opinion

regardless of science. In Central and Eastern Europe there is on the other hand a tradition of always accepting what the political authorities say. Both these attitudes strengthen climate denial. The two circumstances to remember is that precisely because of the nature of the issue the Intergovernmental Panel of Climate Change, IPCC, was formed to provide the very best summary of our present knowledge and understanding of climate change. Why deny that? Secondly it is true that in natural science we can never have certainty in the mathematical sense. In fact we seldom have for anything in real life. But we should be wise enough to act on the best knowledge available. For ourselves, our future fellow human beings and our world.

Chapter 2 sources:

Sections 2.1 – 2.6 is written by Lars Rydén based on excerpts from the Summary for Policy-makers from the IPCC's Fifth Assessment Report (AR5) Working Group I published in September 2013 (http://www.climat-echange2013.org/images/report/WG1AR5_SPM_FINAL.pdf). WG I is reporting on the scientific background of the study of Climate Change. Most updated data up to 2018 was obtained from National Oceanic and Atmospheric Administration of the USA, NOAA. <https://www.ncdc.noaa.gov/sotc/global/2017> and <https://www.ncdc.noaa.gov/sotc/global/2018>. **Section 2.7** on climate deniers was written by Lars Rydén

Chapter 3

A future of climate change – assessing the risks

3.1 Observed Impacts, Vulnerability, and Exposure

In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans. Evidence of climate-change impacts is strongest and most comprehensive for natural systems. Some impacts on human systems have also been attributed to climate change. In many regions, changing precipitation or melting snow and ice are altering hydrological systems, affecting water resources in terms of quantity and quality. Glaciers continue to shrink almost worldwide due to climate change, affecting runoff and water resources downstream. Climate change is causing permafrost warming and thawing in high-latitude regions and in high-elevation regions.

Many terrestrial, freshwater, and marine species have shifted their geographic ranges, seasonal activities, migration patterns, abundances, and species interactions in response to ongoing climate change. Only a few recent species extinctions have been attributed as yet to climate change. Natural climate change at rates slower than current anthropogenic climate change caused significant ecosystem shifts and species extinctions during the past millions of years.

Many studies on a wide range of regions and crops have recorded negative impacts of climate change on crop yields. A small number of studies have shown positive impacts on crop yields mainly at high latitudes, although it is not so clear if the balance of impacts has been negative or positive. Climate change has negatively affected wheat and maize yields for many regions and in the global aggregate. Effects on rice and soybean yield have been smaller.

At present the world-wide burden of human ill-health from climate change is relatively small compared to other causes. However, there has been increased heat-related mortality and decreased cold-related mortality in some regions as a result of warming. People who are socially, economically, culturally, politically, institutionally, or otherwise marginalized are especially vulnerable to climate change and also to some adaptation and mitigation responses.

Impacts from recent climate-related extremes, such as heat waves, droughts, floods, cyclones, and wildfires have proved that both ecosystems and many human systems are very vulnerable to current climate variability. Impacts of such climate-related extremes are many. They include alteration of ecosystems, disruption of food production and water supply, damage to infrastructure and settlements, bad health and death of humans, and consequences for mental health and human well-being. Climate-related hazards affect poor people's lives directly through impacts on livelihoods, reductions in crop yields, or destruction of homes. Indirect effects include for example, increased food prices and food insecurity. In addition violent conflict increases vulnerability to climate change. The risk associated with different future climates are shown as scenarios in the IPCC reports (Fig. 3.1). These go from the business-as-usual, meaning no efforts are done to reduce emissions, to a low emission scenario assuming very large reductions of emissions.

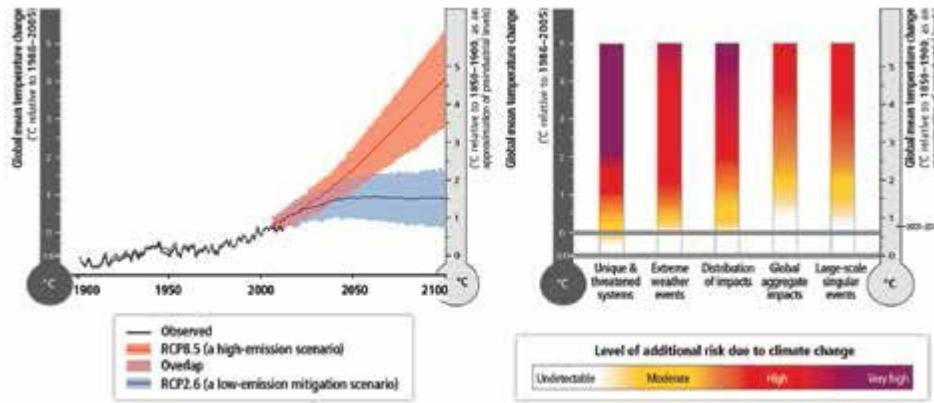


Figure 3.1 Illustration of the core concepts of climate related risks. Risk of climate-related impacts results from the interaction of climate-related hazards (including hazardous events and trends) with the vulnerability and exposure of human and natural systems. Changes in both the climate system (left) and socioeconomic processes including adaptation and mitigation (right) are drivers of hazards, exposure, and vulnerability. The scenarios shown are the RCPs (Representative Concentration Pathways) of the IPCC. The numbers of RCP refers to the radiative forcing values in the year 2100 relative to pre-industrial values for the respective scenario. RCP 8.5 has $+8.5 \text{ W/m}^2$ forcing in 2100, the so-called baseline or “business-as-usual” scenario, while RCP 2.6 has $+2.6 \text{ W/m}^2$ forcing in 2100 which is a high mitigation scenario.

3.2 Climate-related risks

Below follow a list of key risks. All of these have been identified with high confidence, and they span sectors and regions. Many key risks constitute particular challenges for the least developed countries and vulnerable communities, given their limited ability to cope.

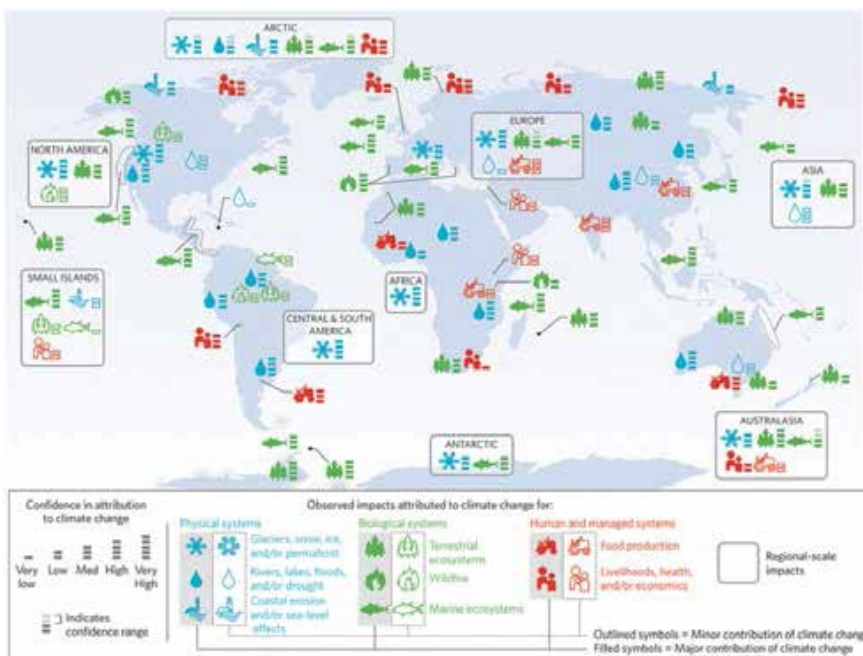


Figure 3.2 Regional distribution of risks with widespread impacts in a changing world. (A) Global patterns of impacts in recent decades attributed to climate change. Impacts are shown at a range of geographic scales. Symbols indicate categories of attributed impacts, the relative contribution of climate change (major or minor) to the observed impact, and confidence in attribution.

1. Risk of death, injury, ill-health, or disrupted livelihoods in low-lying coastal zones and small island developing states and other small islands, due to storm surges, *coastal flooding*, and *sea-level rise*.
2. Risk of severe ill-health and disrupted livelihoods for large urban populations due to *inland flooding* in some regions.
3. Systemic risks due to extreme weather events, such as *storms and tornadoes*, leading to breakdown of infrastructure networks and critical services such as electricity, water supply, and health and emergency services.
4. Risk of mortality and morbidity during periods of *extreme heat*, particularly for vulnerable urban populations and those working outdoors in urban or rural areas.
5. Risk of *food insecurity* and the breakdown of food systems linked to warming, drought, flooding, and precipitation variability and extremes, particularly for poorer populations in urban and rural settings.
6. Risk of loss of rural livelihoods and income due to *insufficient access to water* for drinking and irrigation and reduced agricultural productivity, particularly for farmers and pastoralists with minimal capital in semi-arid regions.
7. Risk of *loss of marine and coastal ecosystems*, biodiversity, and the ecosystem goods, functions, and services they provide for coastal livelihoods, especially for fishing communities in the tropics and the Arctic.
8. Risk of loss of terrestrial and *inland water ecosystems*, biodiversity, and the ecosystem goods, functions, and services they provide for livelihoods.

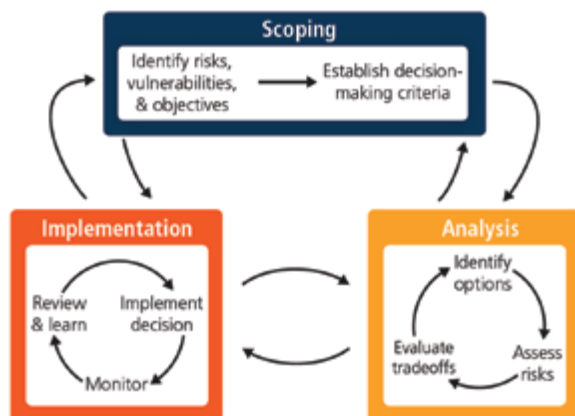


Figure 3.3 Climate-change adaptation as an iterative risk management process with multiple feedbacks. People and knowledge shape the process and its outcomes.

Below follows an estimation of the vulnerability of the different systems given as temperature increase which will cause significant harm. Five integrative reasons for concern provide a framework for summarizing key risks across sectors and regions. They provide one starting point for evaluating dangerous anthropogenic interference with the climate system. All temperatures below are given as global average temperature change relative to 1986-2005 (“recent”).

1. *Unique and threatened systems*: Some unique and threatened systems, including ecosystems and cultures, are already at risk from climate change. 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 and high with 1 °C additional warming. Risks associated with some types of extreme events (e.g., extreme heat) increase further at higher temperatures.

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. Based on projected decreases in regional crop yields and water availability, risks of unevenly distributed impacts are high for additional warming above 2 °C.

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. Extensive biodiversity loss with associated loss of ecosystem goods and services results in high risks around

3 °C additional warming. Aggregate economic damages accelerate with increasing temperature 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. 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, near-complete loss of the Greenland ice sheet would occur over a millennium or more, contributing up to 7m of global mean sea-level rise.

3.3 Impacts in individual sectors

Increasing magnitudes of warming increase the likelihood of severe, pervasive, and irreversible impacts. Some risks of climate change are considerable at 1 or 2 °C above preindustrial levels. Global climate change risks are high to very high with global mean temperature increase of 4 °C or more above preindustrial levels in all reasons for concern, and include severe and widespread impacts on unique and threatened systems, substantial species extinction, large risks to global and regional food security, and the combination of high temperature and humidity compromising normal human activities, including growing food or working outdoors in some areas for parts of the year. The precise levels of climate change sufficient to trigger tipping points (thresholds for abrupt and irreversible change) remain uncertain, but the risk associated with crossing multiple tipping points in the earth system or in interlinked human and natural systems increases with rising temperature.

Freshwater resources. Freshwater-related risks of climate change increase significantly with increasing greenhouse gas concentrations. The fraction of global population experiencing water scarcity and the fraction affected by major river floods increase with the level of warming in the 21st century. Climate change over the 21st century is projected to reduce renewable surface water and groundwater resources significantly in most dry subtropical regions, intensifying competition for water among sectors. In presently dry regions, drought frequency will likely increase by the end of the 21st century. In contrast, water resources are projected to increase at high latitudes. Climate change is projected to reduce raw water quality

and pose risks to drinking water quality even with conventional treatment, due to interacting

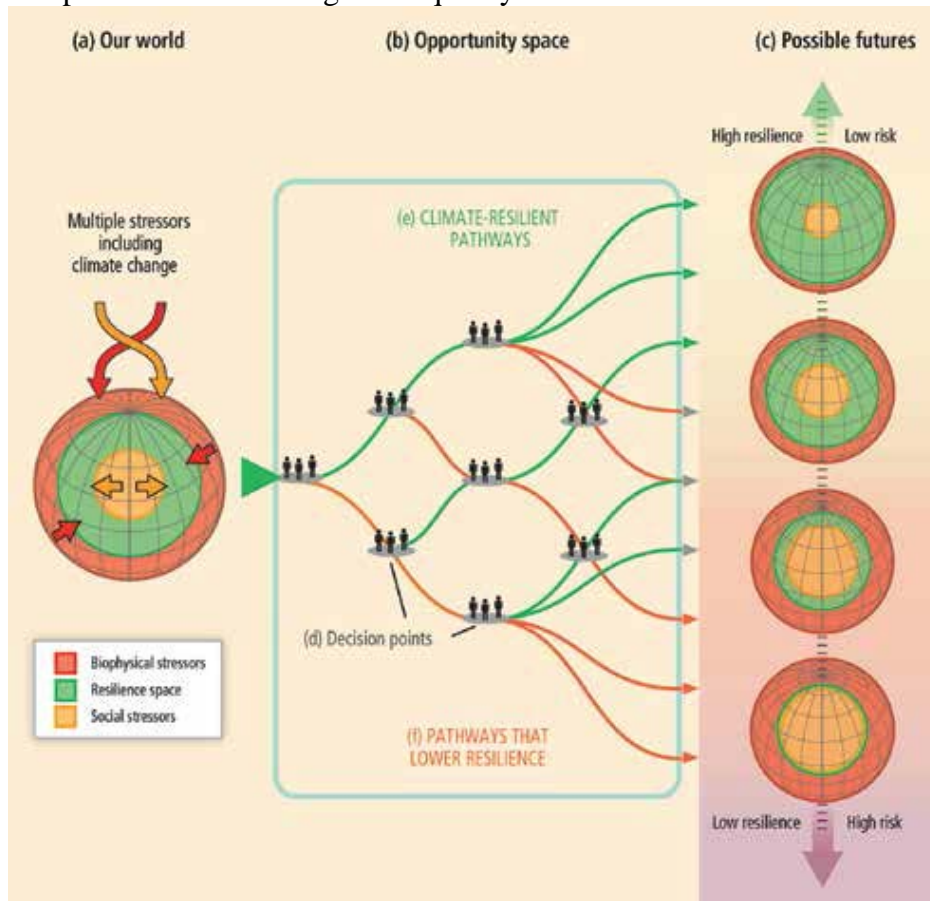


Figure 3.4 The solution space. The picture illustrate overlapping entry points and approaches, as well as key considerations, in managing risks related to climate change.

factors: increased temperature; increased sediment, nutrient, and pollutant loadings from heavy rainfall; increased concentration of pollutants during droughts; and disruption of treatment facilities during floods. Adaptive water management techniques, including scenario planning, learning-based approaches, and flexible and low-regret solutions, can help create resilience to uncertain hydrological changes and impacts due to climate change.

Ecosystems and biodiversity. A large fraction of both terrestrial and freshwater species faces increased extinction risk under projected climate change during and beyond the 21st century, especially as climate change interacts with other stressors, such as habitat modification, over-exploitation, pollution, and invasive species. Within this century, magnitudes and rates of climate change associated with medium to high-emission scenarios pose high risk of abrupt and irreversible regional-scale change in the composition, structure, and function of terrestrial and freshwater ecosystems, including wetlands. Examples that could lead to substantial impact on climate are the boreal-tundra Arctic system and the Amazon forest.

Carbon stored in the terrestrial biosphere (e.g., in peatlands, permafrost, and forests) is susceptible to loss to the atmosphere as a result of climate change, deforestation, and ecosystem degradation. Increased tree mortality and associated forest dieback is projected to occur in many regions over the 21st century, due to increased temperatures and drought. Forest dieback poses risks for carbon storage, biodiversity, wood production, water quality, amenity, and economic activity.

Due to sea-level rise projected throughout the 21st century and beyond, coastal systems and low-lying areas will increasingly experience adverse impacts such as submergence, coastal flooding, and coastal erosion. Due to projected climate change by the mid-21st century and beyond, global marine-species redistribution and marine-biodiversity reduction in sensitive regions will challenge the sustained provision of fisheries productivity and other ecosystem services. For medium- to high-emission scenarios, ocean acidification poses substantial risks to marine ecosystems, especially polar ecosystems and coral reefs, associated with impacts on the physiology, behavior, and population dynamics of individual species from phytoplankton to animals

Food, economy and development. All aspects of food security are potentially affected by climate change, including food access, utilization, and price stability. For the major crops (wheat, rice, and maize) in tropical and temperate regions, climate change without adaptation is projected to negatively impact production for local temperature increases of 2 °C or more above late-20th-century levels, although individual locations may benefit.

Many global risks of climate change are concentrated in urban areas. Steps that build resilience and enable sustainable development can accelerate successful climate-change adaptation globally. Heat stress, extreme precipitation, inland and coastal flooding, landslides, air pollution, drought, and water scarcity pose risks in urban areas for people, assets, economies, and ecosystems.

