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Chapter 3

Climate today

'I am here to sound the alarm: The world must wake up. We are moving in the wrong direction. Our world has never been more threatened. Or more divided.

The climate crisis is pummeling the planet…. Economic lifelines for the most vulnerable are coming too little and too late – if they come at all…. The climate alarm bells are also ringing at fever pitch.

We see the warning signs in every continent and region. Scorching temperatures. Shocking biodiversity loss. Polluted air, water, and natural spaces. And climate-related disasters at every turn.

When they see billionaires joyriding to space while millions go hungry on earth…

When parents see a future for their children that looks even bleaker than the struggles of today…

And when young people see no future at all…

Solidarity is missing in action – just when we need it most. We passed the science test. But we are getting an F in Ethics…..We must get serious. And we must act fast. The problems we have created are problems we can solve.'

Secretary General António Guterres
UN General Assembly, 21 September 2021

There is an amazingly simple characterization of climate change, identified by a single number, the CO_2 concentration, measured in parts per million (ppm). Similarly, any progress in climate actions can be monitored in terms of CO_2 concentration. It is remarkable that a small concentration of about 400 parts per million has such a significant influence on the global temperature. Only 4 molecules out of 10 000 air molecules are CO_2. If there were no greenhouse gases in the atmosphere the global temperature would be around −15°C. Because of the greenhouse effect created by CO_2 and water vapour, the average temperature of the Earth is around 15°C, which allows for life to exist.

Water vapour is also a greenhouse gas, the most abundant one. It absorbs longwave radiation and radiates it back to the surface, thus contributing to warming. Unlike other greenhouse gases, however, water vapour stays in the atmosphere a much shorter time, typically for days (before precipitating out), while CO_2, methane, and other gases will stay from years to centuries. Furthermore, the addition of water vapour to the atmosphere is typically not caused by human activities but is a feedback process. Warmer air can hold more moisture. Thus, the increase in water vapour contributes to even more warming, so the water vapour enhances the greenhouse effect.

To get a feeling for the low CO_2 concentration, imagine that we could collect all CO_2 to atmospheric pressure in one layer around the globe. This layer would be only around 4 metres thick.

Does it sound believable that humans can influence such a thin layer by our emissions?

Gases that undergo chemical reactions, like ozone or ozone-forming chemicals like nitrous oxides are relatively short-lived. CO_2, however, stays in the atmosphere for a long time. Conventionally it is assumed that CO_2 remains in the atmosphere for 100 years. What our generation adds will influence many human lives in the future.

In July 2014 NASA launched the OCO-2 (Orbiting Carbon Observatory) satellite. It gathers global CO_2 data with high precision and resolution and observes the whole Earth. From space it makes around 100 000 measurements of atmospheric CO_2 every day. In 2019 the OCO-3 was launched, further providing crucial atmospheric data. OCO-2 is in a polar orbit and OCO-3 is mounted to the International Space Station, circling Earth from 52° north to 52° south latitudes. This is where most of Earth's living things are found. OCO-3 can collect a denser dataset than OCO-2 over high-carbon regions such as the Amazon rainforest.

The UNFCCC parties (United Nations Framework Convention on Climate Change) have arranged annual formal meetings to assess progress in dealing with climate change. The first COP (Conference of the Parties) meeting was held in Berlin in 1995 and COP26 was recently completed in Glasgow in 2021.

In the 1990s the conferences negotiated the Kyoto Protocol (decided in 1997) and from 2011 the COP meetings negotiated the Paris Agreement in 2015. The negotiations are extremely complex since any final text of a COP must be agreed by consensus.

Two words had never been mentioned in the final documents of the COP meetings, until COP26 in 2021: *fossil fuels* (is it a coincidence?). The cause–effect can be expressed in this dramatically simple relationship. Still the consequences are extremely complex.

The words 'fossil fuel' have not been mentioned in COP documents.

The increased concentrations of CO_2 in the atmosphere and in the oceans are a result of accumulated emissions since the industrial revolution. This is sometimes overlooked in the negotiations where various nations blame each other for the current crisis. CO_2 emissions from fossil fuel combustion were practically zero before 1750. The UK was the first industrialized nation and the first fossil fuel CO_2 emitter. In 1751 its emissions, as well as those at global level, were less than 10 million tons (Mt). Today they are 3600 times higher.[66] Figure 3.1 shows the accumulated emissions from the ten countries with the highest impact.

