

Chapter 1

Defeating the Impacts of Changing Climates



Graham T. Reader

Abstract The Earth's climate has changed several times during the last million years, with many instances of glacial expansion often resulting in drought, famine, and floods. Our human ancestors adapted to these changes, mostly by geographic migration, but if they took no adaptive measures, or were unable to, they likely did not survive. After the last major ice age, the *Holocene* (the last 11,700 years of Earth's history) began and the gradually warming Earth enabled homo sapiens, especially those living in the geographic *lucky latitudes*, to develop agricultural food production and domesticate animals; two of the vital elements which led to the establishment of modern civilizations and societies. More recently, over the past 3 centuries, the global human population has increased by a factor of about 8 and it is forecast, by the United Nations, to increase by at least another 30% from today until the end of the twenty-first century. This recent era of population explosion coincided with an increase in the global consumption of fossil energy, which is now 1400 times greater than at the start of eighteenth century. There were positive outcomes from such energy use but, increasingly, there are concerns about the high possibility of damaging climate effects from fossil fuel emissions, such as Greenhouse Gases (GHGs). Subsequently, in addition to natural climate changes brought about by volcanic eruptions, disruptive solar activity, earthquakes, and periodic orbital cycle variances, anthropogenic (caused by human activity) influences must also be taken into account. Can adaptation alone address the vagaries of changing climates? It appears not, and there is a global belief that only the mitigation of GHG emissions will restore the Earth's inherent ability to accommodate changing climates. So, for the past two decades, global governments focused on mitigation measures involving transitions away from fossil fuels to renewable energies. But will the mitigation of anthropogenic affects also reduce the impact of

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G. T. Reader (✉)

Department of Mechanical, Automotive and Materials Engineering, University of Windsor,
401 Sunset Ave, Windsor, ON, Canada
e-mail: greader@uwindsor.ca

natural changes on climate? Can we afford to overlook adaptation strategies until mitigation is successful? If not, what adaptation strategies will be needed to avoid local weather and climate disasters? Meaningful combinations of mitigation and adaptation to defeat the harmful impacts of changing climates do not appear to receive palpable financial support. Why not? These questions are discussed in this chapter.

Keywords Adaption · Climate change · Mitigation · Variability

1.1 Introduction

Changes in climate prior to the latter part of the twentieth century are normally attributed to natural causes, for example, varying solar activity, volcanic eruptions, earthquakes, and cryosphere melting. Humans adapted to these changes by such measures as migration, precipitation harvesting, flood prevention, and irrigation. Natural causes and climatic occurrences, such as the changing orbits of the Earth relative to the Sun (*Milankovitch* cycles), can have short-term, and sometimes long-term, impacts on climate, but usually the Earth eventually self-adjusts, albeit that glacial expansions, ice-ages, are more frequent than global interglacial periods when atmosphere and water temperatures rise, i.e., the globe *warms*. However, since the start of the industrial revolution, variously defined as 1750 Common Era (CE) or 1850 CE, the human population has rapidly increased, accompanied by similar growths in fossil fuel usage although, even today, biomass, especially wood, is still the fuel source used for cooking, heating, and lighting by between 33 and 39% of the global pollution [1–3]. All these hydrocarbon fuel sources produce Greenhouse Gases (GHGs) which have increased the *natural* global levels at a pace which the Earth cannot readily adjust to in the rest of this century, or, maybe, not even in the next [4]. Numerous scientific investigations since the 1990s have found that the GHG issue is the main cause of rapidly increasing surface and ocean temperatures as well as sea-level rises [5]. The ensuing analyses were, and continue to be, strongly focused on developing complex climate models which have the capability of accurately reproducing past climate observations and, therefore, if successful, can be used to predict¹ future climates with the same degree of precision and confidence. Of course, comparison between modelling results and actual observations can only be made after the future arrives and then becomes the past, nevertheless based on recent measured data it was reported that, despite continuing uncertainties, some models are getting better at projecting future trends [6].