Risks are amplified for those lacking essential infrastructure and services or living in poor-quality housing and exposed areas. Major future rural impacts are expected in the near-term and beyond through impacts on water availability and supply, food security, and agricultural incomes, including shifts in production areas of food and non-food crops across the world. For most economic sectors, the impacts of drivers such as changes in population, age structure, income, technology, relative prices, lifestyle, regulation, and governance are projected to be large relative to the impacts of climate change. Climate change is projected to reduce energy demand for heating and increase energy demand for cooling in the residential and commercial sectors.

Global economic impacts from climate change are difficult to estimate. Economic impact estimates completed over the past 20 years vary in their coverage of subsets of economic sectors and depend on a large number of assumptions, many of which are disputable, and many estimates do not account for catastrophic changes, tipping points, and many other factors. With these recognized limitations, the incomplete estimates of global annual economic losses for additional temperature increases of ~2 °C are between 0.2 and 2.0% of income (± 1 standard deviation around the mean).

Human health, security and livelihood. Until mid-century, projected climate change will impact human health mainly by exacerbating health problems that already exist. Throughout the 21st century, climate change is expected to lead to increases in ill-health in many regions and especially in developing countries with low income, as compared to a baseline without climate change. Examples include greater likelihood of injury, disease, and death due to more intense heat waves and fires; increased likelihood of under-nutrition resulting from diminished food production in poor regions; risks from lost work capacity and reduced labor productivity in vulnerable populations; and increased risks from food- and water-borne diseases and vector-borne diseases.

Climate change over the 21st century is projected to increase displacement of people. Displacement risk increases when populations that lack the resources for planned migration experience higher exposure to extreme weather events, in both rural and urban areas, particularly in developing countries with low income.

Climate change can indirectly increase risks of violent conflicts in the form of civil war and inter-group violence by amplifying well-documented drivers of these conflicts such as

poverty and economic shocks. Throughout the 21st century, climate-change impacts are projected to slow down economic growth, make poverty reduction more difficult, further erode food security, and prolong existing and create new poverty traps, the latter particularly in urban areas and emerging hotspots of hunger.

3.4 What is required to limit global warming to 1.5 °C

The 21st Conference of Parties of the United Nations Framework Convention on Climate Change (COP 21) in Paris in 2015 agreed that the long-term goal for the convention is to keep the increase in global average temperature to well below 2 °C above pre-industrial levels and if possible to limit the increase to 1.5 °C, since this would substantially reduce the risks and effects of climate change. For this reason the Convention Secretariat asked the IPCC to make a special report on the impact of global warming for 1.5 °C. The report was seen as part of the efforts to strengthen the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.

The IPCC published the report *Global warming of 1.5°C* in October 2018. As with the other reports of IPCC it builds on the work of a large network of climate scientist and thousands of individual research papers. This section gives a short summary of the findings.

The report begins by stating that limiting the global warming to both 1.5 °C and 2.0 °C requires large reductions of emissions of CO₂. For 1.5 °C warming, global net anthropogenic CO₂ emissions has to decline by about 45% from 2010 levels by 2030 reaching net zero around 2050. For limiting global warming to below 2 °C CO₂ emissions are projected to decline by about 25% by 2030 in most pathways and reach net zero around 2070.

Pathways limiting global warming to 1.5 °C with no or limited overshoot would require rapid and far-reaching transitions in energy, land, urban and infrastructure (including transport and buildings), and industrial systems. These systems transitions are unprecedented in terms of scale, but not necessarily in terms of speed, and imply deep emissions reductions in all sectors, a wide portfolio of mitigation options and a significant upscaling of investments in those options.

All pathways that limit global warming to 1.5 °C project the use of carbon dioxide removal (CDR) (or so-called negative emission technologies) on the order of 100–1000 Gt CO₂ over the 21st century. Carbon dioxide removal would be used to compensate for residual emissions and, in most cases, achieve net negative emissions to return global warming to 1.5 °C following a peak (Fig. 3.5).

Estimates of the global emissions outcome of current nationally stated mitigation ambitions as submitted under the Paris Agreement would lead to global greenhouse gas emissions in 2030 of 52–58 Gt CO₂ eq/yr. Pathways reflecting these ambitions would not limit global warming to 1.5 °C, even if supplemented by very challenging increases in the scale and ambition of emissions reductions after 2030. Avoiding overshoot and reliance on future large-scale deployment of carbon dioxide removal can only be achieved if global CO₂ emissions start to decline well before 2030.

Mitigation options consistent with 1.5 °C pathways are associated with multiple synergies and tradeoffs across the Sustainable Development Goals (SDGs). While the total number of possible synergies exceeds the number of trade-offs, their net effect will depend on the pace and magnitude of changes, the composition of the mitigation portfolio and the management of the transition.

Limiting the risks from global warming of 1.5°C in the context of sustainable development and poverty eradication implies system transitions that can be enabled by an increase of adaptation and mitigation investments, policy instruments, acceleration of technological

innovation, and behaviour changes. Sustainable development supports, and often enables, the fundamental societal and systems transitions and transformations that help limit global warming to 1.5°C. Such changes facilitate the pursuit of climate-resilient development pathways that achieve ambitious mitigation and adaptation in conjunction with poverty eradication and efforts to reduce inequalities.

Strengthening the capacities for climate action of national and sub-national authorities, civil society, the private sector, indigenous peoples and local communities can support the implementation of ambitious actions implied by limiting global warming to 1.5 °C. International cooperation can provide an enabling environment for this to be achieved in all countries and for all people, in the context of sustainable development. International cooperation is a critical enabler for developing countries and vulnerable regions.

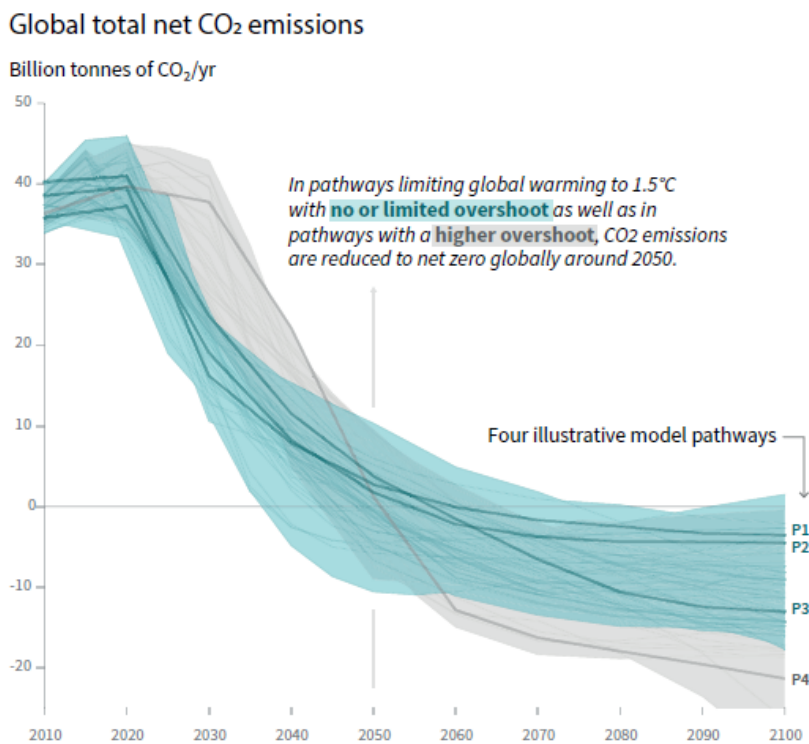


Fig 3.5 Global total net CO₂ emissions under different scenarios. The scenarios P1 to P4 are described below. The emissions are given in Gt of CO₂/yr. CDR = carbon dioxide removal; BECCS= Bio-energy with carbon capture and storage; both these are so-called negative emission technologies. Source: IPCC's Report Global warming of 1.5°C. <https://www.ipcc.ch/sr15/>

Scenario P1: A scenario in which social, business and technological innovations result in lower energy demand up to 2050 while living standards rise, especially in the global South. A downsized energy system enables rapid decarbonisation of energy supply. Afforestation is the only CDR option considered; neither fossil fuels with CCS nor BECCS are used.

Scenario P2: A scenario with a broad focus on sustainability including energy intensity, human development, economic convergence and international cooperation, as well as shifts towards sustainable and healthy consumption patterns, low-carbon technology innovation, and well-managed land systems with limited societal acceptability for BECCS.

Scenario P3: A middle-of-the-road scenario in which societal as well as technological development follows historical patterns. Emissions reductions are mainly achieved by changing the way in which energy and products are produced, and to a lesser degree by reductions in demand.

Scenario P4: A resource- and energy-intensive scenario in which economic growth and globalization lead to widespread adoption of greenhouse-gas-intensive lifestyles, including high demand for transportation fuels and livestock products. Emissions reductions are mainly achieved through technological means, making strong use of CDR through the deployment of BECCS.

3.5 Impacts of global warming of 1.5 °C compared to 2.0 °C.

Climate-related risks to health, livelihoods, food security, water supply, human security, and economic growth are projected to increase with global warming of 1.5 °C and increase further with 2 °C. (Figure 3.6). Limiting global warming to 1.5 °C compared to 2 °C is projected to reduce increases in ocean temperature as well as associated increases in ocean acidity and decreases in ocean oxygen levels. Consequently, limiting global warming to 1.5 °C is projected to reduce risks to marine biodiversity, fisheries, and ecosystems, and their functions and services to humans, as illustrated by recent changes to Arctic sea ice and warm-water coral reef ecosystems.

There is high confidence that the probability of a sea ice-free Arctic Ocean during summer is substantially lower at global warming of 1.5 °C when compared to 2 °C. With 1.5 °C of global warming, one sea ice-free Arctic summer is projected per century. This likelihood is increased to at least one per decade with 2 °C global warming. Effects of a temperature overshoot are reversible for Arctic sea ice cover on decadal time scales.

Global warming of 1.5 °C is projected to shift the ranges of many marine species to higher latitudes as well as increase the amount of damage to many ecosystems. It is also expected to drive the loss of coastal resources and reduce the productivity of fisheries and aquaculture (especially at low latitudes). The risks of climate-induced impacts are projected to be higher at 2 °C than those at global warming of 1.5 °C. Coral reefs, for example, are projected to decline by a further 70–90% at 1.5 °C with larger losses (>99%) at 2°C. The risk of irreversible loss of many marine and coastal ecosystems increases with global warming, especially at 2 °C or more.

The level of ocean acidification due to increasing CO₂ concentrations associated with global warming of 1.5 °C is projected to amplify the adverse effects of warming, and even further at 2 °C, impacting the growth, development, calcification, survival, and thus abundance of a broad range of species from algae to fish.

On land, impacts on biodiversity and ecosystems, including species loss and extinction, are projected to be lower at 1.5 °C of global warming compared to 2 °C. Limiting global warming to 1.5 °C compared to 2 °C is projected to lower the impacts on terrestrial, freshwater and coastal ecosystems and to retain more of their services to humans.

Approximately 4% of the global terrestrial land area is projected to undergo a transformation of ecosystems from one type to another at 1.5 °C of global warming, compared with 13 % at 2 °C. This indicates that the area at risk is projected to be approximately 50 % lower at 1.5 °C compared to 2 °C. High-latitude tundra and boreal forests are particularly at risk of climate change-induced degradation and loss, with woody shrubs already encroaching into the tundra and this will proceed with further warming. Limiting global warming to 1.5 °C rather than 2 °C is projected to prevent the thawing over centuries of a permafrost area in the range of 1.5 to 2.5 million km².

By 2100, global mean sea level rise is projected to be around 0.1 metre lower with global warming of 1.5 °C compared to 2 °C. Sea level will continue to rise well beyond 2100, and the magnitude and rate of this rise depend on future emission pathways. A slower rate of sea level rise enables greater opportunities for adaptation in the human and ecological systems of small islands, low-lying coastal areas and deltas. Sea level rise will continue beyond 2100 even if global warming is limited to 1.5 °C in the 21st century. Marine ice sheet instability in Antarctica and/or irreversible loss of the Greenland ice sheet could result in multi-metre rise in sea level over hundreds to thousands of years. These instabilities could be triggered at around 1.5 °C to 2 °C of global warming.

Five Reasons For Concern (RFCs) illustrate the impacts and risks of different levels of global warming for people, economies and ecosystems across sectors and regions.

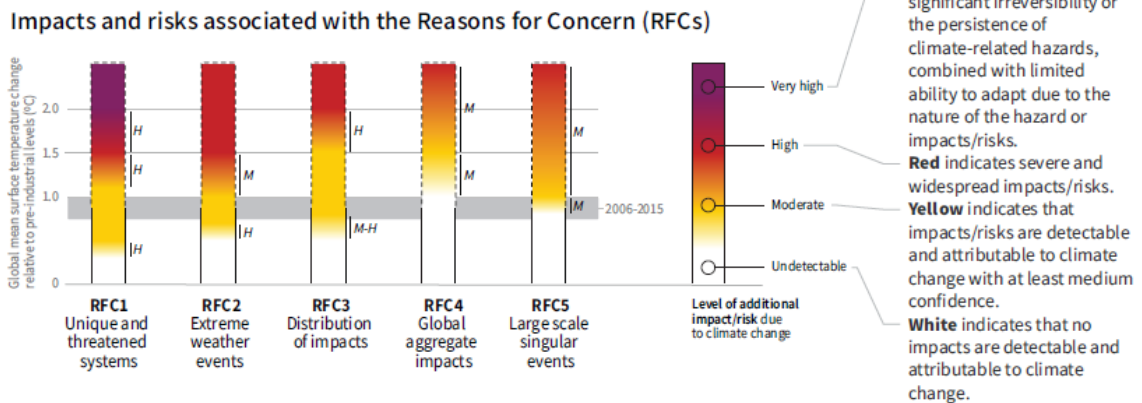


Fig 3.6 Impacts and risks of different levels of global warming for people, economies and ecosystems across sectors and regions. Source: IPCC's Report Global warming of 1.5°C. <https://www.ipcc.ch/sr15/>

Climate models project robust differences in regional climate characteristics between present-day and global warming of 1.5 °C and between 1.5 °C and 2 °C. These differences include increases in mean temperature in most land and ocean regions, hot extremes in most inhabited regions, heavy precipitation in several regions, and the probability of drought and precipitation deficits in some regions. Climate-related risks for natural and human systems are higher for global warming of 1.5 °C than at present, but lower than at 2 °C. These risks depend on the magnitude and rate of warming, geographic location, levels of development and vulnerability, and on the choices and implementation of adaptation and mitigation options.

Chapter 3 sources:

Sections 3.1 to 3.3 are based on and consists mostly of edited excerpts from the Summary for Policy-makers from the IPCC's *Fifth Assessment Report (AR5) Working Group II (WGII)* published in December 2013. (<https://www.ipcc.ch/pdf/assessment-report/ar4/wg2/ar4-wg2-spm.pdf>). WG II is reporting on the consequences of climate change. There is also some material from the Summary for Policy-makers from IPCC AR5 WG III.

Sections 3.4 to 3.5 are based on and consists mostly of edited excerpts from the Summary for Policy-makers from the IPCC's report *Global warming of 1.5°C*. <https://www.ipcc.ch/sr15/> published in October 2018.

Chapter 4

Mitigating and adaptation of climate change

4.1 Managing future risks and building resilience – mitigation and adaptation

Throughout history, people and societies have adjusted to and coped with climate, climate variability, and extremes, with varying degrees of success. In this chapter we will see how impacts and risks related to climate change can be reduced and managed through adaptation and mitigation. The report assesses needs, options, opportunities, constraints, resilience, limits, and other aspects associated with adaptation.

Responding to climate-related risks involves decision-making in a changing world, with continuing uncertainty about the severity and timing of climate-change impacts and with limits to the effectiveness of adaptation. Adaptation and mitigation choices in the near-term will affect the risks of climate change throughout the 21st century. Uncertainties about future vulnerability, exposure, and responses of interlinked human and natural systems are large.

Mitigation refers to actions which reduces the rate as well as the magnitude of warming, Mitigation also increases the time available for adaptation to a particular level of climate change, potentially by several decades. Delaying mitigation actions may reduce options for climate-resilient pathways in the future.

Adaptation refers to the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects.

Resilience refers to the capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation.

Managing the risks of climate change involves adaptation and mitigation decisions with implications for future generations, economies, and environments. National governments can coordinate adaptation efforts of local and subnational governments, for example by protecting vulnerable groups, by supporting economic diversification, and by providing information, policy and legal frameworks, and financial support. Local government and the private sector are increasingly recognized as critical to progress in adaptation, given their roles in scaling up adaptation of communities, households, and civil society and in managing risk information and financing.

A first step towards adaptation to future climate change is reducing vulnerability and exposure to present climate variability. Strategies may include actions with co-benefits for other objectives. Existing and emerging economic instruments can foster adaptation by providing incentives for anticipating and reducing impacts. Instruments include public-private finance partnerships, loans, payments for environmental services, improved resource pricing, charges and subsidies, norms and regulations, and risk sharing and transfer mechanisms.

Significant co-benefits, synergies, and trade-offs exist between mitigation and adaptation and among different adaptation responses; interactions occur both within and across regions. Examples of actions with co-benefits include

- 1) Improved energy efficiency and cleaner energy sources, leading to reduced emissions of health-damaging climate-altering air pollutants;

- 2) Reduced energy and water consumption in urban areas through greening cities and recycling water;
- 3) Sustainable agriculture and forestry; and
- 4) Protection of ecosystems for carbon storage and other ecosystem services.

Limiting the effects of climate change is necessary to achieve sustainable development and equity, including poverty eradication. At the same time, some mitigation efforts could undermine action on the right to promote sustainable development, and on the achievement of poverty eradication and equity. Effective mitigation will not be achieved if individual agents advance their own interests independently.

Climate change has the characteristics of a collective action problem at the global scale, because most greenhouse gases (GHGs) accumulate over time and mix globally, and emissions by any agent (e.g., individual, community, company or country) affect other agents. International cooperation is therefore required to effectively mitigate GHG emissions and address other climate change issues. Issues of equity, justice, and fairness arise with respect to mitigation and adaptation.

