Chapter 7
Climate Emergency

In the first six chapters of this book, we address the three major causes of the ongoing socio-environmental collapse: (1) the decline in forest cover, in water resources, and in soils, driven by the globalized corporate food system; (2) widespread pollution of the environment and intoxication of organisms, and (3) the increasing consumption of fossil fuels, with their equally devastating impacts on ecosystems. In this chapter and the next one, we will address the crux of the planetary environmental crisis: the increasing Earth’s Energy Imbalance (EEI), or the climate emergency, which is deemed the most systemic and impending threat to humankind and to the biosphere in general. This chapter will address the problems on which there is scientific consensus, notably expressed in the IPCC’s Assessment Reports, while the next one will deal more broadly with the uncertainties about the possible outcomes of these ongoing processes. Chapters 10, 11, and 12, which conclude the first part of this book, will discuss the immediate consequences of climate change to humanity and to biodiversity. This chapter and the next one occupy, therefore, a central position in the first part of this book and the preceding chapters can be understood as a long introduction to them.

7.1 The Peak in Global Greenhouse Gas Emissions Is Not Yet in Sight

The physiochemical processes involving carbon release and removal from the atmosphere and oceans were in balance before the Industrial Revolution. In less than two centuries, and especially after 1950 (Steffen et al. 2015), deforestation and the burning of fossil fuels caused an increasing share of carbon—accumulated and stored in forests and underground during historical periods and preceding geological times—to be released into the Earth system. We saw in chapter two that between 1800 and 2010, the growing globalization of capitalism was responsible for the destruction of
ten million km² of forests on the planet. We also saw that between 2001 and 2018 alone, there was a global decrease in tree cover of 3.61 million km² (Fig. 2.3). Due to deforestation, heavily concentrated in the last 50 years, only 450 Gt of carbon was stored by the terrestrial biomass in 2018, a reduction of more than 50% compared to 916 Gt of carbon present in the hypothetical absence of land use change, under current climate conditions (Erb et al. 2018).

Regarding CO₂ emissions from 1750 to 2018, more than 1600 GtCO₂ have been emitted into the atmosphere, especially by industrialized societies. The curve of increase in these emissions is so steep that already in 2014, when a combined 1480 GtCO₂ had been released into the atmosphere, more than half of this release had occurred since 1988 (ironically, the year when, thanks to James Hansen, the evidence of human-caused warming first became widely known), as shown in Fig. 7.1.

More than half of the anthropogenic CO₂ emissions since the Industrial Revolution has occurred in the last three decades, dominated by a runaway globalization of corporate capitalism. The unprecedented concentration of income generated by this process is expressed in the extreme carbon inequality: the richest 10% of people around the world are now responsible for almost 50% of global CO₂ emissions, while the poorest 50% are responsible for only 10% of them (Gore 2015). We will discuss this in detail in chapter nine (Demography and Democracy), but it is worth remembering at the outset that, according to Timothy Gore, from Oxfam, the richest 10% have average carbon footprints 11 times higher than the poorest half of the population and 60 times higher than the poorest 10%. An average Australian or American generates 3.5 times the global average, almost 17 tons of CO₂ per capita.
every year, or more than twice the amount of someone in Europe and China (Jackson and Canadell 2019). If regulations were to force the richest 10% to cut their CO₂ footprint to the level of the European average citizen, global emissions would be reduced by 30% (Anderson 2019). The NGO Atmosfair calculates that a simple return flight from London to New York generates almost one ton of CO₂ per passenger. This estimate does not include emissions generated by building the airplane, nor any other emissions indirectly generated by this trip. It includes only the CO₂ emitted by burning jet fuel. The average citizen of 56 countries in Africa and South America emits less CO₂ over the whole year than each passenger during that flight alone (Kommenda 2019). The unbridled consumption of the richest 10% explains why there is no deceleration in the increase in global CO₂ emissions. Figure 7.2 shows the evolution of these emissions from the burning of fossil fuels between 1965 and 2018.

Note that in 2017 and 2018, the rate of increase in these emissions was the highest in the second decade and occurred at rates similar to those of the first decade. CO₂ emissions went up in 2018 by more than 2%, the fastest rate of increase in the last 7 years. The USA, China, and India increased their emissions by 2.5%, 4.7%, and 6.3%, respectively. Using aircraft measurements over Canadian oil sands, John Liggio and colleagues (2019) indicate that:

CO₂ emission intensities for oil sand facilities [in Canada] are 13–123% larger than those estimated using publicly available data. This leads to 64% higher annual GHG emissions from surface mining operations, and 30% higher overall oil sand GHG emissions (17 Mt) compared to that reported by industry.

Between 1990 and 2017, global CO₂ emissions increased by 63% (GCP, Global Carbon Budget 2018). Anthropogenic emissions of all GHG, expressed in terms of global warming potential of CO₂ (CO₂-eq), increased by almost the same proportion. In 2017, they reached 55.1 GtCO₂-eq, having increased 55% in relation to 1990 and 40% in relation to 2000, as shown in Fig. 7.3.

![Fig. 7.2 CO₂ global emissions in Gt (1965–2018) from fossil fuels. From bottom to top: USA, Europe, China, India, all others. (Source: Figueres et al. 2018, based on Global Carbon Project)](image-url)
According to the IPCC SR1.5C (2018), global emissions of CO₂ must peak by 2020 to ensure a reasonable chance that global warming will not exceed 1.5 °C above the pre-industrial period until 2100. But, as seen in the previous two chapters, low-carbon renewables are not replacing fossil fuels. They are just diversifying and adding more alternatives to society’s energy greed. There are no convincing signs that the fossil fuel consumption curve and, hence, global GHG emissions will begin its decline phase in a foreseeable future. Global CO₂ emissions hit an all-time high in 2019 (+0.6% from 2018 or about 43.1 GtCO₂, according to the Global Carbon Project), and all projections indicate an increase in fossil fuel consumption over the next decade (Andrews 2017).

7.2 The Current CO₂ Atmospheric Concentration Is Unprecedented Over the Past 3 Million Years (and Its Rate of Increase Is Unprecedented Over At Least the Past 55 Million Years)

Thanks to the measurement method created by Charles David Keeling (1928–2005) at the Mauna Loa observatory in Hawaii, the Keeling curve has been used since 1958. It measures the concentration of CO₂ in the atmosphere in parts per million.
(ppm) at an altitude of 3400 m in the northern subtropics. Other centers for measuring these concentrations exist in other countries and latitudes, with very close results. In 1750, these concentrations were at about 227 parts per million (ppm). In 2019, they had momentarily reached 415 ppm. Since 2000, the increase in atmospheric CO₂ concentrations has been around 20 ppm per decade, which is up to 10 times faster than any sustained rise in CO₂ during the past 800,000 years (Steffen et al. 2018). In 2013, when these concentrations hit 400 ppm, Ron Prinn (2013) warned that there was more CO₂ in the Earth’s atmosphere than ever before in the past three million years (see also Rahmstorf 2017). Matteo Willeit and colleagues (2019) confirmed this estimate: “the current CO₂ concentration is unprecedented over the past three million years,” that is, it is equivalent only to the Pliocene (the epoch in the geologic timescale that extends from 5.33 million ton 2.58 million years BP).

More worrying than the magnitude of these CO₂ concentrations is its rate of increase, as shown in Table 7.1.