The seriousness of the issue among climate scientists was expressed by Raymond Pierrehumbert, lead author of the 2018 IPCC report: '*Let's get this on the table right away, without mincing words. With regards to the climate crisis, yes, it's time to panic…. We are in deep trouble.*'[67]

3.1 THE 1992 RIO CONFERENCE

The scientific community has been aware of climate change and its dramatic consequences for decades. The Keeling curve had developed into a clear warning sign of climate change since 1958. Prime Minister Margaret Thatcher had warned the UN General Assembly in 1989 and in a resolution 44/228, adopted by the General Assembly on 22 December 1989,[68] it was decided to

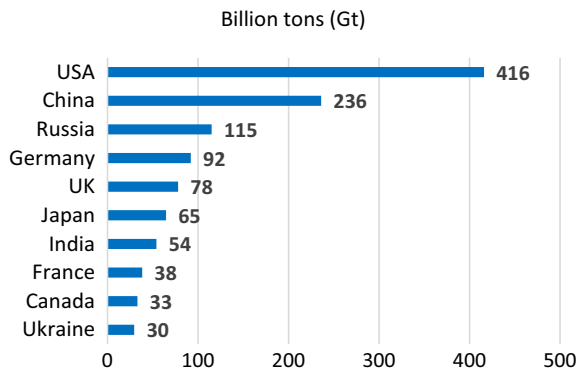

Figure 3.1 Cumulative emissions of CO_2 between 1750 and 2020.

convene the UN Conference on Environment and Development, to coincide with World Environment Day, in June 1992. '*The Conference should elaborate strategies and measures to halt and reverse the effects of environmental degradation; … to examine the state of the environment and changes that have occurred since the UN Conference on the Human Environment, held in 1972, … to recommend measures to be taken at the national and international levels to protect and enhance the environment, … to examine the relationship between environmental degradation and the international economic environment.*'

The principle of international responsibility concerning climate change, documented in the *UN Framework Convention on Climate Change*,[69] decided in the Rio conference in 1992 is crystal clear:

> *The Parties should* ***protect the climate system*** *for the benefit of present and future generations of humankind.*
>
> UN Rio 1992

Principle 3.1: *'The Parties should protect the climate system for the benefit of present and future generations of humankind, on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities. Accordingly, the developed country Parties should take the lead in combating climate change and the adverse effects thereof.'*

Principle 3.2: *'The specific needs and special circumstances of developing country Parties, especially those that are particularly vulnerable to the adverse effects of climate change, and of those Parties, especially developing country Parties, that would have to bear a disproportionate or abnormal burden under the Convention, should be given full consideration.'*

Principle 3.3: *'The Parties should take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures, taking into account that policies and measures to deal with climate change should be cost-effective so as to* ***ensure global benefits*** *at the lowest possible cost.'*

> *Where there are threats of serious or irreversible damage,*
>
> *lack of full scientific certainty should not be used as a reason for postponing such measures*

Among the commitments, these may be emphasized:

Article 4.4: *'The developed country Parties and other developed Parties included in Annex II shall also assist the developing country Parties that*

are particularly vulnerable to the adverse effects of climate change in meeting costs of adaptation to those adverse effects.'

Article 4.8: *'In the implementation of the commitments in this Article, the Parties shall give full consideration to what actions are necessary under the Convention, including actions related to funding, insurance and the transfer of technology, to meet the 15 specific needs and concerns of developing country Parties arising from the adverse effects of climate change and/or the impact of the implementation of response measures, especially on:*

a *Small island countries;*
b *Countries with low-lying coastal areas;*
c *Countries with arid and semi-arid areas, forested areas and areas liable to forest decay;*
d *Countries with areas prone to natural disasters;*
e *Countries with areas liable to drought and desertification;*
f *Countries with areas of high urban atmospheric pollution;*
g *Countries with areas with fragile ecosystems, including mountainous ecosystems;*
h *Countries whose economies are highly dependent on income generated from the production, processing and export, and/or on consumption of fossil fuels and associated energy-intensive products; and*
i *Land-locked and transit countries.*

….. The Parties shall take full account of the specific needs and special situations of the least developed countries in their actions with regard to funding and transfer of technology.'