Countries' past and future contributions to the accumulation of GHGs in the atmosphere are different, and countries also face varying challenges and circumstances, and have different capacities to address mitigation and adaptation. Many areas of climate policy-making involve value judgements and ethical considerations. These areas range from the question of how much mitigation is needed to prevent dangerous interference with the climate system to choices among specific policies for mitigation or adaptation. Among other methods, economic evaluation is commonly used to inform climate policy design. Practical tools for economic assessment include cost-benefit analysis, cost-effectiveness analysis, multi-criteria analysis, and expected utility theory.

4.2 Emission and Mitigation scenarios and measures in the context of sustainable development

A number of mitigation scenarios or pathways under different assumptions of GHGs emission reductions have been examined (see Fig. 4.1). These are seen in the light of the global agreement (e.g the Paris Agreement) that countries will work to keep global warming within or below 2 °C, a level that is perceived as not too dangerous to human society. The scenarios where it is likely that the temperature change caused by anthropogenic GHG emissions can be kept to less than 2 °C relative to pre-industrial levels are characterized by atmospheric concentrations in 2100 of about 450 ppm CO₂eq. Scenarios reaching concentration levels of about 500 ppm CO₂eq by 2100 are not likely to limit temperature change to less than 2 °C relative to pre-industrial levels.

The baseline scenario is the “business as usual” development, that is, a future where no particular mitigation activities are made and emissions are continuing to rise in the fashion we see today. All other scenarios assumes different mitigation options to reduce emissions. In the IPCC reports the scenarios, called *Representative Concentration Pathways* (RCPs), are named RCP 8.5, RCP 6.0, RCP 4.5 and RCP 2.6. The numbers refers to the radiative forcing values in the year 2100 relative to pre-industrial values, +2.6, +4.5, +6.0, and +8.5 W/m², respectively.

Scenarios reaching atmospheric concentration levels of about 450 ppm CO₂eq by 2100 include substantial cuts in anthropogenic GHG emissions by mid-century through large-scale changes in energy systems and potentially land use. Scenarios reaching these concentrations by 2100 are characterized by lower global GHG emissions in 2050 than in 2010, 40-70%

lower globally, and emissions levels near zero Gt CO₂eq or below in 2100. In scenarios reaching 500 ppm CO₂eq by 2100, 2050 emissions levels are 25-55% lower than in 2010 globally. In scenarios reaching 550 ppm CO₂eq, emissions in 2050 are from 5% above 2010 levels to 45% below 2010 levels globally. At the global level, scenarios reaching 450 ppm

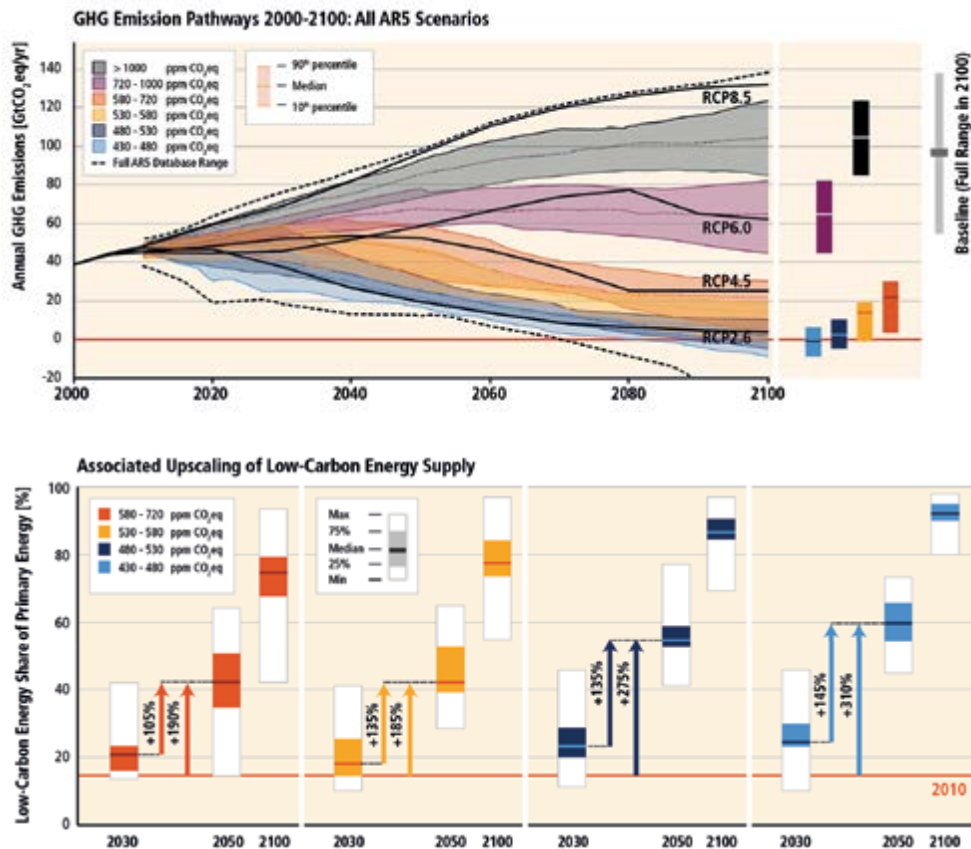


Figure 4.1. Pathways of global GHG emissions (Gt CO₂eq/year) in baseline and mitigation scenarios for different long-term concentration levels (upper panel) and associated up-scaling requirements of low-carbon energy (% of primary energy) for 2030, 2050 and 2100 compared to 2010 levels in mitigation scenarios (lower panel). The upper and lower panels exclude scenarios with limited technology availability and the lower panel in addition excludes scenarios that assume exogenous carbon price trajectories.

CO₂eq are also characterized by more rapid improvements of energy efficiency, a tripling to nearly a quadrupling of the share of zero- and low-carbon energy supply from renewables, nuclear energy and fossil energy with carbon dioxide capture and storage (CCS), or bioenergy with CCS (BECCS) by the year 2050.

Mitigation scenarios reaching about 450 ppm CO₂eq in 2100 typically involve temporary overshoot of atmospheric concentrations, as do many scenarios reaching about 500 ppm to 550 ppm CO₂eq in 2100. Depending on the level of the overshoot, overshoot scenarios typically rely on the availability and widespread deployment of BECCS and afforestation in the second half of the century.

The availability and scale of these and other Carbon Dioxide Removal (CDR) technologies and methods are uncertain and CDR technologies and methods are, to varying degrees, associated with challenges and risks. Meeting the 2 °C goal would require further substantial reductions beyond 2020. Delaying mitigation efforts beyond those in place today through

2030 is estimated to substantially increase the difficulty of the transition to low longer-term emissions levels and narrow the range of options consistent with maintaining temperature change below 2 °C relative to pre-industrial levels. Cost-effective mitigation scenarios that make it at least as likely as not that temperature change will remain below 2 °C relative to pre-industrial levels are typically characterized by annual GHG emissions in 2030 of roughly 30 GtCO₂eq, as suggested by the 2018 IPCC report.

4.3 Mitigation pathways and measures

In baseline scenarios, GHG emissions are projected to grow in all sectors, except for net CO₂ emissions in the AFOLU sector. Energy supply sector emissions are expected to continue to be the major source of GHG emissions, ultimately accounting for the significant increases in indirect emissions from electricity use in the buildings and industry sectors. In baseline scenarios, while non-CO₂ GHG agricultural emissions are projected to increase, net CO₂ emissions from the AFOLU sector decline over time, with some models projecting a net sink towards the end of the century. Infrastructure developments and long-lived products that lock societies into GHG-intensive emissions pathways may be difficult or very costly to change, reinforcing the importance of early action for ambitious mitigation. This lock-in risk is compounded by the lifetime of the infrastructure, by the difference in emissions associated with alternatives, and the magnitude of the investment cost. As a result, lock-in related to infrastructure and spatial planning is the most difficult to reduce.

There are strong interdependencies in mitigation scenarios between the pace of introducing mitigation measures in energy supply and energy end-use and developments in the AFOLU sector. The distribution of the mitigation effort across sectors is strongly influenced by the availability and performance of BECCS and large scale afforestation. Well-designed systemic and cross-sectorial mitigation strategies are more cost-effective in cutting emissions than a focus on individual technologies and sectors. At the energy system level these include reductions in the GHG emission intensity of the energy supply sector, a switch to low carbon energy carriers (including low-carbon electricity) and reductions in energy demand in the end-use sectors without compromising development. Mitigation scenarios reaching around 450 ppm CO₂eq concentrations by 2100 show large-scale global changes in the energy supply sector. In these selected scenarios, global CO₂ emissions from the energy supply sector are projected to decline over the next decades and are characterized by reductions of 90% or more below 2010 levels between 2040 and 2070.

Efficiency enhancements and behavioural changes, in order to reduce energy demand compared to baseline scenarios without compromising development, are key mitigation strategies in scenarios reaching atmospheric CO₂eq concentrations of about 450 or 500 ppm by 2100. Near-term reductions in energy demand are an important element of cost-effective mitigation strategies. Behaviour, lifestyle and culture have a considerable influence on energy use and associated emissions, with high mitigation potential in some sectors, in particular when complementing technological and structural change. Emissions can be substantially lowered through changes in consumption patterns (e.g., mobility demand and mode, energy use in households, choice of longer-lasting products) and dietary change and reduction in food wastes. A number of options including monetary and non-monetary incentives as well as information measures may facilitate behavioural changes.

4.4 Energy supply

In the baseline scenarios direct CO₂ emissions from the energy supply sector are projected to almost double or even triple by 2050 compared to the level of 14.4 Gt CO₂eq/year in 2010, unless energy intensity improvements can be significantly accelerated beyond the historical development. In the last decade, the main contributors to emission growth were a growing energy demand and an increase of the share of coal in the global fuel mix. The decreased availability of fossil fuels alone (past peak oil, gas and coal) will not be sufficient to limit CO₂eq concentration to levels such as 450 ppm, 550 ppm, or 650 ppm.

Therefore reducing the carbon intensity of electricity generation is a key component of cost-effective mitigation strategies. Thus fossil fuel based electricity generation must be exchanged for *renewable (RE) technologies*, such as biomass based generation, hydropower, wind and wave power, and solar electricity. Nuclear power is also included; even if it is not counted as renewable, it is not fossil fuel based.

Since 2007, many RE technologies have demonstrated substantial performance improvements and cost reductions, and a growing number of RE technologies have achieved a level of maturity to enable deployment at significant scale. Regarding electricity generation alone, RE accounted for just over half of the new electricity-generating capacity added globally in 2012, led by growth in wind, hydro and solar power. However, many RE technologies still need direct and/or indirect support, if their market shares are to be significantly increased; RE technology policies have been successful in driving recent growth of RE.

Challenges for integrating RE into energy systems and the associated costs vary by RE technology, regional circumstances, and the characteristics of the existing background energy system.

Nuclear energy is a mature low-GHG emission source of base load power, but its share of global electricity generation has been declining since 1993. Nuclear energy could make an increasing contribution to low-carbon energy supply, but a variety of barriers and risks exist. Those include: operational risks, and the associated concerns, uranium mining risks, financial and regulatory risks, unresolved waste management issues, nuclear weapon proliferation concerns, and adverse public opinion. New fuel cycles and reactor technologies addressing some of these issues are being investigated and progress in research and development has been made concerning safety and waste disposal. Today investment in Nuclear Energy is less profitable than in e.g. wind and solar electricity. The decision to out phase Nuclear energy in e.g. Germany and Sweden also contributes to the reduction of Nuclear Energy. Presently (2018) only China has a growing Nuclear Energy market.

Carbon Capture and Storage (CCS) refers to a technology where the carbon dioxide generated from fossil fuel incineration is collected and transferred to underground storage place, often a chalk mine. A major drawback with this technology is that the incineration has to be done in almost 100% clean oxygen prepared from air, at a considerable energy cost. If air is used to burn the gas to be stored would consist of 80% nitrogen and be five times as large as otherwise. CCS technology has been used for ex by Norway to store carbon dioxide extracted together with natural gas from the North Sea fields. The storage has then been under the sea bottom. For CCS plants in Germany public protests have been considerable; people are afraid of gas leaking from the storage. Thus CCS plants are at present not allowed in the country. Still experts believes that CCS constitutes an essential technology for mitigating climate change in the future.

Bioenergy with CCS (BECCS) refers to a power plan using biomass and CCS. This means that effectively carbon dioxide will be removed from the atmosphere as the carbon in the

biomass is not fossil. It is the most important out of several technologies on the drawing board for removing CO₂ from the atmosphere, so-called negative emission technologies.

GHG emissions from energy supply can be reduced significantly by replacing current world average coal-fired power plants with modern, highly efficient natural gas combined-cycle power plants or combined heat and power plants (CHP), provided that natural gas is available and the fugitive emissions associated with extraction and supply are low or mitigated. In mitigation scenarios reaching about 450 ppm CO₂eq concentrations by 2100, natural gas power generation without CCS acts as a bridge technology, with deployment increasing before peaking and falling to below current levels by 2050 and declining further in the second half of the century.

Carbon dioxide capture and storage (CCS) technologies could reduce the lifecycle GHG emissions of fossil fuel power plants. While all components of integrated CCS systems which exist and are in use today by the fossil fuel extraction and refining industry, CCS has not yet been applied at scale to a large, operational commercial fossil fuel power plant. For the large-scale future deployment of CCS, well-defined regulations concerning short- and long-term responsibilities for storage are needed as well as economic incentives. Barriers to large-scale deployment of CCS technologies include concerns about the operational safety and long-term integrity of CO₂ storage as well as transport risks. There is, however, a growing body of literature on how to ensure the integrity of CO₂ wells, on the potential consequences of a pressure build-up within a geologic formation caused by CO₂ storage (such as induced seismicity), and on the potential human health and environmental impacts from CO₂ that migrates out of the primary injection zone

Combining bioenergy with CCS (BECCS) offers the prospect of energy supply with large-scale net negative emissions which plays an important role in many low-stabilization scenarios, while it entails challenges and risks. These challenges and risks include those associated with the upstream large-scale provision of the biomass that is used in the CCS facility as well as those associated with the CCS technology itself.

4.5 Transport

The transport sector accounted for 27% of final energy use and 6.7 Gt CO₂ direct emissions in 2010, with baseline CO₂ emissions projected to approximately double by 2050. This growth in CO₂ emissions from increasing global passenger and freight activity could partly offset future mitigation measures that include fuel carbon and energy intensity improvements, infrastructure development, behavioural change and comprehensive policy implementation. Overall, reductions in total transport CO₂ emissions of 15-40% compared to baseline growth could be achieved in 2050. Technical and behavioural mitigation measures for all transport modes, plus new infrastructure and urban redevelopment investments, could reduce final energy demand in 2050 by around 40% below the baseline, with the mitigation potential assessed to be higher than reported in the 2007.

Projected *energy efficiency and vehicle performance improvements* range from 30-50% in 2030 relative to 2010 depending on transport mode and vehicle type. Integrated urban planning, transit-oriented development, more compact urban form that supports cycling and walking, can all lead to modal shifts as can, in the longer term, urban redevelopment and investments in new infrastructure such as high-speed rail systems that reduce short-haul air travel demand. Such mitigation measures are challenging, have uncertain outcomes, and could reduce transport GHG emissions by 20-50% in 2050 compared to baseline.

Exchange of fossil fuels for bio based fuels is a main technology here. Strategies to reduce the carbon intensities of fuel and the rate of reducing carbon intensity are constrained by challenges associated with energy storage and the relatively low energy density of low-carbon transport fuels. Integrated and sectorial studies broadly agree that opportunities for switching to low-carbon fuels exist in the near term and will grow over time.

Methane-based fuels (biogas) are already increasing their share for road vehicles and waterborne craft. Electricity produced from low-carbon sources has near-term potential for electric rail and short- to medium-term potential as electric buses, light duty and 2-wheel road vehicles are deployed. Hydrogen fuels from low-carbon sources constitute longer term options. Commercially available liquid and gaseous biofuels already provide co-benefits together with mitigation options that can be increased by technology advances. Reducing transport emissions of particulate matter (including black carbon), tropospheric ozone and aerosol precursors (including NO_x) can have human health and mitigation co-benefits in the short term.

The cost-effectiveness of different carbon reduction measures in the transport sector varies significantly with vehicle type and transport mode. The levelized costs of conserved carbon can be very low or negative for many short-term behavioural measures and efficiency improvements for light- and heavy-duty road vehicles and waterborne craft.

Increased use of *electric cars and vehicles* constitute a main option. Electric motors are much more energy efficient than combustion motors. The main difficulty lies in the limited performance of batteries. Until battery technology has improved the use of electric vehicles will probably be limited to shorter travels e.g. in cities. Still about 80% of car travels presently are shorter than 5 km.

Change in *mobility behaviour* is an important development. Thus the use of ICT for meetings, and distance work has increased tremendously with the increased use of computer networks and Internet, which reduced travelling. In the same vein we should point to the increased use of *public transport* in large cities. This also contributes to reduced use of the private car, which is the most difficult to replace when discussing low carbon travelling options. Regional differences influence the choice of transport mitigation options. Institutional, legal, financial and cultural barriers constrain low-carbon technology uptake and behavioural change. Established infrastructure may limit the options for modal shift and lead to a greater reliance on advanced vehicle technologies; a slowing of growth in light duty vehicle demand is already evident in some OECD countries. For all economies, especially those with high rates of urban growth, investment in public transport systems and low-carbon infrastructure can avoid lock-in to carbon-intensive modes. Prioritizing infrastructure for pedestrians and integrating non-motorized and transit services can create economic and social co-benefits in all regions.