Between 1959 and 1997, there was no annual increase above 2.2 ppm. Between 1998 and 2016, there were six annual increases above 2.2 ppm. In this most recent period, there were three real jumps of 2.93, 3.03, and 2.77 ppm in 1998, 2015, and 2016, respectively, and the estimated margin of uncertainty at these growth rates is 0.11 ppm/ year. Finally, between May 2018 and May 2019, there is a jump of about 3.5 ppm. Three of the four highest annual increases in CO₂ atmospheric concentrations have occurred in the past 4 years (2015–2018). “The rate of CO₂ growth over the last decade is 100–200 times faster than what the Earth experienced during the transition from the last Ice Age. This is a real shock to the atmosphere” (Tans 2017). According to a review published in 2013 by the US National Research Council of the National Academies (Somero et al. 2013):

Past increases in CO₂ occurred over periods of hundreds of thousands to millions of years, and thus differ considerably from the very rapid present day increase related to human activities. The current rate of increase in the level of atmospheric carbon dioxide is unprecedented over at least the past 55 million years. The rate is far greater than occurred in even the most rapid events known from Earth history, and each of these past events were accompanied by important changes in ocean chemistry and mass extinctions of ocean or terrestrial life or both.

| Decade         | Atmospheric CO₂ average growth rates (Parts per million / year) |
|---------------|---------------------------------------------------------------|
| 2005–2014     | 2.11                                                          |
| 1995–2004     | 1.87                                                          |
| 1985–1994     | 1.42                                                          |
| 1975–1984     | 1.44                                                          |
| 1965–1974     | 1.04                                                          |
| 1959–1964 (6 years only) | 0.73                                                  |

Source: CO₂ Acceleration [https://www.co2.earth/co2-acceleration](https://www.co2.earth/co2-acceleration) (Concentrations apply to the lower 75–80% of the atmosphere, known as the troposphere)
Ken Caldeira (2012) presents this same worry: “In geologic history, transitions from low to high-CO$_2$ atmospheres typically happened at rates of less than 0.00001 degree a year. We are re-creating the world of the dinosaurs 5,000 times faster.”

496 ppm CO$_2$-eq (2018)
If we consider the CO$_2$ equivalent (ppm CO$_2$-eq), that is, the atmospheric concentrations of all GHGs expressed in terms of the atmospheric warming potential of CO$_2$, the current atmospheric concentration (2019) is not around 410 ppm, but 496 ppm CO$_2$-eq (2018), with a 30% increase in these concentrations in just 40 years: 1979 = 382 ppm; 1990 = 417 ppm; 2010 = 468 ppm; 2018 = 496 ppm (NOAA/AGGI, Spring 2019).

Between 2011 and 2018, the average rate of increase of these concentrations was 1.6% per year. If this rate is maintained (without further acceleration), the doubling of these concentrations from 496 ppm to 992 ppm will occur in 45 years, that is, by the mid-2060s, implying a likely average global temperature increase of 3–4 °C above the pre-industrial period. This level of warming is deemed incompatible with any civilization along the lines of what we know today.

7.3 Between 1.2 °C and 1.5 °C and Accelerating

As the IPCC Special Report 1.5, 2018 asserted for the umpteenth time, “the total amount of CO$_2$ emitted until we reach the threshold of zero global emissions largely determines the amount of warming to which we are committed. We know, therefore, that much more warming is coming. But any reflection on the future scenarios of the climate system and, thus, on the habitability of our planet, must begin with a brief description of the current state of the global climate system. “The average temperature of the last 5 years [2014–2018] was 1.1°C higher than the pre-industrial average (as defined by the IPCC)” (Copernicus Climate Change Service 2019). The 2019 global temperature was 1.2 °C warmer than in the 1880–1920 base period, according to the Goddard Institute for Space Studies global temperature analysis (Hansen et al. 2020). Global average warming may exceed 1.2 °C by 2020 as “monthly temperatures over the past 12 months [October 2018 – September 2019] have averaged close to 1.2°C above the pre-industrial level.” (Copernicus Climate Change Service, “Surface air temperature for September 2019”). Figure 7.4 shows this escalation in global warming in 2019 of 1.2 °C above the average of the 1880–1920 base period.

As can be seen, despite the interannual temperature variations caused by El Niño and other geophysical phenomena, global warming has become, more than ever before, a certainty that is empirically measurable. This can also be inferred from the following evidence, based on data from GISS-NASA, NOAA, MET Office, and WMO:

1. Global temperature hasn’t been cooler than the twentieth-century average since 1976.
2. “Each decade from the 1980s has been successively warmer than all the decades that came before. 2019 concludes the warmest ‘cardinal’ decade (those spanning years ending 0–9) in records that stretch back to the mid-19th century” (MET Office, Press Office, 15/I/2020).

3. Of the 22 warmest years on record, 20 have occurred since 1998.

4. The last 6 years (2014–2019) rank as the warmest on record.

5. 2017 and 2019 were the warmest non-El-Niño years on record.

6. Already in 1999, Michael Mann, Raymond Bradley, and Malcom Hughes had shown, with the famous graphic dubbed hockey stick (Mann 2012), that in the late twentieth century, temperatures were warmer than during the past millennium. More recent research (Marcott et al. 2013), not only confirms the iconic hockey stick but also shows that the global temperature variation observed in the Anthropocene (the proposed current geological epoch), especially since the 1980s, is greater than any other variation throughout the Holocene (11,700 years ago – to 1950). During these almost 12 millennia, natural climate variability has not reached 0.5 °C above or below the 1961–1990 average. Moreover, there is no evidence that the temperature variations observed during the Holocene—the so-called Medieval Climate Anomaly and the “Little Ice Age”—were global phenomena. Based on PAGES 2 k, a compilation including nearly 700 records from trees, ice, sediment, corals, cave deposits, and other sources of information, Raphael Neukom and colleagues (2019) can affirm that the warming observed in the late twentieth century alone occurred simultaneously in more than 98% of the globe. “This provides strong evidence that anthropogenic global warming is not only unparalleled in terms of absolute temperatures, but also unprecedented.
in spatial consistency within the context of the past 2,000 years.” Actually, the Earth’s current climate has already surpassed the warmest period of the Holocene (Marcott et al. 2013) and may be as warm as it was during the Eemian, the prior interglacial period (Hansen et al. 2016).

7. Current warming exceeds the Holocene’s natural variability not only in magnitude, but also in speed. It is much greater than the warming that took place in geological times prior to the Holocene (Aengenheyster et al. 2018).

8. The acceleration of warming in the twenty-first century is absolutely exceptional, even in relation to the late twentieth century. The pace of warming multiplied by a factor of 2.5 in the 2008–2017 period, reaching a rate of 0.43 °C per decade compared to the 1970–2014 period when it still rose at a rate of 0.17 °C per decade in relation to the 1951–1980 period, as shown in Fig. 7.5.