Yet, in the three decades since Rio the world has emitted more CO_2 than during the entire century before. And many of the catastrophes James Hansen warned about in 1988 have become a reality. As Fredi Otto, climate scientist at the University of Oxford, expressed it recently: '*All of this is happening exactly as we have known it would happen.*'

Many of the catastrophe warnings from 1988 have been a reality. '*All of this is happening exactly as we have known it would happen.*'

3.2 CLIMATE AS REPORTED BY IPCC IN 2021

IPCC, the Intergovernmental Panel on Climate Change, was established in 1988 and the first assessment report was published in 1990. The mission of IPCC is '*to provide policymakers with regular scientific assessments – every six or seven years – on the current state of knowledge about climate change.*' The IPCC does not carry out original research but rather serves as a clearinghouse for assessing and synthesizing the relevant literature. Thousands of scientists contribute to writing and reviewing the IPCC reports, which are then reviewed by governments. The IPCC is an association of volunteer scientists who produce arduous technical assessments, not policy recommendations. IPCC is

scrupulous in recognizing any uncertainty in all its estimates. Its targets for the needed level of emissions reductions are never presented as a single figure but in terms of ranges and probabilities.

The sixth assessment report (AR6), published in 2021, formed a basis for the COP26 negotiations. Despite the concerns by the IPCC authors, the scientific evidence from AR6 was explicitly acknowledged in the Glasgow Climate Pact. The authors had reasons for their concern: the IPCC special report on 1.5°C warming was published before the 2018 COP24 in Katowice, Poland. The report was just 'noted' in the final document and no conclusions from the report were acknowledged.

In my summary of the IPCC findings, I have excluded the ranges and the probabilities and refer to the main AR6 report for all details. In short, we have more than enough information to take decisive actions based on what we know, fully aware of uncertainties presented.

The Physical Science Base report in 2021[70] of almost 4000 pages is an overwhelming and convincing documentation of the current climate situation. The report is a high-level summary of scientific results concerning climate, the role of human influence, and information about certain regions of the world. The AR6 cites more than 14 000 scientific papers and IPCC has received around 78 000 comments. It should be emphasized that all the results in AR6 are approved by all the authors. There are further scientific findings in the literature, but if there is no unanimous agreement of them, they are not included in the AR6.

The report states that *'It is unequivocal that human influence has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred.'* Note that the greenhouse gas (GHG) concentration measurements are well-mixed and can represent the global situation. In 2019, atmospheric CO_2 concentrations were higher than at any time in at least 2 million years, and concentrations of methane and nitrous oxide were higher than at any time in at least 800 000 years. Since 1750, increases in CO_2 (49%), methane (162%), and in nitrous oxide (23%) concentrations far exceed the natural multi-millennial changes between glacial and interglacial periods over at least the past 800 000 years. As of August 2021, the GHG concentrations had reached:

IPCC: 'it is unequivocal that human influence has warmed the atmosphere, ocean and land'.

- CO_2 – 410 parts per million (ppm)
- Methane (CH_4) – 1866 parts per billion (ppb)
- Nitrous oxide (N_2O) – 332 ppb.

IPCC is now clear: human influence on the climate system is an established fact. The report claims that *'human influence has warmed the climate at a rate that is unprecedented in at least the last 2000 years'*. IPCC has further concluded (with various but high likelihoods) that human activities have been the main drivers of several signs of climate change:

- *Global surface temperature*: each of the last four decades has been successively warmer than any decade that preceded it since 1850. Global surface temperature was 1.09 [0.95 to 1.20]°C higher in 2011–2020 than during 1850–1900. Land warming, ice loss, and atmospheric warming accounted only about 5%, 3%, and 1%, respectively of the heating, while ocean warming accounted for 91% of the heating in the climate system. The land surface will continue to warm more than the ocean surface and the Arctic will continue to warm up more than global surface temperature, above two times the rate of global warming. Natural land and ocean carbon sinks are projected to become less effective, that is, the proportion of emissions taken up by land and ocean will decrease with increasing cumulative CO_2 emissions. As a result, a higher proportion of emitted CO_2 will remain in the atmosphere. Compared to preindustrial times, over the past 5 years 8–11% of the globe had exceeded 2°C warming and in Sweden the year 2020 was 3.3°C warmer.
- *Precipitation:* changes have been observed since the mid-20th century.
- *Snow cover*: there has been a decrease in the Northern Hemisphere spring snow cover since 1950.
- *Ice sheets*: there has been a global retreat of glaciers since the 1990s, a decrease in the Arctic Sea ice area, and the observed surface melting of the Greenland Ice Sheet over the past two decades. In 2011–2020, annual average Arctic Sea ice area reached its lowest level since at least 1850. Late summer Arctic Sea ice area was smaller than at any time in at least the past 1000 years. The global nature of glacier retreat since the 1950s, with almost all the world's glaciers retreating synchronously, is unprecedented in at least the last 2000 years. Permafrost thawing, loss of seasonal snow cover, of land ice, and of Arctic Sea ice will be amplified by the additional warming. The Arctic is likely to be practically sea ice-free in September at least once before 2050.
- *Ocean warming*: The global upper ocean (0–700 metres) has warmed since the 1970s. The world ocean, in 2021, was the hottest ever recorded by humans[71] and the last 5 years have had the warmest seas since records began. There is a year-to-year variation of the ocean heat content primarily tied to the El Niño-Southern Oscillation. Despite the La Niña oscillation in 2021 that cooled the Pacific Ocean, the record temperature was reached. Changes in ocean circulation play important roles locally, but the predominant changes result from human-related changes in atmospheric composition. Warmer oceans supercharge weather systems, creating more powerful storms and hurricanes. Warmer oceans lead to a warmer and moister atmosphere, promoting more intense rainfall in all storms. This will increase the risk of flooding. Warming oceans also threaten marine ecosystems, like coral reefs and fisheries.
- *Ocean salinity:* The low pH value as observed in recent decades, is unusual in the last 2 million years. There is a pattern of observed changes in near-surface ocean salinity.
- *Sea level rise*: the global mean sea level increased by 0.20 metres between 1901 and 2018. Global mean sea level has risen faster since 1900 than