Mitigation strategies, when associated with non-climate policies at all government levels, can help decouple transport GHG emissions from economic growth in all regions. These strategies can help reduce travel demand, incentivise freight businesses to reduce the carbon intensity of their logistical systems and induce modal shifts, as well as provide co-benefits including improved access and mobility, better health and safety, greater energy security, and cost and time savings.

4.6 Buildings

In 2010, the building sector accounted for around 32% final energy use and 8.8 Gt CO₂ emissions, including direct and indirect emissions, with energy demand projected to

approximately double and CO₂ emissions to increase by 50-150% by mid-century in baseline scenarios. This energy demand growth results from improvements in wealth, lifestyle change, access to modern energy services and adequate housing, and urbanisation. There are significant lock-in risks associated with the long lifespans of buildings and related infrastructure, and these are especially important in regions with high construction rates.

A main concern in this sector is the *heating of buildings* at least in cold climates. Presently most buildings use fossil fuel for heating, either coal, oil or gas. One option is to exchange the fuel used to biofuel. Well established is wood pellet, small balls of wood such as sawdust, which are easy to handle and can be treated almost as a liquid. Less comfortable but also in wide use is wood chips, especially for larger buildings. To go from heating individual buildings to district heating contribute with a considerable lower use of energy as efficiency is increasing. It is also connected to a considerable improvement in cleaning of flue gases. Heating power plants may use either forest wood waste (roots and branches) or wood chips. Other options are peat and household waste. Waste incineration may contribute some 5% of the energy budget of a country. District heating and waste incineration are recognised as the most efficient options for reducing energy in the building sector within the EU.

Other heating technologies which are increasing include *heat pumps*. These work as “reversed refrigerators” extracting heat from the outside air or ground or even water such as rivers and lakes. They are using electricity but close to 3-4 times more efficiently than direct heating with electricity. Solar heating by *solar panels* mounted on roofs of buildings may provide all hot water during a large part of the year. Solar panels are very common in southern Europe.

Improved insulation of buildings is just as important. For new buildings, the adoption of very low energy building codes is important and has progressed substantially since 2007. New buildings are improved by careful design, in *low energy buildings*. The cost is slightly higher but this investment is quickly coming back as the energy costs are much lower. *Passive houses* are buildings in which practically all heating needs are covered by internal sources, such as people and machinery. Passive houses are becoming more common in northern Europe, especially Germany, Denmark and Sweden.

Retrofits form a key part of the mitigation strategy in countries with established building stocks, and reductions of heating/ cooling energy use by 50-90% in individual buildings have been achieved. More typically retrofitting of older buildings to become more energy efficient most often reduce energy needs by 20-40%. Investments required are paid back typically after 7-9 years by reduced energy costs.

Lifestyle, culture and behaviour significantly influence energy consumption in buildings. A three- to five-fold difference in energy use has been shown for provision of similar building-related energy service levels in buildings. For developed countries, scenarios indicate that lifestyle and behavioural changes could reduce energy demand by up to 20% in the short term and by up to 50% of present levels by mid-century. In developing countries, integrating elements of traditional lifestyles into building practices and architecture could facilitate the provision of high levels of energy services with much lower energy inputs than baseline.

Most mitigation options for buildings have considerable and diverse co-benefits in addition to energy cost savings. These include improvements in energy security, health (such as from cleaner wood-burning cook stoves), environmental outcomes, workplace productivity, fuel poverty reductions and net employment gains.

Studies which have monetized co-benefits often find that these exceed energy cost savings and possibly climate benefits. Strong barriers, such as split incentives (e.g., tenants and builders), fragmented markets and inadequate access to information and financing, hinder the market-based uptake of cost-effective opportunities. Barriers can be overcome by policy interventions addressing all stages of the building and appliance lifecycles.

Adaption measures in this sector most importantly is not to allow buildings near water ways or on coasts. Flooding of rivers and water ways are becoming more common and buildings may then be flooded or in the extreme removed by the water masses. Buildings close to coasts may be flooded as sea level rise increases towards the end of the 21st century. Regulations on building sites have to include these concerns.

4.7 Industry

Emissions from industry accounted for just over 30% of global GHG emissions in 2010 and are currently greater than emissions from either the buildings or transport end-use sectors. There are big potentials to reduce the energy use in the industry sector. The energy intensity of the industry sector could be directly reduced by about 25% compared to the current level through the wide-scale upgrading, replacement and deployment of best available technologies, particularly in countries where these are not in use and in non-energy intensive industries. Additional energy intensity reductions of about 20% may potentially be realized through innovation. Barriers to implementing energy efficiency relate largely to initial investment costs and lack of information. Information programmes are a prevalent approach for promoting energy efficiency, followed by economic instruments, regulatory approaches and voluntary actions. Improvements in GHG emission efficiency and in the efficiency of material use, recycling and reuse of materials and products, and overall reductions in product demand (e.g., through a more intensive use of products) and service demand could, in addition to energy efficiency, help reduce GHG emissions below the baseline level in the industry sector.

Together these measures are part of the *Cleaner Production* (CP) approach. This is well established in the industrialised countries since the 1990s. Parts of CP are very simple to introduce, the so-called low-hanging-fruits. These include insulation of tubes and containers, covering of containers, simple adjustments of temperatures. The more advanced include recycling of process water or solvents, more efficient use of the raw materials in the process. Even more advanced are the development of the technologies used themselves and so-called green engineering.

Many emission-reducing options are cost-effective, profitable and associated with multiple co-benefits (better environmental compliance, health benefits etc.). In the long-term, a shift to low carbon electricity, new industrial processes, radical product innovations (e.g., alternatives to cement), or CCS (e.g., to mitigate process emissions) could contribute to significant GHG emission reductions. Lack of policy and experiences in material and product service efficiency are the major barriers.

CO₂ emissions dominate GHG emissions from industry, but there are also substantial mitigation opportunities for non-CO₂ gases. CH₄, N₂O and fluorinated gases from industry accounted for emissions of 0.9 Gt CO₂eq in 2010. Key mitigation opportunities include, e.g., the reduction of hydrofluorocarbon emissions by process optimization and refrigerant recovery, recycling and substitution, although there are barriers.

Systemic approaches and collaborative activities across companies and sectors can reduce energy and material consumption and thus GHG emissions. The application of cross-cutting technologies (e.g., efficient motors) and measures (e.g., reducing air or steam leaks) in both large energy intensive industries and small and medium enterprises can improve process performance and plant efficiency cost-effectively. Cooperation across companies (e.g., in industrial parks or in *industrial symbioses*) and sectors could include the sharing of infrastructure, information, and waste heat utilization.

Important options for mitigation in waste management are waste reduction, followed by re-use, recycling and energy recovery. Waste and wastewater accounted for 1.5 Gt CO₂eq in 2010. As the share of recycled or reused material is still low (e.g., globally, around 20% of municipal solid waste is recycled), waste treatment technologies and recovering energy to reduce demand for fossil fuels can result in significant direct emission reductions from waste disposal. Compostable waste may be used for biogas production while solid organic waste can be used for incineration, in both cases the management option is waste to energy. Landfilling of organic waste is since some years not allowed according to the EU waste directives.

4.8 Agriculture, Forestry and Other Land Use (AFOLU)

The AFOLU sector accounts for about a quarter (~10-12 Gt CO₂eq/year) of net anthropogenic GHG emissions mainly from deforestation, agricultural emissions from soil and nutrient management and livestock. Most recent estimates indicate a decline in AFOLU CO₂ fluxes, largely due to decreasing deforestation rates and increased afforestation. However, the uncertainty in historical net AFOLU emissions is larger than for other sectors, and additional uncertainties in projected baseline net AFOLU emissions exist. Nonetheless, in the future, net annual baseline CO₂ emissions from AFOLU are projected to decline, with net emissions potentially less than half the 2010 level by 2050 and the possibility of the AFOLU sectors becoming a net CO₂ sink before the end of century. AFOLU plays a central role for food security and sustainable development.

The most cost-effective mitigation options in forestry are afforestation, sustainable forest management and reducing deforestation, with large differences in their relative importance across regions. In agriculture, the most cost-effective mitigation options are cropland management, grazing land management, and restoration of organic soils. The economic mitigation potential of supply-side measures is estimated to be 7.2 to 11 Gt CO₂eq/year in 2030 for mitigation efforts consistent with carbon prices up to 100 USD/t CO₂eq, about a third of which can be achieved at a <20 USD/t CO₂eq. There are potential barriers to implementation of available mitigation options. Demand-side measures, such as changes in diet and reductions of losses in the food supply chain, have a significant, but uncertain, potential to reduce GHG emissions from food production. Estimates vary from roughly 0.76-8.6 Gt CO₂eq/year by 2050.

Bioenergy can play a critical role for mitigation, but there are issues to consider, such as the sustainability of practices and the efficiency of bioenergy systems. Barriers to large-scale deployment of bioenergy include concerns about GHG emissions from land, food security, water resources, biodiversity conservation and livelihoods. The scientific debate about the overall climate impact related to land use competition effects of specific bioenergy pathways remains unresolved.

Bioenergy technologies are diverse and span a wide range of options and technology pathways. Evidence suggests that options with low lifecycle emissions (e.g., sugar cane, *Miscanthus*, fast growing tree species, and sustainable use of biomass residues), some already available, can reduce GHG emissions; outcomes are site-specific and rely on efficient integrated 'biomass-to-bioenergy systems', and sustainable land-use management and governance. In some regions, specific bioenergy options, such as improved cook stoves, and small-scale biogas and bio-power production, could reduce GHG emissions and improve livelihoods and health in the context of sustainable development.

Adaptation measures are important and prevalent in this sector. Crops have to be adapted to higher temperatures, and perhaps also less water requiring species and varieties to maintain

food production. More efficient irrigation techniques may be needed in many regions, such as drip irrigation, as water scarcity starts to be felt. Land, which is close to water, risks being flooded and measures to increase the capacity of land surrounding the large rivers to store water are needed and already implemented in many countries. In other areas dams are built to protect land from being flooded. Measures may also be needed to reduce the dependency of this sector of fossil fuels, by turning to biofuels, or electricity which may be locally produced e.g. by solar electricity to wind energy fields.

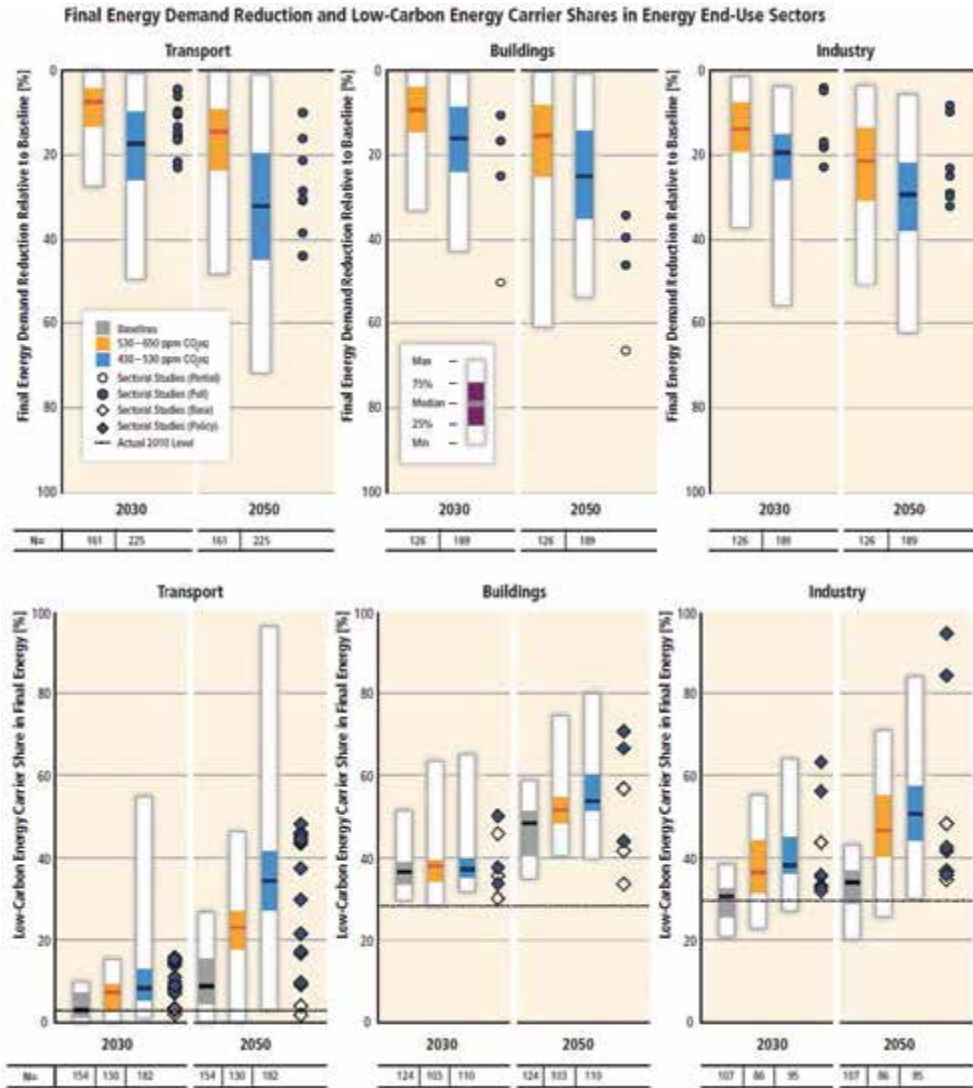


Figure 4.2. Final energy demand reduction relative to baseline (upper row) and low-carbon energy carrier shares in final energy (lower row) in the transport, (upper row) and low-carbon energy carrier shares in final energy (lower row) in the transport, buildings, and industry sectors by 2030 and 2050 in scenarios from two different CO₂eq concentration categories compared to sectorial studies. Low-carbon energy carriers include electricity, hydrogen and liquid biofuels in transport, electricity in buildings and electricity, heat, hydrogen and bioenergy in industry. The numbers at the bottom of the graphs refer to the number of scenarios included in the ranges which differ across sectors and time due to different sectorial resolution and time horizon of models.

4.9 Human Settlements, Infrastructure and Spatial Planning

Urbanization is a global trend and is associated with increases in income, and higher urban incomes are correlated with higher consumption of energy and GHG emissions. As of 2011, more than 52% of the global population lives in urban areas. In 2006, urban areas accounted for 67-76% of energy use and 71-76% of energy-related CO₂ emissions. By 2050, the urban population is expected to increase to 5.6-7.1 billion, or 64-69% of world population. Cities in developing countries generally have higher levels of energy use compared to the national average, whereas cities in industrialised countries generally have lower energy use per capita than national averages.

The next two decades present a window of opportunity for mitigation in urban areas, as a large portion of the world's urban areas will be developed during this period. Accounting for trends in declining population densities, and continued economic and population growth, urban land cover is projected to expand by 56-310% between 2000 and 2030. Mitigation options in urban areas vary by urbanization trajectories and are expected to be most effective when policy instruments are bundled. Infrastructure and urban form are strongly interlinked, and lock-in patterns of land use, transport choice, housing, and behaviour. Effective mitigation strategies involve packages of mutually reinforcing policies, including co-locating high residential with high employment densities, achieving high diversity and integration of land uses, increasing accessibility and investing in public transport and other demand management measures.

The largest mitigation opportunities with respect to human settlements are in rapidly urbanizing areas where urban form and infrastructure are not locked in, but where there are often limited governance, technical, financial, and institutional capacities. The bulk of urban growth is expected in small- to medium-size cities in developing countries. The feasibility of spatial planning instruments for climate change mitigation is highly dependent on a city's financial and governance capability.

Thousands of cities are undertaking climate action plans, but their aggregate impact on urban emissions is uncertain. There has been little systematic assessment on their implementation, the extent to which emission reduction targets are being achieved, or emissions reduced. Current climate action plans focus largely on energy efficiency. Fewer climate action plans consider land-use planning strategies and cross-sectorial measures to reduce sprawl and promote transit-oriented development.

Successful implementation of urban-scale climate change mitigation strategies can provide co-benefits. Urban areas throughout the world continue to struggle with challenges, including ensuring access to energy, limiting air and water pollution, and maintaining employment opportunities and competitiveness. Action on urban-scale mitigation often depends on the ability to relate climate change mitigation efforts to local co-benefits.

Adaptation measure in this sector is dominated by actions to reduce the risk for flooding, by building the proper infrastructure and protecting existing one. Many cities are close to coasts and this constitute a special challenge as sea water level is rising. Building of dams and other protection measures have started or is planned in many large and old, even ancient, cities.

Chapter 4 sources:

This chapter builds on and includes edited and shortened excerpts from the Summary for Policy-makers from the IPCC's Fifth Assessment Report (AR5) Working Group III published in April 2014. <http://mitigation2014.org/>. Some updating has been added.

Chapter 5

United Nations Climate Convention

5.1 International cooperation for the environment

The origins of present day international co-operation on environment and sustainable development go back to the late 1960s, when Sweden took the initiative to place the issue of environment on the agenda of the United Nations. The background was an increasing awareness in the scientific community about the serious nature of the negative environmental side-effects of the technological and scientific advances after the Second World War. The initiative also reflected a realization that environmental problems did not stop at national borders, nor did regional cooperation suffice to deal with them. Sweden thus proposed that a global United Nations Conference be convened to increase awareness about the implications of this situation among governments and the public at large and to identify those problems which could only, or best, be solved through international co-operation.

The United Nations Conference on the Human Environment convened on 5 June 1972 in Stockholm. This day in June is now yearly celebrated as the World Environment Day. The motto of the Conference was “Only One Earth,” a revolutionary concept for its time. The conference was attended by 113 countries at the ministerial level and by representatives of many international organisations. In the 1980s Sweden took up the recommendation of the Stockholm Conference to convene another conference on the human environment. This time, on the advice of the Brundtland Commission, a shift in emphasis was proposed to clearly underline the relationship between environment and development. In 1989 the UN General Assembly decided to convene in 1992 the United Nations Conference on Environment and Development (UNCED).