![Fig. 7.5](image_url) Acceleration of the 10-year average global warming rate in 2008–2017 compared to 1970–2014, relative to the 1951–1980 average. Land data prepared by Berkeley Earth and combined with data adapted from the UK Hadley Centre. Global temperature anomalies relative to 1951–1980 average. (Source: Based on Climate Change Data Center from the Chiangmai University [http://ccdatacenter.org/PageFact.aspx?FactPageID=8&Categories=YES])

### 7.3.1 Spatial Distribution: Global vs. Regional Warming

There is, therefore, a consistent and growing body of evidence showing that the rise in the Earth’s average surface temperatures is not only occurring, but also accelerating. However, as is well-known, the Earth has not warmed evenly over the past century. Two major differentials should be noted in the spatial distribution of warming: (a) warming over continents is faster than over oceans (and, therefore, it tends to be
faster in the Northern Hemisphere than in the Southern Hemisphere); and (b) warming at high latitudes is also faster than global average warming. Figure 7.6 discriminates between terrestrial and ocean warming between 1880 and 2018 relative to the 1880–1920 base period.

Compared to the 1880–1920 period, global land warming reached 1.8 °C in 2016, dropping to 1.6 °C in 2018, while global ocean warming, naturally much slower, reached 1 °C in 2016 and 0.8 °C in 2018. From the late 1970s on, land and sea warming rates have become more clearly divergent, with land warming increasing at a much faster rate. Consequently, in various terrestrial regions of the planet, especially at high latitudes, the warming that occurred until 2019 has already exceeded the 2 °C threshold, when compared to the pre-industrial period. According to data from Berkeley Earth, roughly one-tenth of the planet surface has already warmed by more than 2 °C when the last 5 years (2014–2018) are compared with the mid- to late 1800. Regarding the higher warming velocity at high latitudes when compared to the global average, measurements at the Byrd station showed that average temperatures in Central West Antarctica had already risen by 2.4 °C (+/−1.2 °C) between 1958 and 2010 alone (Bromwich et al. 2013).¹

Over the past 50 years, the Arctic region has warmed more than any other region on Earth, a phenomenon known as Arctic amplification. According to NOAA, in the first half of 2010, air temperatures in the Arctic were 4 °C warmer than the

¹See also “West Antarctica Warming Three Times Faster Than Global Average, Threatening To Destabilize This Unstable Ice Sheet.” Climate Progress, 27/XII/2012
1968–1996 reference period. Arctic atmospheric changes from 1971 to 2017 indicate warming: by 2.7 °C at the annual scale, by 3.1 °C in the cold season (October–May), and by 1.8 °C in the warm season (June–September) (Box et al. 2019). Due to these major climate anomalies, we find unprecedented weather patterns in the Arctic. In 4 out of the past 5 years (2014–2018), the North Pole has experienced the most intense heat waves ever recorded (historical records began in 1958), with temperatures of 17–19 °C above normal (Samenow 2018). In February 2016, parts of the Arctic reached temperatures above freezing that were more than 16 °C above the average for this month. In February 2018, although it was still practically without sunlight, Siberia’s temperature reached 35 °C above the historical average for that month. In the middle of a February 2018 winter night, the temperature in Greenland stayed above zero, three times the average of any previous year, for 61 successive hours (Watts 2018). In Finland and Scandinavia, temperatures have exceeded several historical records, with temperatures of around 33 °C sometimes at latitudes above 70°N. On the night of July 18 to July 19, 2018, the temperature did not drop below 25.2 °C at 70.7°N, the hottest night ever seen in northern Scandinavia, on the shore of the Barents Sea in the Arctic Ocean.

Outside the Arctic, temperatures in the Northern Hemisphere are also warming at an average rate faster than the Southern Hemisphere, because, as already mentioned, it contains more land. According to the Japan Meteorological Agency, the rise in temperatures in the Northern Hemisphere has been consistently double that of the Southern Hemisphere; in 2018, this rise corresponded, respectively, to 0.41 °C and 0.20 °C above the 1981–2010 average. During the last decade (2008–2017), the average annual temperature in European land areas was between 1.6 °C and 1.7 °C above the pre-industrial level, but strong temperature anomalies are also found in the Southern Hemisphere. In the winter of 2015, temperatures reached 3–4 °C above normal in Brazil (Nobre et al. 2019). In 2014, the Southeastern region of Brazil had already registered temperatures between 1 °C and 2 °C higher than the 1961–1990 average (Marengo 2014). And in the Northeastern region of the country, the average temperature increased by 2.5 °C in the last decades compared to this same period.

As shown also in Fig. 7.6, from 2014 onward, the rise in the temperature curve of ocean, as well as terrestrial areas, becomes steeper. This acceleration in ocean heating has been observed at increasing depths. In the first decade of the twenty-first century, about 30% of the heating was already occurring beyond a depth of 700 meters (Balmaseda et al. 2013). There was a surge in ocean warming in 2017, by far the hottest year on record for the oceans, when the top two thousand meters of the oceans were $1.51 \times 10^{22}$ Joules hotter than in 2015, the second hottest year of these records. As a reference, the increase in oceanic heat in 2017 alone was 699 times greater than all the electricity generated in China in 2016 (Cheng and Zhu 2018).

“The ocean has been heating at a rate of around 0.5–1 watt of energy per m² over the past decade, amassing more than $2 \times 10^{23}$ joules of energy — the equivalent of roughly five Hiroshima bombs exploding every second — since 1990” (Katz 2015).

The linear trend of ocean heat content (OHC) at a depth of 0–700 m during 1992–2015 shows a warming trend four times stronger than the 1960–1991 period (Cheng et al. 2017).
7.4 Suffering and Greater Lethality due to the Current Warming

An average global warming of 0.74 °C already in 2005 (reported by the IPCC in 2007) was capable of triggering unbelievable socio-environmental crises in the history of civilization. The suffering inflicted on humans and on so many other life-forms by the current warming is tremendously greater. It cannot, however, be grasped by abstract trends, such as a global average warming of 1–1.5 °C. In the world of concrete experience, these references are translated in many tragic ways.

As stressed by the World Health Organization (WHO), vectors, pathogens, and hosts survive and reproduce within a range of optimal climatic conditions. Changes in infectious disease transmission patterns are a likely major consequence of climate change. The increasing burden of insect-borne or tick-borne diseases caused by bacteria, viruses, and protozoa is now being exacerbated by higher temperatures. In July 2016, an outbreak of anthrax in Siberia killed more than 2000 reindeers. Populations of insects such as *Aedes aegypti* and *Aedes albopictus* or arachnids, like ticks, are clearly increasing at low latitudes and spreading toward higher latitudes, thanks to milder winters and longer and warmer summers. These vectors transmit a number of serious, and sometimes lethal, diseases that tend to acquire epidemic proportions. Global warming is also fueling a rise in dangerous fungal infections. As pointed out by Arturo Casadevall, “as the climate has gotten warmer, some of these organisms, including *Candida auris*, have adapted to the higher temperature, and as they adapt, they break through human’s protective temperatures” (Andrei 2019).

Global warming also increases ozone concentrations and atmospheric pollution and already decreases yields of major crops in some regions. Global maize and wheat production, for instance, declined by 3.8 and 5.5%, respectively, between 1980 and 2008, relative to a counterfactual without climate trends (Lobell et al. 2011). Furthermore, according to Kristie Ebi and Irakli Loladze (2019):

Increased concentrations of CO$_2$—by directly affecting plants—worsen the nutritional quality of food by decreasing protein and mineral concentrations by 5–15%, and B vitamins by up to 30%. Higher CO$_2$ concentrations increase photosynthesis in C$_3$ plants (e.g., wheat, rice, potatoes, barley), which can increase crop yields. But those increases come at the cost of lower nutritional quality as plants accumulate more carbohydrates and less minerals (e.g., iron and zinc), which can negatively affect human nutrition.