over any preceding century in at least the last 3000 years. Thermal expansion explains 50% of sea level rise since the 1970s, while ice loss from glaciers contributed 22%, ice sheets 20% and changes in land-water storage 8%. The rate of ice-sheet loss increased by a factor of 4 between the 1990s and the 2010s. Icesheet and glacier mass loss were the dominant contributors to global mean sea level rise during 2006–2018. In the longer term, sea level is committed to rise for centuries to millennia due to continuing deep-ocean warming and ice-sheet melt and will remain elevated for thousands of years. Over the next 2000 years, global mean sea level will rise by about 2–3 metres if warming is limited to 1.5°C, 2–6 metres if limited to 2°C.

Are we planning our civilisation to last for millennia?

After the IPCC report, further evidence of ocean temperature increases have been reported.[72] Monthly sea-surface temperatures from 150 years, from 1870 through 2019, were mapped and the location and time of extremes were recorded decade by decade. By comparing monthly instead of annual averages more in detail it was detected how the oceans are warming, and an increasing number of extremes were detected. From 2014 on, more than half the surface water areas of the oceans are warmer than the most extreme events from 1870 to 1919. Extremes of yesterday are now the new normal.

3.3 CLIMATE PIONEERS

We may recall the results published by Svante Arrhenius in 1896. Using the Stefan Boltzmann law, he formulated his original greenhouse law, expressed mathematically by:

$$\Delta T = \alpha \cdot \ln(c / c_0)$$

where ΔT is the temperature change, c the CO_2 concentration and α and c_0 constants. The formula is still useful today. Arrhenius estimated that a doubling of CO_2 would cause a temperature rise of 5–6°C. Later he adjusted the value downwards to 1.6°C (including water vapour feedback: 2.1°C). Estimates from IPCC, a hundred years later say this value (the climate sensitivity) is likely to be between 2 and 4.5°C. Arrhenius expected CO_2 levels to rise at a rate given by emissions in his time, so a CO_2 doubling would take about 3000 years; since Arrhenius time the increase has been almost 50%.

It is also appropriate to pay attention to the 2021 Nobel Prize winner in physics, Syukuro Manabe. He pioneered climate models to be simulated in computers in the 1960s. Considering the computing power at that time he was forced to simplify to make the models possible to compute. Only the key processes were included, such as solar radiation, water vapour, CO_2, and a reflecting land area. Still he was able to predict the temperature increase to 2–3°C when the CO_2 concentration in the atmosphere had been doubled, a similar range to Arrhenius's as well as IPCC's models.

For me as a Swede it is particularly interesting to note that the scientific background material published with the 2021 Nobel Prize mentions Svante Arrhenius 14 times, just 4 fewer than Manabe, who actually won.

Quite naturally the current climate models are enormously more complex and include more greenhouse gases, vegetation, sea currents, geological processes, and human activities. Also, all the CO_2 that we emit into the atmosphere does not stay there but is partly absorbed by vegetation and the oceans. Still the largest supercomputers do not have sufficient capacity to simulate the climate with the same degree of details as the weather forecasting models.

The other 2021 Nobel Prize winner Klaus Hasselmann has together with Syukuro Manabe built a basic understanding of climate modelling. Hasselmann wrote a model in the 1970s that helped scientists understand both how weather and climate interact and how to diagnose humanity's role in heating the atmosphere. Hasselmann has warned us about global warming for 50 years. Now he is pinning his hope on the young generation and trusts that the decision makers will listen to them. Professor Manabe testified in the US Congress in 1988 together with James Hansen. Manabe, however, talked with a heavy Japanese accent and now believes that the politicians did not understand anything that he said. Still James Hansen was 99% sure that human activities had already caused global warming. Hansen's testimony caused a lot of media attention. Nevertheless, hardly anything happened.