In spite of the progress generated through the processes set up in Stockholm, the global conditions were much worse in 1992. World population had increased by 1.7 billion to more than 5 billion. Almost 500 million acres of trees had been lost in the preceding 20 years. Chemical substances had damaged the ozone layer and deserts were rapidly expanding. The climate change problems had also begun to receive serious attention.

In contrast to Stockholm, the Rio Conference was a summit, attracting some 120 Heads of State of Government. Altogether, 178 countries participated. In an important change of direction, the United States which had played a leading role 20 years before, this time took a defensive position. The Conference became a success. It adopted three documents, the Rio Declaration, Agenda 21, and the Statement of Forest Principles. It also adopted two global conventions, the Convention on Climate Change and the Convention on Biological Diversity. During the period described, from the 1960s to today more than 200 global conventions have been set in place. *Conventions* are legally binding instruments, containing commitments by States. They have to be ratified by the legislative organs of each signatory state. Each convention is governed by a Conference of the Parties (COP) and is serviced by a secretariat. (The Climate Convention secretariat is located in Bonn, Germany.) UNEP (UN Environmental Programme) has a special role in many cases to provide administrative and other kinds of support. The undertakings in the conventions are often amplified by special protocols that contain more detailed and, at times time bound, commitments.

Box 5.1. Conventions and their structure

Rules for global conventions are legally binding agreements, containing commitments by states, which make part of international law. How a convention is set up, supervised and ratified, as well as how states join a convention and leave it is today regulated in the so-called 1969 Vienna Convention. Conventions that are considered part of customary law becomes binding to all states, and conventions are thus a forceful part of international law. The United Nation Secretary General serves as the depositary of international conventions.

Global conventions are the results of extensive, often several year long, negotiations between many, often up to some 100, states. After the negotiators have come to an agreement the text of the convention is signed by representatives of the governments and later ratified by the legislative organs of each signatory state, most often the parliament. When the specified number of ratifications have been reached the convention enters into force.

Today more than 200 global conventions are in place. Each convention is governed by a Conference of the Parties (COP) which meets regularly. It is serviced by a Secretariat which handles the legal procedures, e.g. to oversee that the participating states follow binding commitments, and a secretariat that work with the practical implementation. The undertakings in the conventions are often amplified by special Protocols that contain more detailed and, at times, binding commitments. Very often further resources, such as technical committees, research laboratories, etc., are set up to work with the issues of the convention, such as monitoring, forecasting, etc. The secretariats and other mechanisms of the global conventions are normally financed through obligatory contributions by the parties according to a scale of assessment of the United Nations.

5.2 The climate issue

At the Rio conference, two global conventions were opened for signature, the *UN Framework Convention on Climate Change* (UNFCCC) and the *UN Convention on Biological Diversity* (CBD). This was followed a few years later by the *UN Convention to Combat Desertification* (UNCCD). As the perception of global threats to the environment became stronger in the 1980s, the climate change issue came increasingly into focus. Several international conferences were held, and towards the end of the decade, UNEP and WMO (World Meteorological Organisation) took an initiative that had a major impact on subsequent events. They created jointly the *Intergovernmental Panel on Climate Change* (IPCC). The Panel is composed of the world's most competent climate scientists, but it has also sought to incorporate representatives of governments and experts in the social sciences. It has to be recognized though, that it is in the framework of natural science that the Panel has commanded greatest authority. The purpose of the Panel has not been to carry out research on its own, but to monitor and evaluate existing research, adding its own conclusions and presentations for policy makers.

In this respect, the Panel has been very successful. Under the guidance of its first Chairman, the Swedish scientist Bert Bolin, the assessment reports of IPCC have greatly influenced the climate negotiations and been instrumental in launching the Framework Convention on Climate change (FCCC). The IPCC first assessment report appeared in the autumn of 1990. It stated that the process of global warming, created by what was known as the enhanced greenhouse effect through the accumulation of carbon dioxide and other greenhouse gases in the atmosphere, could lead to an increase of temperature in the Earth's atmosphere by 1.5 to 4.5 degrees centigrade towards the end of the 21st century. The IPCC

statements carried great authority as the mainstream opinion by the great majority of climate experts. Up to the present five Assessments Reports (AR) have been issued, the latest, AR5 in 2013-14. Already since the second assessment report, that appeared in 1995-96, IPCC concluded that there was now beyond doubt a human impact on climate was caused by the increased emissions of greenhouse gases since the beginning of industrialization.

Governments demonstrated that they took global warming seriously by engaging in the negotiations on the Climate Convention. These were concluded in May 1992 after a surprisingly rapid negotiation, which was closely linked to the preparation of the 1992 Rio Conference on Environment and Development. During the Rio Conference 153 states signed the Convention, which entered into force in early 1994, after ratification by the required 50 states. The commitments of the Convention were to a large extent of a procedural nature, but for the industrialised countries, known in Convention language as Annex I states, there was a commitment in principle to stabilize greenhouse gas emissions at 1990 levels by the end of the decade.

Box 5.2. The United Nations Framework Convention on Climate Change (UNFCCC)

The ultimate objective of the Convention is to stabilize greenhouse gas concentrations “at a level that would prevent dangerous anthropogenic (human induced) interference with the climate system.” It states that “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.”

The idea is that, as they are the source of most past and current greenhouse gas emissions, industrialized countries are expected to do the most to cut emissions on home ground. They are called Annex I countries and belong to the Organization for Economic Cooperation and Development (OECD). They include 12 countries with “economies in transition” from Central and Eastern Europe. Annex I countries were expected by the year 2000 to reduce emissions to 1990 levels. Industrialized nations agree under the Convention to support climate change activities in developing countries by providing financial support for action on climate change - above and beyond any financial assistance they already provide to these countries. A system of grants and loans has been set up through the Convention and is managed by the *Global Environment Facility*, GEF. Industrialized countries also agree to share technology with less-advanced nations.

The UNFCCC entered into force on 21 March 1994. Today, it has near-universal membership. The 195 countries that have ratified the Convention are called Parties to the Convention.

Source: http://unfccc.int/essential_background/convention/items/6036.php

5.3 The climate negotiations and the Kyoto Protocol

At the first Conference of the Parties, COP-1, held in Berlin in 1995, it was decided that these commitments were not sufficient or adequate, and a separate negotiation was launched with the aim of reaching agreement on a Protocol with more precise commitments for Annex I states, within specified timeframes. In Berlin it was also confirmed that the process would not introduce any new commitments for developing countries, reflecting the principle of common but differentiated responsibilities.

The decision became known as the *Berlin Mandate*, and it opened a period of intense negotiation up to December 1997, when the third Conference of the Parties after a difficult session concluded the *Kyoto Protocol*, named after the Japanese city where the Conference was held. The Kyoto Protocol introduces commitments of a new nature for industrialised

countries, giving a much more concrete legally binding character than the Convention itself. It thus contains provisions for follow-up and compliance, which open the way for a real legal regime. However, it was not possible in the short time available to agree on all details in the Protocol, and therefore important negotiations continued in the period after Kyoto, leading up to the sixth Conference of the Parties in the Hague in November 2000. The main quantitative commitments in the Kyoto Protocol relate to the period 1990-2010, or rather to an end point defined as an average of the years 2008/2012. Industrialised countries committed themselves to reduce emissions of greenhouse gases during the period with an average of 5.2 percent. The European Union commitment was -8%, that of USA -7% and that of Japan -6%. The commitments were based on a principle of equal effort, taking into account previously undertaken reductions and more general economic considerations.



Figure 5.1. The Kyoto conference.

An unidentified Australian member of the World Wide Fund for Nature (WWF) delegation covers his face with a paper bag to show his shame over his own country's disappointing proposal. The event took place during a press conference at the COP3 conference on global warming in Kyoto, Japan, Monday, Dec. 1, 1997. However the 10-day meeting resulted in an agreement on a protocol for measures to halt global warming. (Photo: Koichi Yamada/ Pressens Bild.)

The agreement would not have been possible without the perspective of softening the commitments with elements that would make it easier to achieve the targets. These refer mainly to the so-called flexible mechanisms, that is, a system of crediting emission reductions achieved abroad through co-operation on such projects as improving efficiency in power plants through what is known as Joint Implementation (JI) or through trading in emission reductions. Negotiations on these rules, which could also apply to developing countries, has been part of the so-called Clean Development Mechanism (CDM). The three Kyoto mechanisms, *International Emissions Trading*, *Joint Implementation*, and the *Clean Development Mechanism*, allow for flexibility in the implementation of the emission reduction efforts. Another element of further negotiations were the rules relating to *sinks and reservoirs*, based on the fact that the ground, and in particular growing forests, absorb carbon.

This carbon cycle is still not well-known, and therefore the rules were restrictive during the first commitment period. Nevertheless, a well-designed system could help sustainable forest management. The arguments around the mechanisms and the rules on sinks have centred around the risk that they would make it too easy to reach the Kyoto targets and thus reduce the credibility of the Kyoto Protocol, and in particular the strong signal effect it has had on actors on the global market, that governments are really taking the greenhouse effect seriously.

The European Union has underlined that there must be no loopholes in the system, whereas the United States and others have emphasised the need for an efficient market-based system, reflecting the principle of cost-effectiveness. Still the new Bush administration declared that the United States would not ratify the Kyoto Protocol. The EU under the Swedish Presidency reacted strongly and stated that the Union and its members would go along with ratification anyway, expecting that other Annex I parties would join in such a way that the required target for entry into force would be met.

At the resumed Conference of Parties, COP-6 in Bonn, a political agreement was reached which will enable countries such as Japan, Canada, and Russia to begin their ratification process. However the agreement meant some weakening of the Kyoto targets in introducing more flexibility in the calculations of sinks and the use of the mechanisms. This was a reasonable price to pay for saving the Kyoto process. Furthermore, important decisions were taken with regard to support for developing countries including assistance for adaptation to climate change.

A number of remaining technical details were finally settled at COP-7 in Marrakesh in October 2001. This first Conference of the Parties in an African country also took important further steps on linkages to the other global conventions, and on transfer of technology and capacity-building in favour of developing countries. The Kyoto Protocol finally enter into force in 2005 after the Russian Federation had signed. Australia ratified the Kyoto Protocol in 2007, while Canada, as more conservative government took power, left the Kyoto protocol in 2011. At the same time the Russian Federation and Japan announced that it would not take on new responsibilities for reduction of emissions of GHGs.

It is not surprising that negotiations have been difficult. Measures to respond to climate change go straight into the heart of our industrial civilization, involving basic questions related to transports or energy. Important economic and social interests are at stake, and the complexity of the regime is daunting. The climate issue makes concrete a number of the more general aspects involved in the discussions and negotiations on sustainable development, and it is sometimes very difficult to see the way forward. Nevertheless it is encouraging that the international community over a short period of time has managed to seriously tackle a long-term survival issue in a serious manner.

5.4 Implementing the Kyoto Protocol

The Kyoto protocol states that by 2010 (as the average of the 2008-2012 window), the parties should have decreased their CO₂ emission by an average of 5.2% as compared to the chosen base year of 1990. The commitments were unevenly distributed and for the European Union members it was -8%, for the USA -7% and Japan -6%. The Kyoto protocol entered into force on the 16th of February 2005 after the Russian Federation had ratified the protocol as one of more than 150 States. Thereby countries, representing the requested 55% of the 1990-emission of CO₂, had ratified the protocol, which was made a precondition for its entering into force. The USA, at the time responsible for about 35% of the global CO₂-emission, was

and is the only major state, which has not ratified the protocol. Later China, after considerable increase of energy use, has become the second largest emitter of GHGs in the world. Neither USA nor China have joined the Protocol.

At the COP-11 in Montreal, Canada in 2005, a sanction system was outlined making the Climate Convention close to becoming a real global legal regime. The COP in Montreal also was the first Meeting of the Parties to the Kyoto Protocol (MOP1).

The first commitment period of the Kyoto Protocol thus started in 2005 and was concluded in 2012. 37 industrialized countries and the European Community (the European Union-15, made up of 15 states at the time of the Kyoto negotiations) committed themselves to binding targets for GHG emissions. The targets applied to the four greenhouse gases carbon dioxide, methane, nitrous oxide and sulphur hexafluoride, and two groups of fluorinated gases, hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). The six GHGs are translated into CO₂ equivalents, CO₂eq, in determining reductions in emissions.

The then 15 EU member states had agreed on a reduction in CO₂ emissions of 8% by 2008-2012 compared to the 1990 base line. These obligations were subsequently distributed among the member states with variations from reductions of e.g. 21% (Germany and Denmark) and 15-27% (Spain, Greece and Portugal). The 10 new member states from 2010 got between 6% and 8% reduction targets relative to the 1990-base line. As these countries have seen a profound economic restructuring over the 1990s with closure of a number of energy consuming industries, this reduction has been met – and more so – by this very economic restructuring.

The Protocol was in great danger to be cancelled after this first commitment period, but at the 17th Conference of the Parties (COP17) in Durban, Republic of South Africa, in 2011 governments agreed to a second term of the Kyoto Protocol.

The agreement came into force in January 2013. The 194 parties to the UN's Nations Framework Convention on Climate Change took almost an entire extra day to thrash out the agreement. The launch of the much-anticipated *Green Climate Fund*, after a year of waiting, was also announced. This, and the Kyoto Protocol extension, falls under a new set of decisions known as the *Durban Platform*. The following year at the COP18 in Doha, Qatar, an agreement was reached to extend the Protocol to 2020 and to set a date of 2015 for the development of a successor document, to be implemented from 2020.

The outcome of the Doha talks has received a mixed response. The Kyoto second commitment period applies to about 15% of annual global emissions of greenhouse gases. The countries joining a second commitment period of the Protocol were Australia, the EU, Croatia, Iceland, Liechtenstein, Monaco, Norway and Switzerland. Major emitters such as China, the USA, Russia, India, Japan, Brazil, Canada, Mexico, Indonesia, South Korea and South Africa announced politically binding reduction targets to be achieved by 2020 under the Climate Convention, but not as part of the Protocol. No targets have so far been agreed for the second commitment period. The European Union has however announced that its goal is to reduce GHG emission by 20%, counted from 2012 as the base line year, to 2020.

5.5 The European Union Climate policy

The European Union has from the early stages of Climate negotiations been a forerunner in climate policies. The European Commission took its first climate-related initiatives in 1991, when it issued the first Community Strategy to limit carbon dioxide emissions and improve energy efficiency. From the first Climate Convention Conference of Parties (COP) in Berlin 1995 the EU countries, then 15 of them, negotiated together as a single actor. Today the

number have increased to 28, to which should be added the four countries which work together with the Union as members of the European Economic Area, EEA. In 1997 at the COP3, the EU was at the forefront to develop the Protocol and implemented it forcefully the following years as the EU Emission Trading Scheme, ETS.

EU leaders have committed themselves to transform Europe into a highly energy-efficient, low carbon economy. The EU has set itself targets for reducing its greenhouse gas emissions progressively up to 2050. To achieve this the Union has introduced a series of Directives and Regulations related to the climate issue on energy production, industry, mobility etc. The policy is described in the European Climate Change Programme (ECCP), the Emissions Trading Scheme (ETS), the National Emission Ceilings (NEC) Directive, and the Carbon Capture and Storage (CCS) Directive. A second European Climate Change Programme (ECCP II) was launched in October 2005.

With the exception of carbon dioxide trading, legislation in this area is rather weak and development is mostly promoted through policy actions and support programmes. There is, however, the Council Directive on limiting carbon dioxide emissions by improving energy efficiency (SAVE), and the Communication from the Commission called Energy Efficiency in the European Community - Towards a strategy for the rational use of energy.

A number of Directives concern energy use and efficiency. These include

- Directive 2001 on the electricity production from renewable energy sources,
- Directive 2002 on the energy performance of buildings,
- Directive 2004 on the promotion of cogeneration in power plants,
- Communication 2007 on reduction of CO₂ emissions from cars to 120 g/km by 2012

In 2007 the European Council adopted an energy policy for Europe, aiming at saving energy and promoting climate-friendly energy sources. EU leaders set a firm target of cutting 20% of the EU's greenhouse gas emissions by 2020. In addition it says that the EU is willing to increase this goal up to 30% if the US, China and India make similar commitments. EU leaders also set a binding overall goal of 20% for renewable energy sources by 2020, compared to the 6.5% in 2011.

A binding minimum target of 10% for the share of biofuels in overall transport petrol and diesel consumption by 2020 was also set. This is together the so-called 20-20-20 strategy to be achieved by the year 2020:

- 20% reduction of emissions
- 20% renewable energy
- 20% increased energy efficiency

In the climate and energy policy framework for 2030, the European Commission proposes that the EU set itself a target of reducing emissions to 40% below 1990 levels by 2030. For 2050, EU leaders have endorsed the objective of reducing Europe's greenhouse gas emissions by 80-95% compared to 1990 levels as part of efforts by developed countries as a group to reduce their emissions by a similar degree.

The European Commission have developed adaptation strategies to help strengthen Europe's resilience to the inevitable impacts of climate change. It says that reigning in climate change carries a cost, but doing nothing would be far more expensive in the long run. Moreover, investing in green technologies that cut emissions will also boost the economy, create jobs and strengthen Europe's competitiveness.

The fight against climate change is increasingly being reflected in other policy areas. To further advance this "mainstreaming" process, the EU has agreed that at least 20% of its €60

billion budget for the 2014-2020 period should be spent on climate change-related action. This is on top of climate finance from individual EU Member States. This budget marks a major step forward in transforming Europe into a clean and competitive low-carbon economy. As the world's leading donor of development aid, the EU also provides substantial funding to help developing countries tackle climate change. It gave just over €7.3 billion in “fast start” financing to developing countries over 2010-2012 and is continuing to provide climate finance every year.