Current warming is the indirect cause of an increasing number of deaths from droughts, floods, landslides, extreme weather events, forest fires, agricultural crises, malnutrition, forced displacement, etc. Moreover, it is the direct cause of heat waves, defined as a combined measure of temperature and relative humidity (heat index). An extreme heat wave occurs when summertime temperatures are much

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2 Cf. IPCC, Fourth Assessment Report, 2007, p. 2: “The 100-year linear trend (1906–2005) of 0.74 [0.56 to 0.92]°C is larger than the corresponding trend of 0.6 [0.4 to 0.8]°C (1901–2000) given in the Third Assessment Report.”
hotter and/or humid than is typical for a location. Increasingly hot summers are now taking place with more frequent and extreme heat waves, such as the heat wave that swept Europe in 2003, Australia in 2012–2013 and 2019–2020, the “Lucifer” heat wave in Europe in 2017, and the heat waves that hit the Northern Hemisphere in 2018, 2019 and 2020. Warmer winters also follow, sometimes (since the 1990s) with exceptional cold spikes in North America and Eurasia (Overland et al. 2016; Kretschmer 2018). But, the disproportion between hot and cold record temperatures is stark. In 2018, a year without El Niño, weather stations recorded 40 cold records and 430 absolute heat records (Wong 2019).

Today, exposure, for just a few hours, to an extreme heat wave can cause damage to the brain and other vital organs or even death by hyperthermia, heat exhaustion, or heat stroke. This is especially the case after 2003, when the first of these well-documented phenomena in Europe caused about 70,000 premature deaths. From June to October 2010, a second heat wave with several record-breaking temperatures devastated the Sahel, the Eastern United States, the Middle East, Eastern Europe, Russia, and China, causing deadly forest fires. In several regions of Russia, one of the countries most affected by these fires, temperatures in June and July 2010 ranged from 36 °C to 42.3 °C (Belogorsk), with 44 °C being the highest temperature ever recorded in Russia on July 11, 2010, in Yashkul, near the Black Sea. Since 2015, the World Meteorological Organization (WMO) has repeatedly acknowledged unbearable temperatures for the human body, between 45 °C and 54 °C, in China, India, Pakistan (53.7 °C), Afghanistan, Iran, Iraq, Jordan, Oman, Turkey, France (45.9 °C), Spain (47.7 °C), Australia (49.9 °C), and Kuwait (Mitribah, 2016, 54 °C), the first country to make it illegal to work in the sun from 11 a.m. to 5 p.m. between July 1 and August 31. According to the WMO Archive of Weather and Climate Extremes, the Mitribah, Kuwait temperature is now accepted as the highest temperature ever recorded for the continental region of Asia. In June 2019, temperatures reached 48 °C in New Delhi, the highest ever recorded in the capital in this month, and hundreds of people were killed in the eastern state of Bihar, where a curfew was imposed, preventing people from going outside. The Nature editorial of June 22, 2017, reflects the concern that heat waves are increasingly exceeding human thermoregulatory capacity:

From extreme rainfall to rising sea levels, global warming is expected to wreak havoc on human lives. Sometimes, the most straightforward impact – the warming itself – is overlooked. Yet heat kills. The body, after all, has evolved to work in a fairly narrow temperature range. Our sweat-based cooling mechanism is crude; beyond a certain combination of high temperature and humidity, it fails. To be outside and exposed to such an environment for any length of time soon becomes a death sentence.

Camilo Mora and colleagues (2017) identified a global threshold beyond which daily mean surface air temperature and relative humidity become deadly and showed that around 30% of the world’s population (13.6% of land area) is currently exposed to climatic conditions exceeding this deadly threshold for at least 20 days a year. Also, the “Lancet Countdown,” a collective effort published under the coordination of Nick Watts (2017), affirms that:
The evidence is clear that exposure to more frequent and intense heatwaves are increasing, with an estimated 125 million additional vulnerable adults exposed to heatwaves from 2000 to 2016. Higher ambient temperatures have resulted in estimated reduction of 5.3% in labour productivity, globally, from 2000 to 2016.

The current trend toward more intense, expansive, longer-lasting, and more frequent heat waves is clear. James Hansen, Makiko Sato, and Reto Ruedy (2012) demonstrated a higher probability of extremely hot summers compared to the years 1951–1980 and “the emergence of a category of ‘extremely hot’ summers, more than $3\sigma$ [standard deviations] warmer than the base period mean” (1951–1980). Moreover, while these extreme summer heat waves covered much less than 1% of Earth’s surface during the base period, they typically covered about 10% of the land area in 2012. Concerning the number and the recurrence of extreme heat waves, “worldwide, the number of local record-breaking monthly temperature extremes is now on average five times larger than expected in a climate with no long-term warming” (Coumou et al. 2013). Events that would occur twice a century in the early 2000s are now expected to occur twice a decade (Christidis et al. 2014). Referring to the European heat waves in the summer of 2018, Peter Stott declared at the COP24 (December 2018) that “the intensity of this summer’s heatwave is around 30 times more likely than would have been the case without climate change.”

The future will bring more severe and more lethal heat waves. Mora and colleagues (2017) predict that a global warming of 2 °C could expose 48% of the population to deadly heat waves. They project that in 2100, this percentage will be about 74% of the global population, maintaining the current scenario of rising emissions with global warming at 4 °C above the pre-industrial period. The heat lethality threshold will then be reached for 365 days a year in the equatorial region, making it, therefore, uninhabitable and will condemn what remains of the Amazon rainforest and of rainforests in general to final disappearance. The authors conclude: “An increasing threat to human life from excess heat now seems almost inevitable, but will be greatly aggravated if greenhouse gases are not considerably reduced.” Commenting on his own work, Camilo Mora concludes: “for heat waves, our options are now between bad or terrible. Many people around the world are already paying the ultimate price of heatwaves” (as quoted by Chow 2019). According to the IPCC’s Special Report 1.5 °C (2018), the difference between a warming of 1.5 °C and a warming of 2 °C in the tropics is equivalent to a difference in heat waves lasting 2 or 3 months. In Europe, a heating of 1.5 °C or 2 °C is expected to cause the July 2018 heat wave to repeat itself every 2 years or every year, respectively. In the USA, by the mid-twenty-first century (2036–2065), the annual numbers of days with heat indices exceeding 37.8 °C and 40.6 °C are projected to double or triple under RCP4.5 and RCP8.5 emission scenarios, respectively, compared to a 1971–2000 baseline (Dahl et al. 2019).

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3 Cf. MET Office, “2018 UK summer heatwave made thirty times more likely due to climate change,” 6/XII/2018
7.5 2 °C: A Social–Physical Impossibility

In a historic Ted Talk, titled “Why I must speak about climate change” (2012), James Hansen, former director of NASA’s Goddard Institute for Space Studies, made the most didactic and decisive argument on how the Earth’s system is already locked into successive temperature increases:

There is a temporary energy imbalance. More energy is coming in than going out until Earth warms up enough to again radiate to space as much energy as it absorbs from the Sun. More warming is in the pipeline. It will occur without adding any more GHG.