The third Nobel Prize winner Giorgio Parisi has also contributed to understanding climate change, even though he had another viewpoint, explaining complex physical systems. His results in complex theory have made it possible to understand and describe many different and apparently entirely random material and phenomena (such as weather) and relate this to a better understanding of long-term phenomena such as climate change. Knowledge about the climate rests on a solid scientific foundation.

The fact that decision makers now consider climate research more seriously is probably thanks to IPCC, since the first report in 1990. In 2007 IPCC and Al Gore shared the Nobel Peace Prize.

Actually, global warming was discussed in a popular TV show in Sweden in 1969 called 'Ask Lund' where researchers from my own Lund University were answering questions from a panel. The CEO of Volvo, Gunnar Engellau, asked if increasing concentrations of gases from human activities would influence the global temperature. My former colleague Bertram Broberg (1925–2005) gave a most insightful answer how both water vapour and CO_2 will influence the global temperature.

3.4 THE MILLION-YEAR PERSPECTIVE

Temperature and CO_2 variations during the last 800 000 years have been carefully recorded, using measurements from ice cores from Greenland and Antarctica. There is a clear relationship between temperature variations and CO_2 concentrations. The rising and falling CO_2 levels coincide with the onset of ice ages (low CO_2) and interglacial periods (high CO_2). There is a temperature and CO_2 peak around every 100 000 years, the natural changes between glacial

and interglacial periods. These periodic fluctuations are caused by changes in the Earth's orbit around the sun, the precessional movements of the Earth axis, and the position of the moon. This link between global temperatures and greenhouse gas concentrations – especially CO_2 – has been valid throughout Earth's history. There is a time lag between atmospheric concentration variations and temperature changes. Consequently, even if we finally do manage to stabilize atmospheric concentrations, temperatures will continue to slowly rise for years or decades.

Over the period of 800 000 years, the CO_2 concentration varied mostly between around 180 and 280 ppm and for most of the period atmospheric concentrations of CO_2 did not exceed 300 ppm. From the industrial revolution to the end of the 1980s, the CO_2 concentration had risen by around 70 ppm (keep in mind the warning by Margaret Thatcher in 1989). For the last 30+ years we have seen an additional rise of around 70 ppm and the atmospheric concentrations is now approaching 420 ppm. Looking at the long-term concentration diagram, it seems that the CO_2 and temperature peaks were reached quickly. However, these 'rapid' increases usually took place over around ten millennia. Now we have seen the CO_2 concentration increase even more in a couple of generations, at least a factor 100 faster time scale. This is the core of the problem: nature – which we are part of – has too little time for adaptation.

3.5 THE CO_2 BUDGET

From a physical point of view the answer is straight-forward. It is obvious that it is necessary to limit cumulative CO_2 emissions in combination with other greenhouse gases, in particular methane. IPCC has confirmed that there is near-linear relationship between cumulative anthropogenic CO_2 emissions and the increase in global surface temperature.

Over the period 1850–2019, a total of 2390 ± 240 (likely range) $GtCO_2$ of anthropogenic CO_2 was emitted. Remaining carbon budgets have been estimated for several global temperature limits and various levels of probability, based on the estimated value of the so called TCRE (transient climate response to cumulative CO_2 emissions) and its uncertainty, estimates of historical warming, variations in projected warming from non-CO_2 emissions, climate system feedbacks such as emissions from thawing permafrost, and the global surface temperature change after global anthropogenic CO_2 emissions reach net zero.

To limit the temperature increase to 1.5°C, there is only 500 Gt left to emit from the beginning of 2020. Even so, there is only 50% probability that global warming will remain below 1.5°C (Table SPM.2, IPCC, 2021). If we would obtain 83% probability, then the budget shrinks to 300 Gt. With the current emission rate of 31.5 Gt/year this means that all CO_2 budget is used up before 2030. UNEP analysis[73] suggests the world is on course to warm around 2.7°C with hugely destructive impacts. In its report 'State of climate 2021' the World Meteorological Organization (WMO) states

With current greenhouse gas emission rate all remaining CO_2 budget is used up before 2030.

that the build-up of warming gases in the atmosphere rose to record levels in 2020 despite the pandemic.[74] The amounts of CO_2, methane, and nitrous oxide rose by more than the annual average in the past decade. WMO finds that the national pledges to cut greenhouse gas emissions by 2030 are just 7.5% per year compared to the previous pledges made in 2015. To keep the 1.5°C goal alive would require 55% cuts by the 2030, a seven-times higher ambition.