5.6 A global climate agreement

From the beginning of the Climate Convention the goal was to establish a global agreement on reduction of emissions of greenhouse gases. This turned out to be very difficult. An agreement in the United Nations Conventions requires consensus. To arrive to a consensus between more than 190 states is not easy. It is enough that two or three have different interests and see themselves as unable to agree. These are typically states whose economy is very much dependent on fossil fuel trading and/or use and see themselves as unable to follow a proposed reduction.

The first serious efforts to forge a global agreement are connected to the development of the Kyoto Protocol. However several main emitters did not take part in the Protocol and the Protocol itself got weaker as the negotiations of it was concluded by 2005.

A series of COPs then led up to the COP15 in Copenhagen in 2009. The Copenhagen Conference raised climate change policy to the highest political level. Close to 115 world leaders attended making it one of the largest gatherings of world leaders ever outside UN headquarters in New York. More than 40,000 people, representing governments, nongovernmental organizations, intergovernmental organizations, faith-based organizations, media and UN agencies attended. A global agreement was meticulously prepared and expectations were high to have it adopted. In spite of the presence of world leaders, including US President Obama, EU leaders among them Angela Merkel and Nicolas Sarkozy, and European Union Commission President Jose Manuel Barroso, the agreement failed and many felt a great disappointment. Instead the so-called *Copenhagen Accord* was signed. The Accord contained several key elements in which the views of governments converged. Most importantly it included the long-term goal of limiting the maximum global average temperature increase to no more than 2 degrees Celsius above pre-industrial levels, subject to a review in 2015. There was, however, no agreement on how to do this in practical terms. It was far from a protocol.

At the following COP-16 in Cancun, Mexico, the Copenhagen Accord was formalized to become the *Cancun Agreement*, including the development of new reporting rules to significantly improve the transparency of developing country emissions and actions. After the disappointment with the Copenhagen COP the international community had to find a new starting point. It was created at the COP 17 in Durban, South Africa, in 2011. First of all after tough talks a number of member states agreed to establish a second commitment period of the Kyoto Protocol (2013-2020). Secondly the meeting agreed to start a new process for a global agreement applicable to all Parties to be signed by 2015 at the COP21 in Paris and to take effect from 2020.



Figure 5.3 COP15 in Copenhagen 2009. President Barack Obama briefs European leaders, including British Prime Minister Gordon Brown, French President Nicolas Sarkozy, EU President Swedish Prime Minister Fredrik Reinfeldt, German Chancellor Angela Merkel, European Union Commission President Jose Manuel Barroso, and Danish Prime Minister Lars L. Rasmussen, following a multilateral meeting at the United Nations Climate Change Conference in Copenhagen, Denmark, Dec. 18, 2009. Photo by Pete Souza.

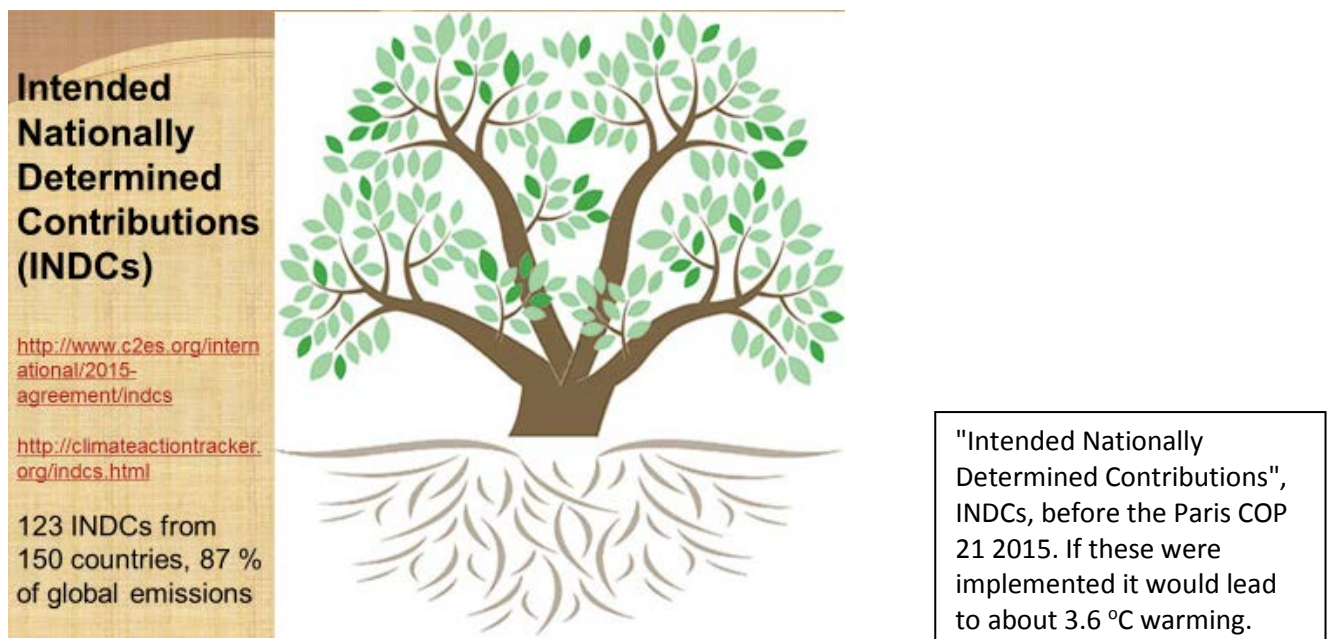
This so called *Durban Platform for Enhanced Action* (ADP) has since then been the main focus for international climate policy development. It was in focus at the Rio+20 Meeting in 2012 on Sustainable Development where the document *The Future We Want* was the main document. At the COP 19 in Warsaw 2013 member states agreed to announce nationally determined contributions for the post-2020 period well in advance of the Paris COP. At the COP20 in Lima in 2014 work was done to elaborate the elements of the new global agreement. Most importantly rules on how all countries can submit contributions to the new agreement during the first quarter of 2015 were set. These Intended Nationally Determined Contributions (INDCs) will form the foundation for climate action post 2020 when the new agreement will take effect.

A most remarkable extra meeting, the UN Climate Summit, supported this process. On the 23rd of September 2014 the UN Secretary General Ban Ki-Moon gathered world leaders from government, finance, business, and civil society to New York with the intention to “ask these leaders to bring bold announcements and actions to the Summit that will reduce emissions, strengthen climate resilience, and mobilize political will for a meaningful legal agreement in 2015”.



Figure 5.4 Peoples Climate March New York 21st of September 2014

The meeting was supported by an enormously large manifestation, *Peoples Climate March*, on the streets of New York as a hundred thousand people marched to support the Climate meeting, together with similar manifestations in hundreds of cities around the world. New commitments, new ideas, and new financing for significant actions to address the challenge of climate change dominated the announcements made by more than 100 Heads of State and Government and leaders from the private sector and civil society. Most remarkable is that several institutional investors, including large asset managers and pension funds, announced that they will reduce the carbon footprint of US\$ 100 billion of institutional investments by *divesting in fossil fuel companies*. We may have come to a stage where investing in a fossil fuel based economy is a risk rather than an asset. May be this is a precondition for success in combatting climate change. (<http://www.un.org/climatechange/summit/>). It appears that finally the forces supporting a global climate agreement finally will be the stronger and the result will come in Paris in 2015.



5.7 The Paris agreement

The two following COPs, COP 19 in Warsaw, Poland on November 2013 and COP 20 in Lima, Peru in December 2014, were much devoted to prepare for COP 21 in Paris. In Lima the EU delegation announced its policy towards a legally binding 40% drop in emissions by 2030 against carbon output in 1990 as baseline. At the same time the oil producing countries increased the oil production and oil became cheaper than it had been for years.

The strategy to build an agreement from below, rather than negotiate a top down resolution was introduced these years. Each member states were encouraged to decide on how much reduction of GHGs they were prepared to take on and announce that prior to the Paris COP. These were called "Intended Nationally Determined Contributions", INDCs. For example, the EU's INDC was based on the mentioned commitment to a 40 percent reduction in emissions by 2030 compared to 1990. These suggested commitments were estimated to limit global warming to 2.7 to 3.6, degrees Celsius by 2100.

The COP 21 was held in Paris from 30 November to 12 December 2015. After two weeks of negotiations and some tough exchanges between the parties, the conference finally could conclude the so-called *Paris Agreement*, a global agreement on the reduction of climate

change, the text of which represented a consensus of the representatives of the 196 parties attending it.

The key result was a goal of limiting global warming to "well below 2° Celsius and "pursue efforts to" limit the temperature increase to 1.5 °C compared to pre-industrial levels". The agreement called for zero net anthropogenic greenhouse gas emissions to be reached during the second half of the 21st century. The 1.5 °C goal will require zero emissions sometime between 2030 and 2050, according to some scientists.

The agreement establishes a "global stock take" which revisits the national goals to "update and enhance" them every five years beginning 2023. However, no detailed timetable or country-specific goals for emission reductions were incorporated into the Paris Agreement - as opposed to the previous Kyoto Protocol. The Paris Agreement, was thus not a "protocol", it did not include binding obligations from the parties on amount of fossil fuel use reductions or time limits. From that point of view it was a disappointment for many. It should also be noted that the announced INDCs would be far from sufficient to achieve the goals of the agreement of 2.0 or even 1.5 degrees Celsius.



The agreement entered into force on the 22 April 2016 (Earth Day), when the required 55 countries together representing at least 55 percent of global greenhouse emissions had signed. In fact 174 countries signed the agreement in New York, and began adopting it within their own legal systems through ratification, acceptance, approval, or accession.

The COPs following the Paris COP21 have been much devoted to the issue of how to implement the Paris Agreement and make it practical. The COP 23 in Katowice Poland were close to a failure but eventually the parties could agree on basic rules on how to monitor the Paris Agreement, which will come into force in 2020. The "rulebook" that now exists defines how governments will measure and report on their emissions-cutting efforts. However, due to difficulty to reach agreement between parties, questions remain, such as ways to scale up existing commitments on cutting emissions, ways to provide financial help for poor countries, and these were postponed to the next conference.

Just before the conference in Katowice, in October 2018, on request of the FCCC, the Intergovernmental Panel on Climate Change (IPCC) published its Special Report on Global

Warming of 1.5 °C (SR15). It is perfectly clear from this report that the difference between 1.5 °C and 2.0 °C warming is big, as illustrated by the estimate that at the lower temperature the worlds coral reefs will decline by 50 %, but at the higher temperature they will be close to 100 % gone. The World Meteorological Organization released a report stating that at the time of the conference atmospheric carbon dioxide levels had reached 415 parts per million (ppm), a level not seen in three to five million years.

In spite of its results a reaction after Paris COP15 and following COPs is an awareness that the international negotiations are too slow, have too great difficulties to reach consensus, which is now required, and will be insufficient to achieve what is needed. It is also clear that to achieve the INDCs states have to rely on so-called negative emissions, that is, using fossil fuels without causing emissions of CO₂, e.g. by CCS, which means storing the resulting CO₂ underground. At the scale required it seems quite unrealistic.

In the end it appears that the required reduction of GHGs emission will in many ways rely on what can be done on lower levels, the EU, the national states, the local authorities and individuals.

Chapter 5 sources:

This chapter includes excerpts from Chapter 23 of the book *Environmental Science* of the Baltic University Programme authored by Bo Kjellén, <http://www.balticuniv.uu.se/index.php/boll-online-library#environmental-science>; as well as excerpts from Chapters 10 and 11 in the book *Environmental Management volume 1 Environmental Policy - Legal and Economic Instruments* of the Baltic University Programme authored by Børge Klemmensen and Lars Rydén. <http://www.balticuniv.uu.se/index.php/boll-online-library/826-em-1-environmental-policy-legal-and-economic-instruments->

It also includes information from the European Union websites on Climate Policies <http://ec.europa.eu/clima/policies/brief/eu/>

A series of excerpts from the UNFCCC COPs websites have also been used.

Information on the Paris Agreement and the following COPs have been extracted from the Internet and Wikipedia.

Chapter 6

Climate and Energy policies in the Baltic Sea region

6.1 Climate and energy policy in the European Union (EU)

The Baltic Sea region countries are all parties to the United Nations Framework Convention on Climate Change (UNFCCC), and the Kyoto Protocol. Except Russia they are also EU member states and thus obliged to adopt the EU policy framework (280/2004/EC) and its 20-20-20 targets. This chapter provides an overview of the existing data for emissions of greenhouse gases from the countries in the region and relates this to the sources, such as the energy and transport sectors, as well as existing efforts to improve energy efficiency and renewable energy infrastructure.

Annual greenhouse gas (GHG) emissions are estimated and reported under the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol and the The 'Kyoto basket' includes six gases: carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF₆). The impact of land use, land use changes and forestry (LULUCF) on the GHG inventories is excluded. International aviation is included. Emissions are weighted according to the global warming potential of each gas, and a CO₂ equivalent (CO₂ eq.) is calculated.

The European Union states divided the Kyoto obligations of reduction of emissions between themselves unequally, depending on economy and level of emissions. Based on the COP3 in Kyoto EU established a cap and trade system for CO₂, called European Trading System, ETS. In this system a number of major European industries, about 11 000 covering around 45% of the EU's greenhouse gas emissions, have been given allowances (rights) to emit specified amounts of CO₂. Those emitting more have to buy additional rights and those, which can reduce their emissions may finance the costs of the investments needed by selling emission rights. The third trading period, 2013-2020, include more GHGs, especially methane and nitrous oxide, more sections especially air traffic, and reduced allowances of emission rights. In 2020, emissions from sectors covered by the system will be 21% lower than in 2005, the year it started. Emission rights, although increasing, are still too cheap – in January 2019 25 Euro - for ETS to be effective. A fourth trading period 2021-2030 is foreseen.

The overarching policy initiative in the energy sector in the BSR is the European Union 2020 Growth Strategy. The EU 2020 Strategy lists three targets to be reached by 2020 in the 'Climate and Energy Package' (CEP). These are

- 20 % lower GHG emissions,
- 20 % of energy production should stem from renewable energy sources
- 20 % increase in energy efficiency.

The 20-20-20 targets provides the means to pursue a low-carbon economy across the EU. The CEP provides a set of binding legislation to ensure that the EU meets its climate and energy targets for 2020, but gives considerable freedom to EU member states on how they can achieve their targets. The CEP does not address the energy efficiency target directly as this is achieved via the EU Energy Efficiency Directive.

The CEP comprises four pieces of complementary legislation for the 20-20-20 targets:

- (I) *reform of the EU Emissions Trading System (EU ETS)*, which should cut industrial GHG emissions cost-effectively;
- (II) *national targets for non-EU ETS emission*, in which Member States (MS) have taken on binding annual targets for reducing their GHG emissions from the sectors not covered by the EU ETS (e.g. housing, agriculture, waste and transport); national targets are differentiated according to member states relative wealth: they range from a 20 % emissions reduction (compared to 2005) by the richest to a 20 % increase by the least wealthy;
- (III) *national renewable energy targets*, under the Renewable Energy Directive Member States have taken on binding national targets for raising the share of renewable energy in their energy consumption by 2020. These targets reflect different starting points and potential for increasing renewable production in the member states.
- (IV) *carbon capture and storage*, a legal framework has been created for the environmentally safe use of carbon capture and storage technologies. Carbon capture and storage involves capturing the carbon dioxide emitted by industrial process and storing it underground geological formations where it does not contribute to global warming.

Long term trends and projections estimates that EU is making good progress towards these climate and energy targets: the EU's energy consumption decreased faster between 2005 and 2012 than required to achieve the 2020 energy efficiency target, the 2012 share of renewable energy sources (RES) was above interim target levels, and 2013 levels of GHG emissions were already very close to the 20 % reduction target, seven years ahead of the 2020 deadline. Recent developments, however, is less optimistic.

The CEP package constitutes an essential tool to pursue a low carbon economy and to combat climate change. It also constitutes a part of the attempt to mainstream Sustainable Development (SD) across the EU. The EU Strategy for SD, revised in 2009, laid out the foundations for a sustainable future built on smart, sustainable and inclusive growth. Though the objective of SD has been mainstreamed into a range of policies, unsustainable trends persist in several areas in the EU. Since the EUSDS has been viewed as not having sufficient influence on EU policies (Council of the European Union 2009), the EU 2020 Strategy has been suggested as an effective tool for delivering SD in the EU.

In 2014, the European Union agreed on the so-called 2030 framework for Climate and Energy Policies. A focal point of the framework is the binding target to reduce EU domestic GHG emissions by at least 40 % below the 1990 level by 2030, and increase the share of renewable energy to at least 27 % as well as increase energy efficiency by at least 27 %. The 2030 framework also proposed a new governance framework based on national plans for competitive, secure and sustainable energy as well as a set of key indicators to assess progress over time.

In addition to the 2020 Strategy and the 2030 targets there are a number of policy initiatives and frameworks which support the EU climate and energy policy. The European Union Strategy for the Baltic Sea Region (EUSBSR), with its three pillars, contains a strong focus on energy and climate. Energy is a priority area within the pillar 'connect the region', while climate is an overarching theme across the three pillars. Under the priority area of energy there are two flagship projects that seek to improve the efficiency of energy markets, increase the use of renewable energy and promote energy efficiency.

The Baltic Climate Project (<http://www.balticclimate.org/>) is an initiative that seeks to identify the impacts and opportunities that climate change affords to the Baltic Sea Region.

Climate projections are applied to explore development opportunities and to provide support for local decision-makers to incorporate climate change into long-term strategies and plans.