More recently, James Hansen and colleagues (2016) reiterated the inevitability of this future warning: “Earth is out of energy balance with present atmospheric composition, implying that more warming is in the pipeline.” Let us repeat once more: as long as this Earth Energy Imbalance (EEI) persists, the planet’s temperature will inevitably increase, even “without adding any more GHG,” as James Hansen states. This imbalance is already huge. According to Kevin Trenberth and colleagues (2016, 2018), the Earth’s current Energy Imbalance (EEI) amounts to about 1 Watt/m² (0.9 +/- 0.3 W/m²) or about 500 terawatts globally for the period of 2005–2014. How much is a terawatt (TW) or a million megawatts? In 2008, for example, humans used energy (this includes all types of energy, not just electricity) at an average rate of about 16.5 TW of power.⁴ “Even during the solar minimum,” James Hansen (2018) says, “it was equivalent to the energy of 400,000 Hiroshima atomic bombs per day every day of the year.” Moreover, simulations done by Catherine Ricke and Ken Caldeira (2014)—on the time series of marginal warming for the first 100 years after CO₂ emission—show that “maximum warming occurs a median of 10.1 years after the CO₂ emission event.” In other words, the more than 41Gt of CO₂ emitted by mankind in 2019 will have its full impact on global warming in the late 2020s. In short, we are warming the planet on credit.

7.5.1 The Imminence of 1.5 °C

The IPCC and almost all statements on global warming take the “pre-industrial” period as their reference period and place it in the years 1850–1900. Michael Mann (2015) correctly disputes this conventional definition:

[T]he base year implicitly used to define “pre-industrial” conditions is 1875, the mid-point of that interval. Yet the industrial revolution, and the rise in atmospheric CO₂ concentrations associated with it, began more than a century earlier. (...) It is evident that roughly 0.3 °C greenhouse warming had already taken place by 1900, and roughly 0.2 °C warming by 1870. While that might seem like a minor amount of warming, it has significant implications for the challenge we face in stabilizing warming below 2 °C, let alone 1.5 °C.

⁴See Climate Central, “Helpful Energy Comparisons, Anyone? A Guide to Measuring Energy,” 14/VII/2011.
If Mann’s adjustment is adopted, the current global warming average of 1.2 °C (2019) should be about 1.5 °C above the “true” pre-industrial period (1750–1850). But even if we adopt the conventional base period (the second half of the nineteenth century), the strong 2016 El Niño effect caused the planet’s average temperature to approach or even momentarily surpass the Paris Agreement target: in February 2016, for the first time, monthly average global warming exceeded 1.5 °C above the 1880–1899 average, and the year 2016, as a whole, was hotter than this same period by an average of 1.24 °C.

In any case, a global warming average above 1.5 °C relative to the 1850–1900 average is considered imminent. The IPCC (SR1.5 2018) projects that “global warming is likely to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate.” This prediction was considered conservative by many scientists. As Michael Mann warned: “We are closer to the 1.5°C and 2°C thresholds than they [IPCC, SR1.5 2018] indicate and our available carbon budget for avoiding those critical thresholds is considerably smaller than they imply. In other words, they paint an overly rosy scenario by ignoring some relevant literature” (Waldman 2018). Also for the European Environment Agency, the 1.5 °C mark can be reached much earlier than the IPCC suggests: “If the concentrations of the different greenhouse gases continue to increase at current rates, peak concentration levels required to stay below a temperature increase of 1.5°C above pre-industrial levels could be reached within the next 3–13 years.”5 The IPCC’s prediction can be considered too cautious also because, as seen above (Fig. 7.5), global warming is not increasing at the same rate. It is currently (2008–2017) accelerating and unfolding at a rate of 0.43 °C per decade. According to the MET Office’s Decadal Forecast (January 2020), during the 5-year period 2020–2024, global average temperature is expected to remain between 1.06 °C and 1.62 °C (90% confidence range) above the pre-industrial period (1850–1900) with a small (~10%) chance of 1 year temporarily exceeding 1.5 °C. This first possible breach of the 1.5 °C threshold in the global annual average by 2024 would still be momentary, that is, it is subject to the usual interannual temperature variations. But it may become irreversible as early as the second half of the third decade (Henley and King 2017; Stone 2017; Xu et al. 2018).6 Kevin Trenberth expresses the same view. He declared in 2016: “I don’t see at all how we’re going to not go through the 1.5 degree-number in the next decade or so” (Schlossberg 2016).

More important than predicting the date—after 2025 or after 2030 (IPCC)—when we will irreversibly go beyond 1.5 °C, is understanding that avoiding this threshold now seems to be a nearly impossible task. For Chris Field, co-director of the IPCC, “the 1.5°C goal now looks impossible or at the very least, a very, very difficult task. We should be under no illusions about the task we face” (McKie 2016). Drew Shindell, co-author of the IPCC SR1.5 (2018), affirmed in September

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5 See EEA’s Indicator Assessment, published on 5/XII/2019, last modified 25/II/2020. https://www.eea.europa.eu/data-and-maps/indicators/atmospheric-greenhouse-gas-concentrations-6/assessment-1

6 See also Climate Central Research Report, “Flirting with the 1.5 °C Threshold.” 20/IV/2016
2018: “It’s extraordinarily challenging to get to the 1.5°C target and we are nowhere near on track to doing that. While it’s technically possible, it’s extremely improbable, absent a real sea change in the way we evaluate risk. We are nowhere near that” (Milman 2019). With the US decision to leave the Paris Agreement, the further increases in coal consumption in 2017 and 2018 (see Chap. 6), and the brutal regression in climate mitigation policies in Brazil, Australia, Japan, and some Eastern European countries, the current chances of slowing down global warming are virtually nil.

That said, according to the laws of physics, what is the least amount of warming possible for this century? In November 2017, Richard Millar and colleagues maintained that keeping global warming below 2 °C, this century was not yet a geophysical impossibility:

Limiting cumulative post-2015 CO₂ emissions to about 200 GtC would limit post-2015 warming to less than 0.6 °C in 66% of Earth system model members of the CMIP5 [Coupled Model Intercomparison Project Phase 5] ensemble with no mitigation of other climate drivers, increasing to 240 GtC with ambitious non-CO₂ mitigation. (…) Assuming emissions peak and decline to below current levels by 2030, and continue thereafter on a much steeper decline, which would be historically unprecedented but consistent with a standard ambitious mitigation scenario (RCP2.6), results in a likely range of peak warming of 1.2–2.0 °C above the mid-nineteenth century.

This projection has been the subject of much criticism. Andrew Schurer and colleagues (2018), for example, criticized the author’s starting point, that is, the use of an observational dataset (HadCRUT4) that does not include data from the Arctic, which has been found to be warming at a rate much faster than the global mean. In fact, in 2017 global warming was already about 1.1 °C above the pre-industrial period, not “about 0.9°C from the mid-nineteenth century,” as the authors propose. Furthermore, Millar and colleagues do not seem to take due account of the recent increase in atmospheric concentrations of methane and their potential positive feedbacks on the global climate system in a post-1.5 °C world (Wadhams 2015, 2016; Dean et al. 2018; Beckwith 2019; see Chap. 8, particularly Sect. 8.2 The Arctic Methane Conundrum). The increased vulnerability of all forests to fires and their diminishing ability to function as a carbon sink are other positive feedbacks that are not mentioned in the study in question. In fact, in terrestrial ecosystems, the vegetation canopy, from tropical and boreal forests to semi-arid vegetation (Poulter et al. 2014), is largely responsible for land sink, that is, the removal of carbon from the atmosphere by plants through photosynthesis. According to Simon L. Lewis (2009), in the years of the first decade of the century, tropical forests were absorbing 18% of the CO₂ added to the atmosphere each year from the burning of fossil fuels. In the tropics, however, biomass mortality increased, leading to a shortening of carbon residence times. Thus, the benefit once provided by the net increase in biomass has been reversed and is declining in recent years, as shown by Roel Brienen and colleagues (2015):

Atmospheric carbon dioxide records indicate that the land surface has acted as a strong global carbon sink over recent decades, with a substantial fraction of this sink probably located in the tropics, particularly in the Amazon. (…) We find a long-term decreasing trend
of carbon accumulation [in the Amazon forest]. Rates of net increase in above-ground bio-
mass declined by one-third during the past decade compared to the 1990s.