Around half of emissions from human activity are absorbed by oceans, and to some extent trees and land. But this ability can vary significantly, depending on for example temperatures and rainfall. The Keeling curve clearly indicates the role of CO_2 absorption by vegetation: there is an annual oscillation of the CO_2 concentration with a maximum in the spring of the Northern Hemisphere. As summer approaches more CO_2 will be caught. NOAA (National Oceanic & Atmospheric Administration) results confirm that the amplitude of the annual oscillations is 4–5 ppm, corresponding to only 2 years of CO_2 base level increase. More vegetation is valuable for the climate, but it does not solve the climate crisis. Even more important, it is not correct to compare just carbon masses and not to consider their chemical bindings. To compensate for example burned aircraft fuel with trees in the Amazonas is an oversimplification. Carbon in the fuel has high-energy bindings unlike the carbon in the plant mass.

WMO confirms that the CO_2 level in 2020 was 149% of the pre-industrial level. The last time the Earth experienced a comparable concentration of CO_2 was 3–5 million years ago, when temperatures were 2–3°C warmer and sea level was 10–20 metres higher than it is today.

The National Academies of Sciences, Engineering and Medicine in the USA have assessed the latest in climate science, technology options, and socioeconomic dimensions and provide advice how to reach the goal of net zero emissions by 2050.[75]

3.6 THE COP26 AGREEMENTS

Current policies to reduce, or at least slow down, growth in CO_2 and other greenhouse gas emissions will have some impact on reducing future warming. But if the aim is to limiting warming to 'well below 2°C' – as is laid out in the Paris Agreement – the world is clearly far off-track. In Glasgow the countries of the world were called upon to improve their pledges in 2022 to satisfy what had been decided in the Paris agreements in 2015. The G20 countries have a particularly high responsibility, having a majority of the global economy. They are also responsible for some 75% of the global emissions.

The UN Secretary General Mr Guterres was talking a very clear language: '*Enough of brutalizing biodiversity, killing ourselves with carbon, treating nature like a toilet, burning, and drilling and mining our way deeper.*' He added '*we are digging our own graves*', reminding us that our planet is changing before our eyes from melting glaciers to relentless extreme weather events. He also reiterated that sea-level rise is double the rate it was 30 years ago, that oceans are hotter than ever, and that parts of the Amazon Rainforest now emit more carbon than they absorb.

> *'Scientists are clear on the facts. Now leaders need to be just as clear in their actions.'*
>
> UN Secretary General António Guterres at COP26

The famous environmental activist and broadcaster David Attenborough said that if working apart we are a force powerful enough to destabilize our planet, working together, we are powerful enough to save it.

We may have the impression that climate conferences are organized so that the countries of the world meet to solve the climate crisis. This is only partially true. Countries are also there, and some countries are primarily there, to protect their national interests.

Some of the COP26 agreements and pledges are summarized here:

- *Deforestation*: leaders from more than 100 nations, representing about 85% of the world's forests, promised to stop deforestation by 2030. In a separate move, a group of high-income countries pledged US $12 billion for forest protection until 2025. There is no specific information how the funding will be provided.
- *Methane*: more than 100 countries agreed to cut 30% of current methane emissions by 2030. Methane is currently responsible for a third of human-generated warming. China, Russia, and India did not join, but there is hope that they will later. China and Russia are the methane top emitters with 18% and 10% respective of the total global methane emissions.
- *Coal*: more than 40 countries agreed to shift away from coal. This included major coal-users like Poland, Vietnam, and Chile. However large coal-dependent countries like Australia, India, China, and the USA did not sign. The agreement covered coal but no other fossil fuels like oil and gas.
- *Finance*: around 450 financial organizations agreed to back renewable energy and direct finance away from industries depending on fossil fuels. These organization control together some US$130tn ($10^{12}$). High-income countries were asked to double their collective commitments by 2025 compared to 2019, to address the climate crisis.
- *Climate fund*: the governments have failed to meet a 2009 pledge to provide US$100 billion per year in climate finance for low- and middle-income countries by 2020. It looks as if it will take until 2023 to reach this goal, and that around 70% of the finance will be provided as loans.
- *US and China*: the countries pledged to co-operate on climate over the next decade. This would include methane emissions, the transition to clean energy, and de-carbonization.