6.2 Emissions in the BSR – an overview

Comprehensive data are available for the whole region for the period 1990-2013. Later data have been extracted for individual countries (see below). Since 1990 there have been declines in the total GHG emissions across the BSR, excluding Norway which experienced a 5% growth. Over the period 2002-2012 the greatest reductions in total GHG emissions were seen in Denmark (41%), Finland (36%) and Sweden (21%), while increases were seen in Latvia (3%), Estonia (2%), Lithuania (1%) and Russia (12%).

When examining total emissions per capita, a 10 to 45% growth in emissions across the BSR occurred between 1990 and 2012. However, in the period from 2002-2012 there were variable changes, with the greatest proportional increases in GHG emissions in Denmark (32%), Finland (29%) and Sweden (21%) and greatest proportional reductions in Lithuania (15%) and Latvia (16%). Lithuania, Sweden and Latvia have the highest emissions per capita in the BSR, while Estonia and Finland have the lowest.

Within the BSR, the energy industry is the highest net producer of GHG emissions, followed by the transport sector. Emissions from transport have grown over the period 1990 – 2012, while other sectors have seen a decline, although variations at the national scale are evident.

The greenhouse gas intensity (carbon content) of energy consumption is the ratio between two subindicators: energy-related greenhouse gas emissions (carbon dioxide, methane and nitrous oxide and fluorinated gases) and gross inland energy consumption, expressed as g CO₂eq/kWh. The indicator is measured in comparison to the values for the year 2000 (Index 2000 = 100) and indicates progress towards the objectives and targets of the EU Sustainable Development Strategy. Since 2000, there have been reductions in the GHG intensity of energy consumption throughout the BSR, excluding Lithuania, which has experienced a 9% increase in the ratio of intensity. The greatest reduction in the ratio of intensity occurred in Denmark (17.3%), Finland (17.4%) and Sweden (17.5%).

The Baltic Sea region countries in a global context is summaries in Fig 6.1. Industrialized and traditionally largely coal-dependent countries – Canada, Australia, and United Kingdom - have large emissions. In the BSR Germany is the largest emitter, almost in the same category, and it also has a long history of coal-based energy supply. Poland, with a similar history, has lower emission per capita explained by its weaker economy. Lithuania, Sweden and Latvia is in the bottom of the table. It is noted that Estonia is a very large emitter of GHG, explained by its dependency of oil shale, a fossil fuel with low energy and high carbon content.

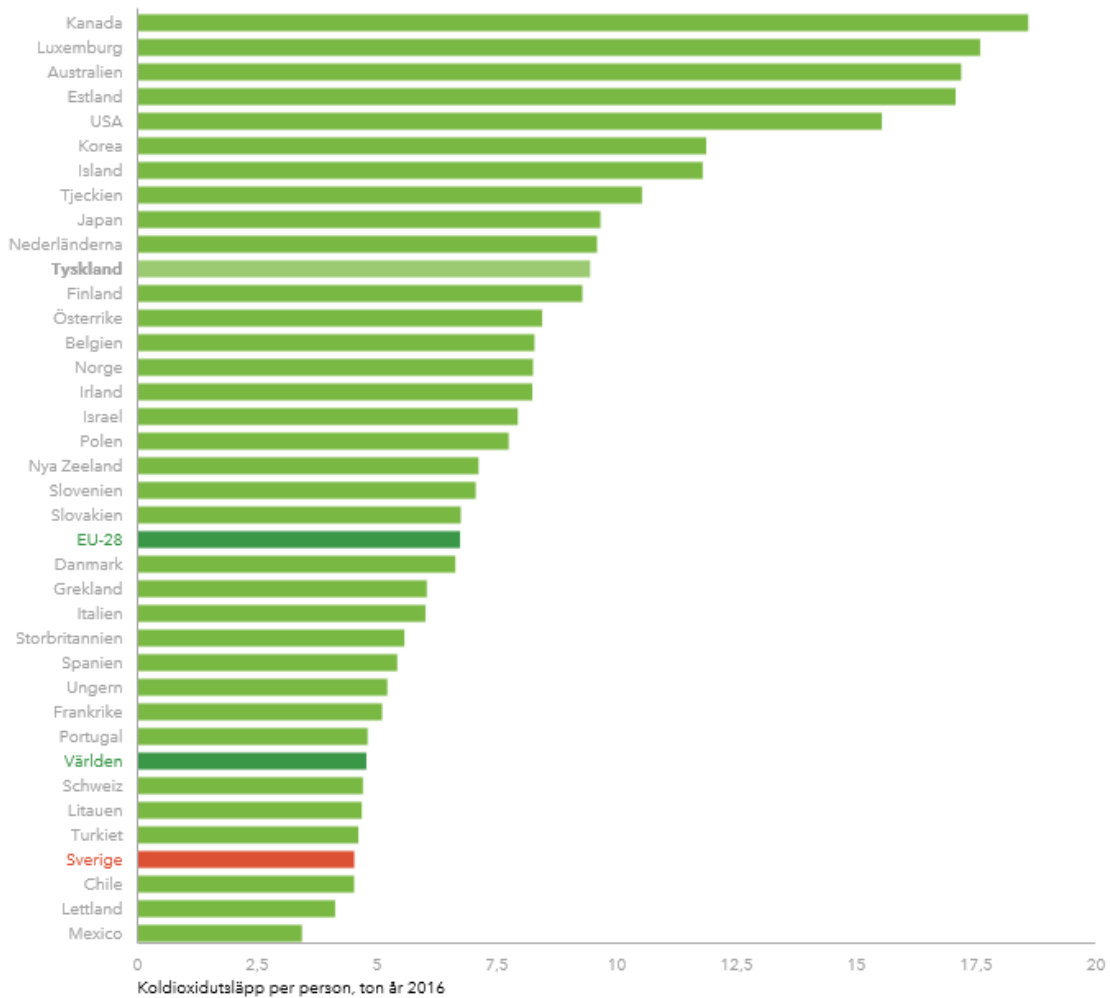


Fig 6.1 CO₂ emission per capita in 2016. Global data.

(<https://www.ekonomifakta.se/fakta/miljo/utslapp-internationellt/koldioxid-per-capita/>)

6.3 Emission data for some BSR countries

Germany's greenhouse gas emissions reductions were given a head start in 1990 when, following the fall of the Berlin Wall and reunification, the decline of the East German industrial and power sectors meant automatic CO₂ reductions (so-called “wall-fall profits”). In 2009, emissions dropped further, this time by 6.9 percent compared to the previous year, due to the economic crisis, which saw many companies scale down production. However, in the years that followed, the hope that this trend would continue remained unfulfilled.

Presently Germany's energy situation is dominated by its *Energiewende*, energy transition, policy. It originated in large popular protests against nuclear power. In 2010 Nuclear Power accounted for 22.4% of the electricity supply from 17 reactors. After the 2011 Fukushima disaster protests mounted and 8 reactors were closed immediately and a decision was taken to out phase the remaining reactors to 2022. In 2017 11.63% of German electricity was nuclear. As part of the *Energiewende* decision a policy was taken to increase strongly renewable energy, such as wind and solar, with the goal to reach 18 % in 2020, 30 % in 2030 and 45% in 2040 of total energy consumption.

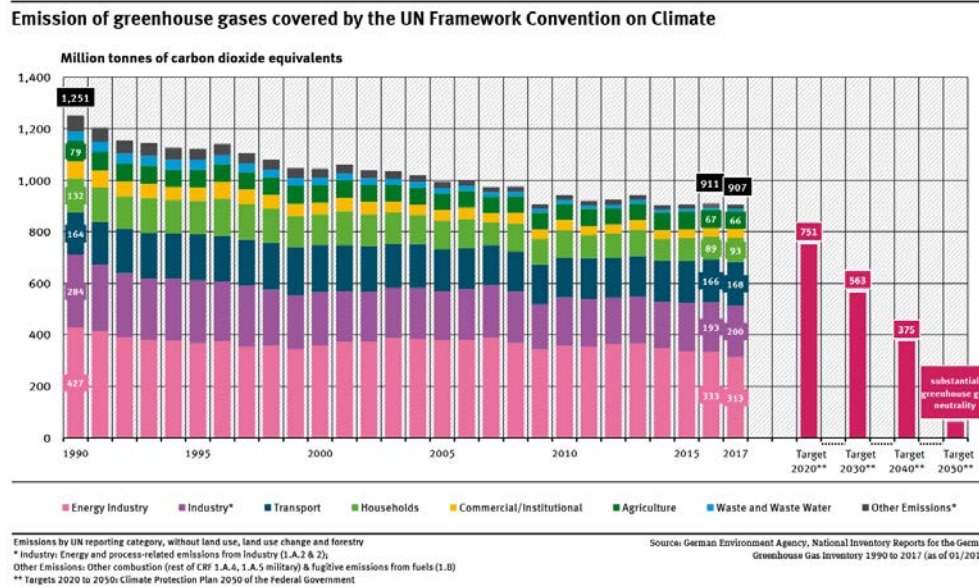


Fig. 6.2 Emission of greenhouse gases in Germany covered by the UN Framework Convention on Climate Source: German Environment Agency (<https://www.umweltbundesamt.de/en/indicator-greenhouse-gas-emissions#textpart-1>)

However, the latest Climate Protection Report, released by the environment ministry in June 2018 to examine the progress made within the Climate Action Programme, said that the programme's measures were not enough to close the gap to the 2020 goal. The expert opinion accompanying the latest *Energiewende* Monitoring Report by the federal economy ministry in June 2018 also warned that the country would probably miss crucial *Energiewende* goals.

The German government has been well aware of the “climate gap”. In June 2018, it conceded that the country is on course to widely miss its 2020 target. The economic boom, the pressure of immigration, and high emissions in transport mean that the energy transition pioneer is headed for a greenhouse gas emission cut of only 32 percent compared to 1990, according to the government’s Climate Protection Report.

The total emissions of GHGs in **Sweden** have decreased 26% from 1990 to 2107. Most of it was between 2003 and 2014, as a result of energy efficiency measures and the introduction of renewable energy sources, as well as reclining industrial production. Recent reductions have, however, been small. Emissions of GHGs from Sweden was 52.7 million tons CO₂eq in 2017, a reduction of 0.5 % from 2016. It was 53.7 million tons CO₂eq in 2015. It is a reduction of 0.3 % compared to 2014. CO₂ accounts for about 80 % of total emissions of GHGs. Energy sector including transports is about 87 % of total emissions of CO₂ and the largest source of emissions in Sweden.

These figures can be compared to the uptake of CO₂ due to forest growth and land use changes (LULUCF). Total uptake remained on a high level in 2015. It has increased with almost 40 % since 1990 since growth of forest and land use changes is larger than deforestation and timbering. The Swedish forest is thus an important sink for GHGs.

Another aspect is the import of goods which have caused emissions during their production outside the country. Data on “imported emissions” have been kept by the Swedish Environmental Protection Agency and they are as large as the territorial emission in Sweden, and fairly constant over a long period with a small reduction during the economic downturn in 2009. The sum of the territorial and imported emissions over the period 2008 to 2016 have been fairly constant of about 100 million tons of CO₂eq/year. Not much has been achieved.

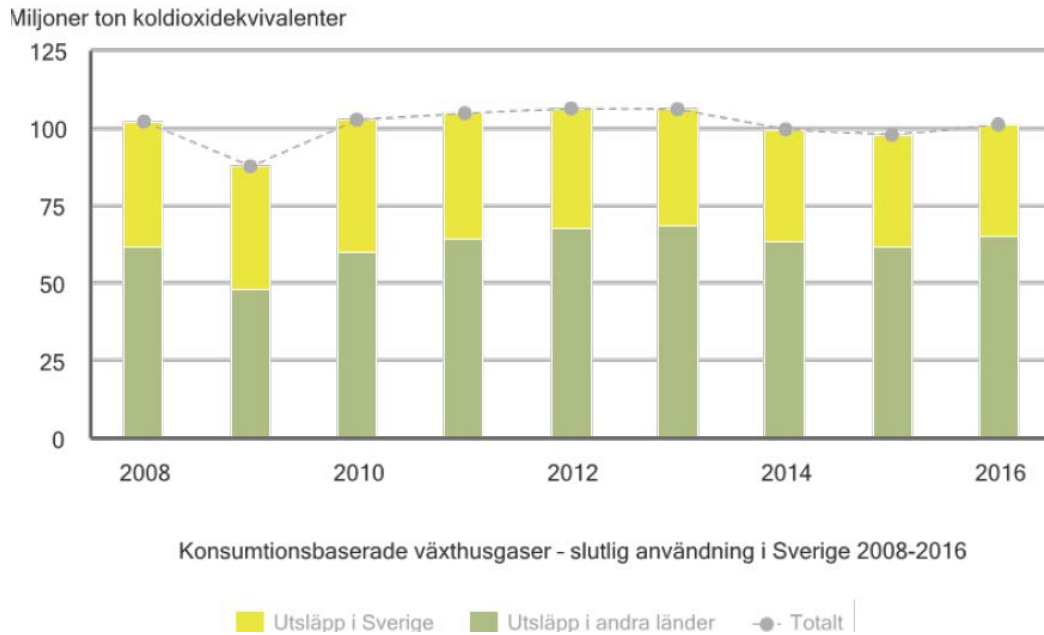


Fig. 6.3 The Swedish emissions of GHGs (million tons of CO₂eq). Yellow bars territorial emissions in Sweden. Green bars imported emission to Sweden. Source: Swedish Environmental Protection Agency.

https://www.naturvardsverket.se/PageFiles/33078/9621_sv.pdf. A more detailed report is found at <https://www.naturvardsverket.se/upload/miljoarbete-i-samhallet/internationellt-miljoarbete/miljokonventioner/FN/national-inventory-report-2018-annex.pdf>

Finland. The preliminary data for total GHG emission during 2017 was 55.5 million tons of CO₂eq. Compared to the base year of 1990 it's a decrease of 15.8 million tons. Compared to the previous year 2016 the decrease was 5 %. The most important cause was the reduced use of fossil fuels and increase use of biofuels in the transport sector.

Finland has, as Sweden, large forest areas. The sink in Finland caused by the forest and land use (LULUCF) was estimated to be 20.4 million tons of CO₂eq during 2017. This is an increase of 5.6 million tons or 38% compared to the base year 1990, and an increase of 10 % compared to 2016. The figures are mainly dependent on larger growth than timbering of the forests.

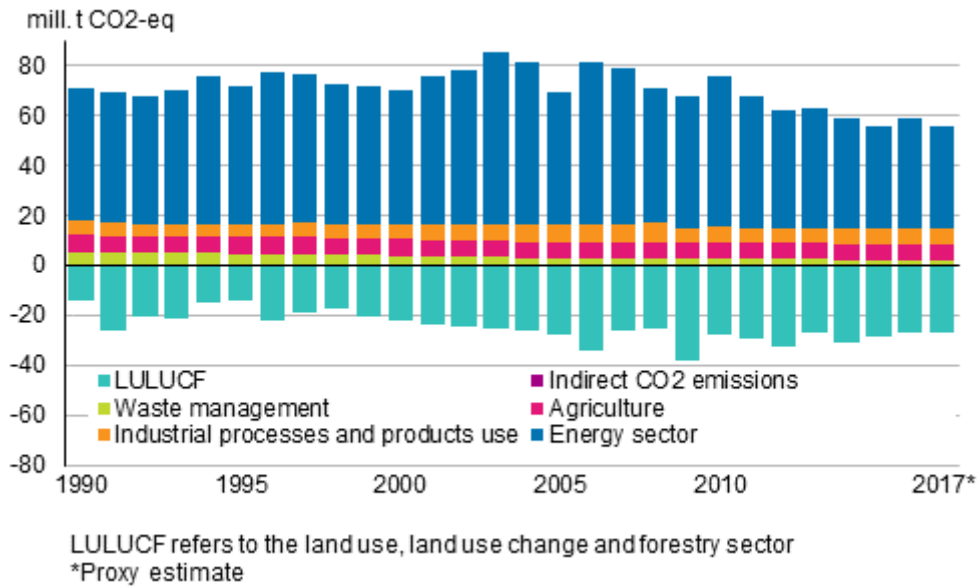


Fig. 6.4 Emissions of GHGs in Finland. (https://www.stat.fi/til/khki/2017/khki_2017_2018-05-24_tie_001_en.html).

In *Denmark* the emission of CO₂ from Energy Industries has decreased by 51.6 % from 1990 to 2015. The relatively large fluctuation in the emission is due to international electricity trade. Thus, the high emissions in 1991, 1994, 1996, 2003 and 2006 reflect a large electricity export and the low emissions in 1990, 1992 and 2005, 2008 and 2011-2014 are due to a large import of electricity. (Emission caused by imported electricity is reported by the exporting countries.) The main reason for the decrease in emissions are decreasing fuel consumption, mainly for coal and natural gas, as this is replaced by increasing production of wind power and other renewable energy sources.

The increasing emission of CH₄ during the nineties is due to the increasing use of gas engines in decentralised cogeneration plants. The CH₄ emissions from this sector have been decreasing from 2001 to 2015 due to the liberalisation of the electricity market. The CO₂ emission from the transport sector has increased by 15.3 % from 1990 to 2015, which is mainly due to increasing road traffic.