7.5.2 “The Great Deceleration”?

Suppose for a moment, however, that Millar and colleagues are correct in their affir-
mation that keeping global warming below 2 °C is not yet a “geophysical impossi-
bility.” That would be great news. The bad news is that, given society’s weak
political resistance and the current strong power of corporations to impose their
paradigms, worldviews, and business plans on humanity, a global average warming
below 2 °C is now considered a social–physical impossibility. The assumption that
the Great Acceleration, which began around 1950 (Steffen et al. 2015), might be
converted into a “Great Deceleration” while maintaining the political status quo is
illusory. The ten editions of the Emissions Gap Report produced by the United
Nations Environment Programme (UNEP) measure the gap between what countries
have pledged to do to reduce their GHG emissions and what they need to do to meet
the UNFCCC goals. Niklas Höhne and colleagues (2020) show that “the gap has
widened by as much as four times since 2010.” The hypothesis envisioned by Millar
and colleagues that we will not exceed a 200 GtC (about 730 GtCO₂) carbon budget,
based on 2015 emissions, is clearly disconnected from reality. Global annual GHG
emissions increased by 14% between 2008 and 2018. In the present scenario, noth-
ing in the logic of the capital accumulation driving our thermo-fossil civilization
toward its end allows for such a conjecture. From 2016 to 2018 alone, about 120
GtCO₂ and about 160 GtCO₂-eq were emitted globally. These CO₂ emission levels
are projected to grow 0.6% in 2019. Let us not fool ourselves. After an important,
but probably ephemeral, reduction in 2020 caused by the COVID-19 pandemic,
global CO₂ emissions will remain substantially unchanged or even increase further
in the next years. It is practically certain, therefore, that between 2016 and 2024 at
least an additional 320 GtCO₂ will have been emitted globally; this is about 44% of
the carbon budget allowed by the calculations of Richard Millar and colleagues in
order to not exceed a warming of 2 °C above the pre-industrial period. Figure 7.7
shows how radical the reduction in anthropogenic emissions must be or should have
been since 2016, in order to keep global average warming between 1.5 °C and 2 °C
until 2100.

Depending on the chosen probability, a warming below 2 °C would imply that
future emissions be limited to a range between 150 and 1050 GtCO₂. Christiana
Figueres and colleagues (2017) work with the arithmetic mean of these two values
(600 GtCO₂). To reach this limit, net emissions should be zeroed by 2040 and
remain zero throughout the century. In this way, if we had started the reduction
curve in 2016, we would have until 2045 to permanently clear emissions. Nothing
indicates that we will begin a steep decline of CO₂ emissions between 2020 and
2024. If we finally start the decline in net CO₂ emissions by 2025, we will have to
zero them by 2035 and keep them at zero after that. As Christiana Figueres and
colleagues affirmed in 2017, “delaying the peak by a decade gives too little time to transform the economy.”

As is well-known, while the diplomats’ applause still resounded, the Paris Agreement goal to limit global warming “well below” 2 °C above the pre-industrial period was immediately denounced by James Hansen and others as a fictional play (Milman 2015):

It’s a fraud really, a fake. It’s just bullshit for them to say: ‘We’ll have a 2C warming target and then try to do a little better every five years.’ It’s just worthless words. There is no action, just promises. As long as fossil fuels appear to be the cheapest fuels out there, they will be continued to be burned.

Immediately thereafter, in January 2016, 11 eminent scientists affirmed that the Paris Agreement raised a false hope and that the 2 °C warming threshold had become unattainable without a massive use of geo-engineering (Bawden 2016)\(^7\):

The time for the wishful thinking and blind optimism that has characterized the debate on climate change is over. The time for hard facts and decisions is now. Our backs are against the wall and we must now start the process of preparing for geo-engineering. We must do this in the knowledge that its chances of success are small and the risks of implementation are great.

Successive facts confirm these verdicts. Continuing to invoke the pledges made by its signatories as an apotropaic formula cannot and should not conceal the emptiness of this agreement. Such lack of credibility is underlined by David Victor and colleagues (2017):

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\(^7\) Signed by Paul Beckwith (University of Ottawa), Stephen Salter (University of Edinburgh), James Kennett (University of California), Hugh Hunt (Cambridge), Alan Gadian (University of Leeds), Mayer Hillman (Institute of the Policy Studies), John Latham (University of Manchester), Aubrey Meyer (Global Commons Institute), John Nissen (Arctic Methane Emergency Group), Kevin Lister, and Peter Wadhams (University of Cambridge)
No major advanced industrialized country is on track to meet its pledges to control the greenhouse-gas emissions that cause climate change. Wishful thinking and bravado are eclipsing reality (...) National governments are making promises that they are unable to honour.

Peter Wadhams endorses this statement, reaffirming his disbelief in the ability of governments—partners in corporations’ expansive strategies and also dependent on them—to fulfill their own commitments: “The [UK] government can make a commitment saying in 30 years time it will reduce our CO₂ emissions by 80%. They can quote any number they like because they have no intention of keeping to it.” On May 2019, the UK Parliament declared a “climate change emergency.” Hundreds of cities, towns, and countries have also declared “climate emergencies” during 2019. Oxford Dictionaries has declared “climate emergency” the word of the year for 2019 and defined it as “a situation in which urgent action is required to reduce or halt climate change and avoid potentially irreversible environmental damage resulting from it.” But, again, these declarations are not legally binding, and there is no clear definition of what they imply in economic and political terms (see Nature 9/V/2019, p. 165).

Australia, Canada, Japan, South Korea, and South Africa are not even on track to achieve their now plainly inadequate 2015 pledges (Höhne et al. 2020). Furthermore, we must keep in mind that the Paris Agreement is far from being universal. In 2019 it had not yet been ratified by 13 countries which together produce almost a quarter of world’s oil, including Angola, Libya, Iraq, Iran, and Kuwait. With the US decision to abandon the agreement, more than a third of the world’s oil production comes from countries that cannot be accused of not complying with the Paris Agreement because they do not even officially recognize it. Finally, the 2018 tragic election of a far-right government in Brazil, the seventh largest CO₂ emitter on the planet, is another major blow to the effectiveness of global governance.