A group of high-income countries promised to end fossil fuel financing overseas. This effort could slow the growth of oil and gas projects in low-income countries. However, it would do nothing to decrease the development in top producing countries like the USA, Russia, Saudi Arabia, or Canada. Major funders of fossil fuel projects, like China, Japan, and South Korea, did not join

the deal. Obviously, such a deal will further deepen the injustices of climate change. For example, low-income countries will not get the money to build gas powered plants while high-income countries are free to continue building them domestically.

For the most part, any commitments made at COP26 will have to be self-policed. Only a few countries are making their pledges legally binding. According to the Production Gap Report,[76] governments still plan to produce twice the amount of fossil fuels in 2030 than what would be in line with the global warming goal of 1.5°C. Aminath Shauna, the Maldives' Minister of Environment, Climate Change and Technology, expressed the fear that hard-hit nations have, facing an existential threat: '*The difference between 1.5 and 2°C is a death sentence for us. What is balanced and pragmatic to other parties will not help the Maldives adapt in time. It will be too late.*'

'The difference between 1.5 and 2°C is a death sentence for us'.

One month after COP26 the Glasgow Work Programme was published.[77] This is a 10-year plan, decided by the COP26 Governments, to educate and empower people of various professions to contribute to solutions to the climate crisis. This Action for Climate Empowerment (ACE) has the following elements: climate education and public awareness, training, public access to information, public participation, and international cooperation on these matters.

3.7 DEFORESTATION

All people depend upon forests, some more than others. Around three quarters of accessible freshwater in the world comes from forested watersheds. Forests also have a key role to prevent climate related food insecurity. Forests can facilitate the formation of dew from rising water vapour and the accumulation of water in reservoirs and creeks. Forests intercept rain and enhance the water storage capacity of the soil. They also help to conserve the soil, reducing erosion.

Five countries have more than half the forests in the world: Brazil, Canada, China, Russia, and the USA. Almost one third of the global land area is covered by forests and about half the forest area is relatively intact. About one third of all forests are primary forests, where there are no clearly visible indications of human activity.

As noted in 3.6 ceasing deforestation was one of the pledges at the COP26 meeting. The decade 2011–2020 was declared the UN Decade on Biodiversity and some of the conclusions of this work are summarized in an FAO-UNEP report.[78] The impact of deforestation[79] is widely recognized and later in the book we will illustrate some of the couplings to not only climate but to water, energy, food, and nature, as outlined in Figure 3.2. Obviously human health is closely related to most of these aspects.

In the last 30 years around 4.2 million km^2 – corresponding to half the land area of Brazil – have been lost through conversion to other land uses. The global primary forest area has decreased by more than 0.8 million km^2 in the same period and 1 million km^2 have been impaired by forest fires, pests,

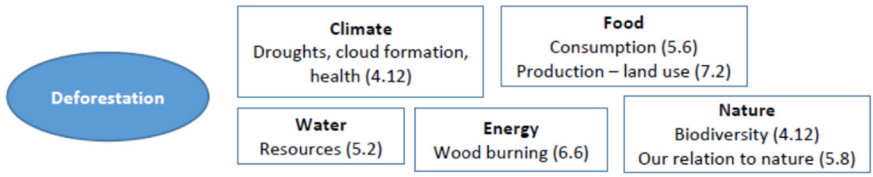

Figure 3.2 The impact of deforestation is further discussed in the sections indicated.

diseases, invasive species, and drought. All of this contributes to the loss of biodiversity. The net deforestation area is lower, 1.77 million km², since new forests have grown by natural expansion or deliberate efforts. As Figure 3.3 shows the rate of deforestation has decreased. The *accumulated* losses for the 3 decades are 4.2 million km² and new forests are 2.4 million km², making the total *net* loss 1.77 million km². The four countries with the highest deforestation have lost 0.44 million km².

The *net* deforestation in 30 years = 1.77 million km²

Agriculture expansion is the main cause of deforestation and the accompanying loss of biodiversity. In general, the need to provide food and energy for a growing global population is a main cause of deforestation and decreasing biodiversity.