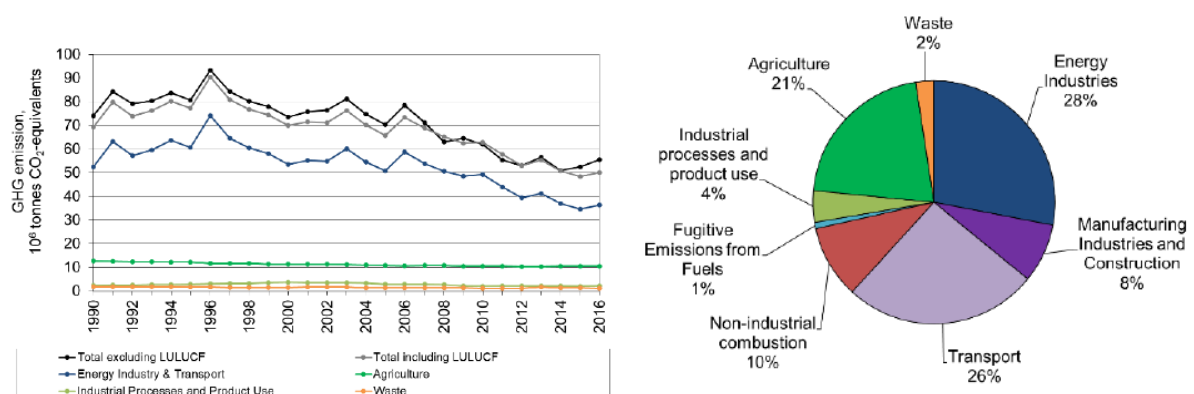


Fig. 6.4 Denmark Greenhouse gas emissions in CO₂ equivalents distributed on main sectors for 2016 (excluding LULUCF and indirect CO₂) and time series for 1990 to 2016. (http://cdr.eionet.europa.eu/dk/Air_Emission_Inventories/Submission_UNFCCC/colwsyr1w/envwsyssq/Danish_NIR_2018.pdf)

6.4 Energy consumption

Final *energy consumption* refers to energy that is supplied to the consumer for all final energy uses such as heating, cooling and lighting. It is the sum of final energy consumption in industry, transport, households, services, and agriculture.

With economic growth in our societies energy consumption is typically increasing in all areas, because of improved comfort requirement, increased mobility, etc. As most energy still is fossil it is important to limit energy consumption to reduce GHG emissions. Several measures are taken to do that. Most typical is taxation. Especially the poor section of societies suffer the consequences of cost increase since this is direct, not progressive, taxation. Social unrest because of increased costs for energy, fuel, etc. are seen in many countries.

Energy consumption can be expressed as *total energy* or relative energy consumption, that is, *energy consumption per capita* (or total energy divided by total population). Relative energy consumption is used when comparing different societies and groups. *Energy productivity* expresses the energy used for a certain economic level. For a country this is most often expressed as Total energy consumption divided by Gross Domestic Product. *Energy Intensity* is the opposite, i.e. the inverse, of Energy productivity.

Between 1990 and 2003, growth in relative final energy consumption was greatest in Latvia (21%), Lithuania (39%) and Estonia (40%), while there were small decreases in relative final energy consumption in Finland (5%) and Poland (5%) over the same period. Between 2003 and 2013, variation in final energy consumption was often less than +/- 15% across the region, excluding Lithuania, which experienced a 29% decrease in relative final energy consumption.

Final energy consumption in industry covers the consumption in all industrial sectors with the exception of the 'Energy sector'. In the BSR, industrial energy consumption declined between 1990 and 2012, excluding Finland. Between 2002 and 2013, Lithuania (8% increase), Latvia (18% increase), Russian Federation (13% increase) and Germany (2.5% increase) experienced a relative increase in energy consumption, while the greatest reductions occurred in Denmark (28%) and Finland (15%).

The greatest decreases in household energy consumption occurred in the Russian Federation (21%), Latvia (18%) and Germany (11%), while the greatest increase was in Poland (7%). Despite declines in the Russian Federation, the share of the housing sector in overall energy consumption has been steadily growing from 13% in 1990 to 24% in 2012. Household energy consumption in the remaining BSR countries remained relatively consistent over the period (+/- 0 to 3%).

Transport has been identified as a critical area of energy consumption, with a target of 10% of renewable energy use within transport by 2020 in the EU Climate and Energy Policy. Final energy consumption in transport covers the consumption in all types of transportation, e.g. rail, road, air transport and inland navigation. In the period 2003-2013, there was growth in energy consumption in transport across all BSR countries, excluding Germany and Denmark, with the greatest growth in consumption occurring in Poland (35%) and Lithuania (22%).

The best performing countries in the BSR have reduced final energy consumption between 6% and 8% (e.g. Sweden and Germany). In some instances, however, there have been increases in final energy consumption; for example, a 7.5% growth in Poland and 4% growth in Latvia.

The *energy productivity* is expected to increase as the economy in the society changes from industrial to a service based economy. The greatest proportional increase in productivity

during 2003-2013 was seen in Lithuania (54%), followed by Latvia (39%) and Poland (39%). Norway and Estonia experienced the lowest increase in energy productivity over this period (27% and 26% respectively). As of 2013, Denmark has the highest productivity, while Estonia had the lowest energy productivity. In the Russian Federation, energy intensity declined by 1.8% in 2014 (from 2013), bringing the cumulative gain over the last decade to 20%. In 2014 Russia's primary energy output declined for the first time in five years, as gains in oil, coal and nuclear were outweighed by losses in gas and hydro-electric power.

6.5 Energy efficiency

Energy efficiency refers to the amount of service obtained from each provided kWh, relevant in all areas where energy is used: heating and cooling, transport, industrial production etc. Traditionally energy efficiency has been low as energy prices have been low. The attitude is that when energy is cheap efforts to improve energy efficiency are not worth making. In Central and Eastern Europe (CEE) energy was not paid at all by the consumer, as in the communist economy natural resources were not taxed. Thus in CEE energy efficiency has been very low. In the western industrialised countries energy costs have been a significant part of the economy but varied, illustrated by the changing costs for oil in the world market, over the years. Increased costs makes energy efficiency measures profitable. As fossil energy is a main part of energy provision energy efficiency improvements are essential parts of combatting climate change. Increased cost of energy, mostly by taxation, is a practical necessity to improve energy efficiency.

Energy efficiency measures have since long been a central part of the EU policy for combatting climate change.

Heating and cooling. Heating, and to an extent cooling, in buildings and homes has been a large part of the energy budget. Several measures can be taken and have been taken to improve that. In the early part of the 1990s when energy prices slowly started to increase "low hanging fruits" to be picked was the insulation of windows to reduce draught, regulation of radiators and reducing indoor temperature. More advanced steps included retrofitting to improve insulation of entire buildings. Several EU Directives address the issue of energy use in buildings. The *Energy Performance of Buildings Directive* requires all new buildings to be nearly zero-energy by the end of 2020. All new public buildings must be nearly zero-energy by 2018. So-called passive houses (German: *Passivhaus*) is a rigorous, voluntary standard for energy efficiency in a building, set to be less than 15 kWh/m²/year. These are not common but low-energy-houses start to be common for newly built houses, especially in Denmark, Germany and Sweden.

The coordinate the source of heat for buildings is very important concern to improve energy efficiency. In older buildings the house – or even the room – has its own source of heating. A very efficient step to improve energy use in a society is to introduce district heating. This is now spreading in Europe and contribute to reduced energy consumption. A central heating station use the fuel much more efficiently than (most) individual burners and reduce air pollution greatly as flue gas cleaning is possible. Advanced heating stations provides not only district heating but also district cooling to be used by e.g. hospitals, large kitchens etc. A heating station can also be used for electricity production in a Combined Heat and Power, CHP station. Presently many power stations do not use the heat produced for district heating. The EU promotes the introduction of CHP technology in all member states as an energy efficiency measure, regulated in its *Combined Heat and Power (CHP) Directive* (2004/8/EC).

Lighting and other household equipment. The introduction of LED technology for lighting has been very important for increased energy efficiency. For a specified amount of light the LED lamp use almost ten times less electricity than a conventional lamp. Considering that an average household used about 28 % of its electricity for light, it is clear that the introduction of LED lamps reduces the total electricity demand by close to 25 %. In the EU the regulation of lamps is covered by the *Ecodesign Directive* (Directive 2009/125/EC) in which the European Commission encourages the improved energy and resource efficiency of household goods. The Directive also touches on other equipment in households and how they can be more energy efficient, e.g. by stand-by standards.

Transport. Car traffic accounts for a large part of energy costs and cars are responsible for around 12% of total EU emissions of carbon dioxide. Almost all cars are conventional combustion cars running on fossil fuel, gasoline or diesel. There are many ways to reduce energy consumption for transport. The cars can be more energy efficient, and they can be used more efficiently if there are more passengers, by car sharing, or more organised, with car pools. One may turn from cars to other means of transport, such as public transport with buses or trains or to bikes or simply walking. Fossil fuels can be replaced by biofuels to reduce emissions and finally one may change to electric cars or hybrids. It should be noted that in a combustion motor only some 20 % of the energy in the fuel is used for running the wheels, while with an electric motor it is more than 80 %. Electric cars are seen as long-term solution, either by using batteries or fuel cells. Rail traffic run on electricity is the much more energy efficient means of transport than cars: it has more passengers, electricity is efficient source of energy and in addition wheels on rail reduces energy costs compared to wheels on roads.

EU legislation has seen the transport sector as a crucial area for improving energy efficiency and there is a long list of regulations and directives in this area. It prescribes that fuel should have no less than 5 % biofuel. EU legislation sets mandatory emission reduction targets for new cars sold on the European market. Similar targets have been set for new vans. Under the Regulation, average CO₂ emissions from cars should not exceed 130 grams CO₂ per km by 2015 and should drop further to 95g/km by 2020.

6.6 Renewable and non-renewable energy

EU Directive 2009/28/EC on the promotion of the use of energy from renewable sources is calculated for four indicators (i) Transport (RES-T); (ii) Heating and Cooling (RES-H&C); (iii) Electricity (RES-E); and (iv) Overall RES share (RES). The goal is to reach the 2020 targets that 20 % of energy production should stem from renewable energy sources in 2020. In 2016 the EU average for renewables was 13%.

Electricity generation is generally the largest problem in the transition to renewable energy. Electricity produced from renewable energy sources comprises the electricity generation from hydropower plants (excluding pumping), wind, solar, geothermal and electricity from biomass/wastes. Nuclear power is not included in the renewables although it during operation does not contribute to CO₂ emissions. During 2004-2013 the greatest increases in renewably produced electricity were seen in Denmark (19%) and Germany (16%). More than 100% of Norway's electricity (more than 100% due to export) is generated from renewable sources, namely hydropower, followed by 62% in Sweden and 48% in Latvia. In Sweden the residual 38% is mostly nuclear meaning that electricity is practically free from GHG emissions.

Transport. The share of renewable energy in fuel consumption in the transport sector is expressed as a percentage and indicates progress towards the 10% of renewable energy use

within transport by 2020 target. As of 2013, Sweden had the highest proportion of renewable energy in fuel consumption of transport (17%), followed by Finland (9%). Sweden and Finland also experienced the greatest growth in the proportion of renewable energy in transport fuel consumption between 2004 and 2013, based on biofuels.

Heating and Cooling. Combined heat and power generation (CHP) or cogeneration reduces the need for additional fuel combustion for the generation of heat and avoids associated environmental impacts, such as CO₂ emissions. As of 2013, Denmark (51%), Latvia (38%), Finland (34%) and Lithuania (35%) had the highest proportion of electricity from CHP generation in total gross electricity generation. Between 2000 and 2013, the greatest growth in CHP generation occurred in Lithuania, Latvia, Poland and Estonia.

With 54 per cent in 2016 of the energy used in *Sweden* coming from renewable sources, the country tops the European Union. It is based on the large contribution from hydropower accounting for close to 50 % of the Swedish electricity, as well as a large sector of bioenergy. Wind and solar power is rapidly increasing but from a low level.

In 2016, renewable energy accounted for about 34 percent of *Finland's* overall consumption, while fossil fuels were responsible for some 38 percent. Use of renewable energy continued growing in 2017. Renewable energy sources covered 37 per cent of total energy consumption and according to preliminary data, over 40 per cent of final use. Renewables grew by six per cent while fossil fuels and peat declined by six per cent.

Latvia's 37% share of renewable energy in its energy mix in 2016 is the third highest in the EU. It imports 51 % of its energy as petroleum products and natural gas from Russia.

By 2014 *Denmark's* share of renewable had reached 29% and was the fifth highest amongst the EU-28 countries. In 2010, coal accounted for nearly 44 percent of total Danish power generation and fossil fuels altogether for two thirds. Denmark is a world leading country in wind energy production and wind turbine production. In 2014 Denmark produced 57.4% of its net electricity generation from renewable energy sources.

Renewable energy made up 16.9 percent of the total amount of electric energy consumed in *Estonia* in 2017. Altogether 1,612 GWh of energy from renewable sources was produced in Estonia 2017, 14 percent more than in 2016.

Germany had the world's largest photovoltaic installed capacity until 2014, and as of 2016, it was third with 40 GW. It is also the world's third country by installed wind power capacity, at 50 GW, and second for offshore wind, with over 4 GW. The share of renewable electricity rose from just 3.4% of gross electricity consumption in 1990 to exceed 10% by 2005, 20% by 2011 and 30% by 2015, reaching 36.2% of consumption by the end of 2017. More than 23,000 wind turbines and 1.4 million solar PV systems are distributed all over the country. As with most countries, the transition to renewable energy in the transport and heating and cooling sectors has been considerably slower.

Poland, Europe's biggest exporter and second-biggest consumer of coal, is cautiously embracing renewables to improve the security of its energy supply and meet European Union targets. At the end of 2018, the conservative parliament removed the investment roadblocks within a new renewable energy law aimed at putting Poland back on track to meet its EU commitment of 15 percent renewables by 2020.

For the *Russian Federation*, in 2014 renewable energy made up 2.8% of total energy consumption, while oil (36%), natural gas (30%), coal (20%), nuclear energy (8%) and hydro-electric (2.6%) made up the remainder. In the Russian Federation, there has been limited progress in the renewable energy sector due in part to the low domestic price of gas. As, however, the price of domestic gas reaches international parity, markets for renewables are expected to increase. OCED (2003) noted that large-scale use of biomass for energy is a cost-effective option in many Russian regions, especially in the north-western part of Russia, where the pulp and paper industry is well developed. The potential to use wood to produce

energy has been achieved in Finland, which has a similar climate and resource capability as this part of Russia.

The transition from fossil fuel dependency to renewable sources will take a long time. In the Baltic Sea region two countries are main oil producers, Norway and Russia. The other countries are largely importers, some of them large importers. Germany, Poland and Ukraine have considerable number of coal mines in operation, even if many coal mines already have been closed, mostly because it is not good business. In Germany public protests against coal mining are considerable and it appears that mining of black coal has ended in 2018.

Norway has recently opened production from a new gas field in the North Sea, the Johan Sverdrup field, which is one of the largest ever detected in the North Sea. After a decline oil and gas production in Norway is thus increasing again. Russia is today the largest oil exporter in the world. However the present lower price of oil is negatively impacting on the Russian economy. Russian oil and gas is of crucial importance for the EU energy provision, especially for the countries in the Baltic Sea region, where most of the oil and gas is imported from Russia. Russian gas is also imported by Germany to replace energy from the closed nuclear power plants.

6.7 Waste management and recycling

The extraction, use and wasting of materials are all connected to energy use. To make the material flows more efficient and more circular is a very important means of reducing energy costs as well as emission of GHG.

The production of metal from scrap metal is much less energy consuming than making it from virgin sources, especially for aluminium. This is now an established routine for iron and copper, where recycling is working comparatively well due to the increasing price for scrap metal. Some metals have a legal requirement on being collected for storing, especially lead and mercury, because of its toxicity. A developed recycling system is still lacking for many other metals, especially the rare earth metals used in many advanced energy technologies, e.g. solar cells and wind turbines.

Production of paper from recycled paper is estimated to be about 2.5 times less energy consuming than making it from virgin cellulose from wood. In addition it obviously saves the trees which otherwise would be cut down, but remains as a sink for CO₂.

Also making glass from recycled glass is less energy consuming than making it from virgin sources, sand.

Food waste is a particularly important area. Food production seen in a life cycle perspective causes close to 1/3 of the GHG emissions in the society. Especially large emission are caused by red meat production, much less by vegetables. Thus food waste should be reduced or best all together avoided, and meat eating reduced. This is not reflected in the price of food and in some countries the taxation of red meat is considered.

Reducing the material flows is in general an important part of sustainable development. It is reflected in the rule “reduce – reuse – recycle”, meaning that we should manage by using less, or using things second hand or, if the goods cannot be used any longer, recycle the materials it consists of. All materials however has an energy content which should be carefully taken care of. Thus organic waste can be used in fermentation to produce biogas, which is a standard procedure in many countries. In Sweden biogas produced in this way is typically used for city buses.

Waste incineration is established in many countries, where it is best done in a CHP station and thus contributes to heating houses and delivery of electricity. In many countries in CEE

putting waste on landfill is still a large part of the waste management system. This not only leads to loss of the energy embedded in the material, but also increases climate impact since landfills typically leak methane as abiotic fermentation is taking place in the oxygen-deprived layers of the landfill.

It is noted that use of fossil fuels for energy production is part of the linear material flows in our societies. In this case the waste, the CO₂ produced, ends up in the atmosphere and causes climate change. Materials management and the economy connected to materials management is at the heart of our present dilemma of climate change. To end our impact on the atmosphere we need to turn to a circular economy and cyclic material flows.

Chapter 6 sources:

This chapter includes excerpts from *Assessing the Status of Sustainable Development in the Baltic Sea Region. A report to the CBSS – Baltic 21 by the Baltic University Programme December 2015.*

Chapter 7. Climate, energy and sustainable development in the BSR – a sector study by Carmen Elrick-Barr and Neil Powell. (<http://www2.balticuniv.uu.se/bup-3/index.php/public/textbooks-course-materials/course-materials/reports>). Other parts are new written by Lars Rydén.

The chapter includes information from the European Union websites on Climate Policies <http://ec.europa.eu/clima/policies/brief/eu/> and subsites on the relevant EU Directives.

Information from each country in the region has been accessed from their official reports to the European Commission. Some information has been extracted from the Internet and Wikipedia.