The dynamics of increased warming, driven by growing GHG emissions and by climate positive feedbacks (see Chap. 8), combined with the failure of the Paris Agreement, explain the scientific community’s skepticism as to the possibility of not exceeding the 2 °C target. Three years ago, Adrian Raftery and colleagues (2017) estimated that there was only a 5% chance that average global warming would be below 2 °C by 2100, compared to the pre-industrial period. Also, in 2017, Andrew Simms surveyed the opinion of a number of experienced climatologists on what chances remain of us not exceeding a global warming of 2 °C above the pre-industrial period:

In short, not a single one of the scientists polled thought the 2C target likely to be met. Bill McGuire, professor emeritus of geophysical and climate hazards at University College London, is most emphatic. “My personal view is that there is not a cat in hell’s chance.”

The IPCC Special Report 1.5 (2018) shows that a warming of 2 °C causes far more deleterious effects on human societies and biodiversity than a warming of 1.5 °C,

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8 Cf. Peter Wadhams, Scientists Warnings.org, 11/XII/2018 https://www.youtube.com/watch?v=AEM2NhPw%2D%2DU
which is already considered very dangerous. As might be expected from an IPCC report, its findings reflect the most representative positions of the scientific community. In fact, as early as 2017, Sir Brian Hoskins had stated to Andrew Simms of *The Guardian*: “We have no evidence that a 1.9°C rise is something we can easily cope with, and 2.1°C is a disaster.” It is certainly a disaster for its reasonably known effects, based on the climate models, but perhaps and most importantly, it is to be feared for its still uncertain or unknown effects (discussed in the next chapter). Also, for the scientists at RealClimate, a “global warming of 2°C would leave the Earth warmer than it has been in millions of years.”

Matteo Willeit and colleagues (2019) give chronological precision to this statement: “global temperature never exceeded the preindustrial value by more than 2°C during the Quaternary” (the last 2.58 million years). Hence, it now seems inevitable that in the near future, the Earth will experience an average temperature never faced by our species and, a fortiori, by agriculture and by the human civilizations that flourished in the 11.7 millennia of relative climatic stability of the Holocene.

### 7.5.3 A 2 °C Warming Will Be Reached in the Second Fourth of the Century

If keeping the Earth’s temperature below 2 °C now seems like a social–physical impossibility, one question arises: when will average planetary temperatures exceed the columns of Hercules of climate, this 2 °C limit of global warming that we could never allow ourselves to exceed? Without any intention of weighing the uncertainties that hinder a more precise answer to this question, projections on a warming of 2 °C above the pre-industrial period converge to the second quarter of this century and, more precisely, to the period between 2035 and 2045. According to the Potsdam Institute for Climate Impact Research (2012), “we could see a 2°C world in the space of one generation.” Michael Mann (2014) projects that, maintaining the baseline scenario, we may exceed the 2 °C limit from 2036 onward. According to Mann, to avoid this, it would have been necessary to keep atmospheric CO₂ concentrations below 405 ppm, while we are already well above 412 ppm. The MET Office forecasts the 2020 annual average CO₂ concentration at Mauna Loa Observatory (Hawaii) to be 414.2 ± 0.6 ppm. For the first time in millions of years, we have hit 416.08 on February 10, 2020, up from 411.97 a year ago and 314 ppm in 1958 when the observations began at Mauna Loa. If the current rate of increase in atmospheric CO₂ concentrations is maintained, by 2030–2035, we will have gone beyond the fateful 450 ppm limit, largely correlated with a global warming of 2 °C above the pre-industrial period. This correlation is restated, for example, in a document titled *Millennium Ecosystem Assessment Findings* (2005):

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*Cf. RealClimate; “Hit the brakes hard”, 29/IV/2009*
The balance of scientific evidence suggests that there will be a significant net harmful impact on ecosystem services worldwide if global mean surface temperature increases more than 2 °C above pre-industrial levels (medium certainty). This would require CO$_2$ stabilization at less than 450 ppm (https://slideplayer.com/slide/711361/).

The IPCC Fourth Assessment Report (AR4 2007) reiterates this prognosis, even if less explicitly: “any CO$_2$ stabilisation target above 450 ppm is associated with a significant probability of triggering a large-scale climatic event.”\textsuperscript{10} Figure 7.8, proposed by the Global Carbon Project (GCP), reaffirms all these estimates.

Sonia Seneviratne and colleagues (2016) point out that a 2 °C target for global warming implies increases much higher than 2 °C over most land regions. Thus, although the authors consider that a 2 °C global warming above the industrial period will occur only by mid-2040, this warming threshold was already crossed in the Arctic around the year 2000 and should be crossed regionally by 2030 “in the Mediterranean, Brazil and the contiguous U.S., under the business-as-usual (RCP8.5) emissions scenario.”

\textsuperscript{10} Cf. IPCC AR4 (2007), Working Group II: Impacts, Adaptation and Vulnerability
The Current Trajectory Leads to a Warming Beyond 3 °C

If we maintain the current trajectory of increasing GHG emissions, deforestation, biodiversity decline, and pollution, the destruction of the environmental foundations that enable the most basic functions of contemporary societies is unavoidable. An environmental collapse of unfathomable dimensions is indeed inevitable with a global warming of 2.6–4.8 °C, which should be reached by the end of this century, as shown in Fig. 7.9.

Figure 7.9 shows the various projections of increase in average surface temperatures until 2100 in relation to the pre-industrial period and in correlation with GHG emission levels. They can be summarized in three scenarios:

1. Scenario one, consistent with the Paris Agreement targets—a global warming “well below” 2 °C (between 1.3 °C and 1.7 °C) by 2100 above the pre-industrial period—assumes that the four conditions set by the IPCC Special Report 1.5 (2018) are fulfilled: (a) drastic and immediate reductions in CO₂ emissions are at a pace of more than 7% per year; (b) by 2030, global CO₂ emissions should be reduced to 1977 levels (18 GtCO₂), which means returning per capita emissions to those recorded for 1955 (Marland et al. 2019; see also Introduction); (c) net global emissions should be zeroed by 2050; and (d) after 2050 it would be necessary to remove carbon from the atmosphere at a rate of 12 GtCO₂ per year (400–800 Gt by 2100) (Lenzi et al. 2018). For reference, China CO₂ emissions in 2018...
reached 10.3 Gt. It would be necessary, therefore, after 2050, to remove every year from the atmosphere almost 20% more than China’s carbon emissions in 2018. Despite a spate of proposals of unknown risk, there is no technology available for the required scale of this CO2 sequestration. Without a true change in the civilizational paradigm, including democratic global governance and a complete reorientation of strategic investments in the energy, food, and transportation systems, there is absolutely no chance of achieving the goals agreed upon in Paris.

2. Scenario two corresponds to the fulfillment of voluntary pledges assumed by the signatory countries of the Paris Agreement. It would lead to a global warming between 2.6 °C and 3.2 °C, considered catastrophic. The USA withdrew from the Agreement in 2019; Brazil is intensifying its oil production and the destruction of its forests, and peak oil demand will not be reached in the short term. Indeed, according to EIA’s Short-Term Energy Outlook (11/III/2020), global oil and liquid fuels demand will rise by less than 0.4 million b/d in 2020 and by 1.7 million b/d in 2021. Therefore, this level of warming cannot be considered a likely scenario.

3. Scenarios 3 and 4, thus, remain the most likely under current conditions. They lead to an average global warming between 3.1 °C and 4.8 °C by 2100. It should be kept in mind that these are global average temperatures. At high latitudes and over land, mostly across the Northern Hemisphere, the warming will likely be double that. According to most models, 4 °C global average surface temperature implies 5–6 °C global land mean. On the hottest days, there will be an increase of 6–8 °C in China, 8–10 °C in Central Europe, and 10–12 °C in New York.