- *Brazil*: Despite the pledge at the COP26 meeting, deforestation in Brazil in 2021 was the highest since 2006: 13 235 km². Expressed differently, a forest area of 1.2 × 1.2 km² was lost *every hour*, around the clock. During January 2022 the Brazilian Amazon lost a rainforest area of 430 km², five times larger than in January 2021, the highest January forest loss since the records began in 2015,[80] according to Brazil's space agency

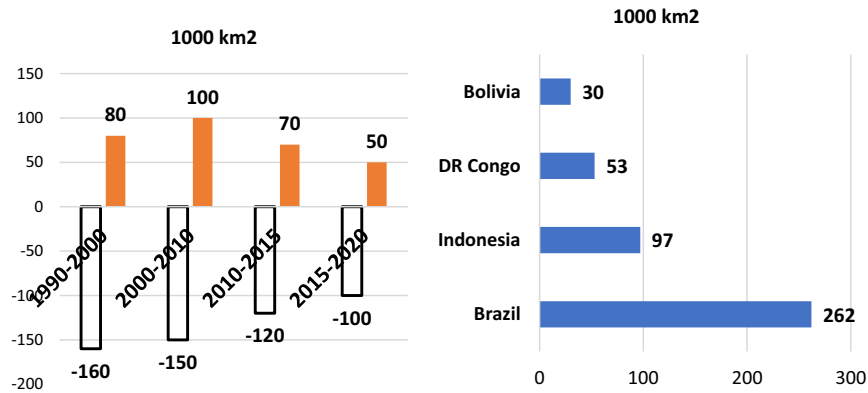

Figure 3.3 The *annual* losses and new forests for three decades (a). The four countries with the highest loss of forests (b).

Inpe. Environmentalists accuse Brazil's President Jair Bolsonaro of allowing deforestation to accelerate. It is suggested that as much as 94% of deforestation in Brazil could be illegal. Deforestation has led to large amounts of habitat and biodiversity loss in the Amazonas. Since 2001, around 100 000–190 000 km^2 of Amazon rainforest has been impacted by fires, potentially affecting the ranges of 77–85% of species that are listed as threatened in this region.[81]

- *DR Congo*: The Congo rainforest is the second largest in the world. Greenpeace estimates that illegal logging is a large cause of the deforestation.[82] Timber gets smuggled outside Congo even though both the USA and EU have banned importing illegal timber. In 2021 Congo lost almost 5 000 km^2 of tropical forest.
- *Indonesia*: the main contributor to deforestation is clearing land for oil palm plantations.
- *Bolivia* lost almost 3 000 km^2 of tropical forest in 2021.

Forests are cleared for local agriculture subsistence. The sad consequence is that the loss of biodiversity will decrease the food supply systems and the ability to adapt to future climate change.

As mentioned earlier the OCO-2 and OCO-3 satellites have provided huge amounts of CO_2 observations. We have always considered the tropical rain forests of the world as the 'lungs of the planet', the most important absorber and storage place of CO_2.

Of global forest cover:

- Tropical and subtropical forests make up 56%
- Forests in temperate regions make up 16%
- Boreal forests in the north make up 27%.

All have an important role to play.

More than 5 years of data from the OCO-2 tell the discouraging story that the tropical regions are a net *source* of CO_2, at least since 2009, according to NASA.[83] Measurements of CO_2 in the tropics are consistently higher than anything around them, and this is still confusing scientists. By observing solar-induced fluorescence (SIF) from chlorophyll in plants, the rate at which plants convert light from the sun and CO_2 from the atmosphere into chemical energy can be measured. It is consistently found that plant respiration is outstripping vegetation's ability to absorb CO_2. It happens throughout the tropics, and almost all the time

However, there are other remarkable consequences. Northern mid- and high-latitude rainforests are now absorbing more CO_2, probably because the growing seasons has become longer. Data so far cannot verify if this has always been the case, but satellite data will produce more evidence with time.

On top of the overshadowing issue of biodiversity, there are so many apparent benefits of trees:

- They reduce heat by providing shade and cool surface temperatures. Urban areas can save air conditioning energy on hot days.
- They absorb carbon and remove pollutants from the atmosphere.

- Trees can improve water quality by taking in polluted surface water and absorbing nitrogen and phosphorus into the soil. Trees reduce flooding by absorbing water and reducing runoff into streams, thus reducing flooding vulnerability (see section 4.3). Trees reduce unpleasant noise while providing enjoyable rustling.

3.8 ACTIONS NEEDED

The needed actions are so apparent and so complex: burning fossil fuels must be phased out as soon as possible. Actions needed are presented in numerous publications, and IPCC has exhaustive lists. They should involve almost all aspects of our lives. Let us just mention a few of them:

- Emphasize the importance of cross-sectoral interactions
- Consider every aspect of our life, where we burn fossil fuels
- How we produce and consume electrical energy
- How we transport goods and people
- How we heat and cool and homes and buildings
- How we take care of and use our water resources
- How we produce and distribute food
- What we eat
- Our economic system and its impact on resource utilization
- How rich countries treat poor countries
- How economic inequality should decrease.