In fact, according to the IPCC AR5 Working Group III (2014), in the absence of strong climate mitigation policies capable of altering this trajectory (RCP 8.5 W/m²), an average global warming of 4.1–4.8 °C above the pre-industrial period will probably be reached during this century. These IPCC projections reiterate the UNEP’s updated Emissions Gap Report (2012), according to which current GHG emission trends are consistent with emission pathways that reach warming in the range of 3.5–5 °C by 2100. The same prognosis is proposed by the World Energy Outlook (IEA 2012) and by Turn Down the Heat: Why a 4 °C Warmer World Must be Avoided (2013), a report by the Potsdam Institute for Climate Impact Research and Climate Analytics. According to this report:

New assessments of business-as-usual emissions (…) as well as recent reevaluations of the likely emission consequences of pledges and targets adopted by countries, point to a considerable likelihood of warming reaching 4 °C above pre-industrial levels within this century. (…) The most recent generation of energy-economic models estimates emissions in the absence of further substantial policy action (business as usual), with the median projections reaching a warming of 4.7 °C above pre-industrial levels by 2100, with a 40% chance of exceeding 5 °C.

This report also warns that in this scenario (RCP8.5 W/m²), “warming continues to increase until the end of the century with global-mean land surface temperature for the Northern Hemisphere summer reaching nearly 6.5°C above the 1951–80 baseline by 2100.” There is now a growing consensus, also reinforced by the IPCC, that
a warming of 3 °C is considered “beyond adaptation.” This is also what Jean Jouzel, former Vice President of IPCC (2002–2015), affirms in an interview with Le Monde in 2019: “I believe that we will not be able to adapt to a warming of 3°C and that we will experience major conflicts” (Herzberg 2019).

This emerging consensus fosters a new interpretation of the terms of the United Nations Framework Convention on Climate Change (UNFCCC 1992). As is well-known, the ultimate objective of this Convention is to “prevent Dangerous Anthropogenic Interference (DAI) with the climate system.” In line with this goal, the IPCC Third Assessment Report (2001) produced the famous five Reasons for Concern (RFCs), further updated by the Fourth Assessment Report (2007) and again by Joel Smith and colleagues (2009). Returning to these two central notions of climate science—DAI and RFCs—Yangyang Xu and Veerabhadran Ramanathan (2017) interpret the Paris Agreement in terms of three climate risk categories:

We are proposing the following extension to the DAI risk categorization: warming greater than 1.5 °C as “dangerous”; warming greater than 3 °C as “catastrophic?”; and warming in excess of 5 °C as “unknown??,” with the understanding that changes of this magnitude, not experienced in the last 20+ million years, pose existential threats to a majority of the population. The question mark denotes the subjective nature of our deduction and the fact that catastrophe can strike at even lower warming levels.

Regarding a warming beyond 3 °C, the first major concern, state the authors, “is the issue of tipping points” (see also Chap. 8):

Several studies have concluded that 3 to 5 °C global warming is likely to be the threshold for tipping points such as the collapse of the western Antarctic ice sheet, shutdown of deep water circulation in the North Atlantic, dieback of Amazon rainforests as well as boreal forests, and collapse of the West African monsoon, among others.

### 7.6.1 Deadlines and Impacts

There is a collective effort to specify the most likely deadlines by which the planet’s average temperatures could exceed 3 °C or 4 °C, maintaining the current trajectory of emissions and deforestation. Projections converge on the third quarter of the century, as shown below:

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11 See UNFCCC, article 2 – Objective: “The ultimate objective of this Convention (...) is to achieve (...) stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.” See also Mann (2009).

12 The five Reasons for Concern (RFC) are (1) unique and threatened systems; (2) frequency and severity of extreme climate events; (3) global distribution and balance of impacts; (4) total economic and ecological impacts, and (5) risk of irreversible large-scale and abrupt transitions. Cf. IPCC. Climate Change 2007: Working Group II: Impacts, Adaptation and Vulnerability (19.3.7 Update on “Reasons for Concern”).
1. As seen above (Fig. 7.8), the Global Carbon Project (GCP) estimates that, maintaining the 2016 level of CO$_2$ emissions, there is a 66% chance of reaching a global warming of 3 °C by 2069.

2. Richard A. Betts and colleagues (2011) project that our currently fossil intensive scenario “would lead to a warming of 4°C relative to pre-industrial during the 2070s. If carbon-cycle feedbacks are stronger, which appears less likely but still credible, then 4°C warming could be reached by the early 2060s in projections that are consistent with the IPCC’s ‘likely range.’”

3. Xu and Ranamathan (2017) affirm that, with unchecked emissions, “there is a low probability (5%) of warming becoming catastrophic [>3°C] by 2050.”

Many scientists, including Kevin Anderson (2011) and the teams from the Potsdam Institute for Climate Impact Research (2012), Carbon Brief (McSweeney 2018), and the project High-End cLimate Impact and eXtremes (HELIX), supported by the European Commission (Richardson & Bradshaw 2017), attempt to describe the world created by a global average warming between 3.1 °C and 4.8 °C above the pre-industrial period (scenarios 3 and 4). It is very difficult to imagine such a world, almost unrecognizable to the world in the twentieth century, but it is possible to highlight some of its most likely features:

1. A dramatic increase in the intensity and frequency of high-temperature extremes in Tropical South America, North and Central Africa, Mediterranean, and the Middle East (4 °C) (Potsdam 2012).

2. “The warmest July in the Mediterranean region could be 9°C warmer than today’s [2012] warmest July” (4 °C) (Potsdam 2012).

3. An increase of about 150% in acidity of the ocean. The death of entire coral reef ecosystems could occur well before 4 °C is reached (Potsdam 2012).

4. Global marine heat wave days per year multiply by 41 (3.5 °C) (McSweeney 2018).

5. Probability of an ice-free Arctic summer at least once before hitting temperature limit (3 °C) = 100% (McSweeney 2018).

6. Probability of an ice-free Arctic summer in any 1 year (3 °C) = 63% (McSweeney 2018).

7. Average drought length (3 °C) = 10 months; Eastern Europe = 8 months; Southern Europe (3 °C) = 12 months (McSweeney 2018).

8. Proportion of living creatures projected to lose over 50% of their climatic range (4.5 °C) (McSweeney 2018): invertebrates = 68%; vertebrates = 44%; plants = 67%.

9. An estimated 1.8 billion people will potentially reach unprecedented levels of vulnerability to food insecurity (4 °C) (Richardson and Bradshaw 2017).

10. The most serious of all these catastrophic impacts anticipates and introduces the next chapter. It is the widely shared opinion in the scientific community that a 4 °C warmer world “would be an interim temperature on the way to a much higher equilibrium level” (Anderson 2011). In this case, the planet’s climate system would be doomed to evolve, driven by positive feedback loops, toward a global warming above 5 °C. As mentioned above, this warming has been cat-
egorized “as ‘unknown?’”, with the understanding that changes of this magnitude, not experienced in the last 20+ million years, pose existential threats to a majority of the population” (Xu and Ramanathan 2017). And it should be remembered that the authors also add: “The question mark denotes the subjective nature of our deduction and the fact that catastrophe can strike at even lower warming levels.”

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