In 1992, the United Nations Framework Convention on Climate Change (UNFCCC) chose to differentiate between changes in climate caused by natural forces and those associated with anthropogenic activity, by defining the impact of

¹ Climate Scientists now tend to use the term projection rather than prediction.

the former as *climate variability* and the latter as *climate change*.² Modern changes in climate, using the same convention, are presumed to be caused by humans, especially from the emissions of GHGs largely generated by the combustion of fossil fuels. Subsequently, instead of humans finding ways to adapt to changes in climate by such measures as migration, precipitation harvesting, flood prevention, and irrigation, *mitigation* has become the approach to reducing the harmful effects of climate change. The focus being on reducing Carbon Dioxide emissions by energy use transitions to renewable and sustainable sources such as solar, wind, and water. The overall aim of mitigation being, not only to reduce anthropogenic impacts on climate, but also to eventually end them and, maybe, even reverse their effects. But can mitigation eradicate non-human climate variabilities? If GHG emissions are removed from the atmosphere will that prevent volcanic activity, earthquakes, cryosphere melting, extreme weather events, sea-level rise, and the orbital effects of Milankovitch cycles? The answer is no, since the probability of mitigation counteracting the natural effects of volcanoes, earthquakes, and orbital causes, range from unrealistic to impossible. However, climate models suggest that mitigation should inhibit ice melts, reduce the number and severity of weather events, restrict, or eliminate, sea-level rises, and limit increases in land and ocean surface temperatures. But how long will it take for mitigation to fulfil these promises? In the meantime, should adaptation measures be encouraged to constrain the harmful effects of both natural and anthropogenic climate drivers?

The appropriation of the term *Climate Change* by the UNFCCC has likely caused confusion among the general population and prompted some of the disagreement in the scientific community debates. Those who comment that changes in the climate have always occurred are often vilified and disparagingly labelled *deniers*. This situation is regrettable, but the confusion and the scientific challenges has roots in the assertion that climate change is due to human activities alone, as pronounced in the first reports of the UN's main scientific source, the Intergovernmental Panel on Climate Change (IPCC), and in the stated 'green' policies of the political governments of the associated UN countries. Providing, an example of what could be described as a *humpty-dumpty* definition [7], i.e.,

“When I use a word,” Humpty Dumpty said in rather a scornful tone, “it means just what I choose it to mean — neither more nor less”. “The question is,” said Alice, “whether you can make words mean so many different things.”

Can it then be assumed that, prior to the arrival of humans, the Earth experienced no changes in climate? Palaeoclimatological studies, i.e., the what, when, and why of the Earth's climate since its formation about 4.6 billion years ago, have shown many changes in climate [8, 9]. The studies identified several factors as climate *influencers*, and these continue to contribute to these changes. Some scientists have found that the *greenhouse-effect* has always been the main climate *controller*, mainly through the variations in the levels of atmospheric Carbon Dioxide (CO₂).

² Defined in Article 1 UN <https://unfccc.int/resource/docs/convkp/conveng.pdf>, 1992.

Other influencers, such as deviations in solar irradiance and cosmic rays are said to have only a small effect on climate, except in a few extreme cases, which are rare and temporary [8]. Not all scientists agree [10, 11]. Perhaps such disagreements are an inherent characteristic of the ubiquitous *scientific method*, compounded by the need for more hypothesis testing data. Despite the age of the Earth, methodical measurements of atmospheric CO₂ concentrations, using scientific instruments, did not start until the middle of the last century. Comparable quality surface temperature measurements have a slightly longer history, being available from the 1850s. How then can there be definitive statements about past climates and their changing nature? The answer is, by using *proxies* such as ice cores, tree-rings, and geological analyses. Subsequently, by using climate models, efforts can be made to replicate the proxy and measured data by finding possible causes for changing climates and assessing their impact on the quality of the model replication. This parametric-type approach has led to CO₂ atmospheric concentrations being considered the main cause of historical, and current, changes in climate; albeit that by volume CO₂ only accounts for 0.0407% of the current atmosphere [12]. Nevertheless, this miniscule proportion, and changes in its level, are believed to be the main influence on anthropogenic climate change and the key disrupter of climate stabilization.

A certain amount of atmospheric CO₂ is a necessary contributor to the *greenhouse-effect* which keeps the Earth at habitable and ecologically beneficial temperatures. But what are these temperatures, i.e., is there an ideal average surface temperature? There appears to be no definitive answer in the available encyclopedic scale literature on *global warming*, especially since the pre-industrial period³ prior to 1750 CE⁴ [13]. At that time, according to the *proxy* data, the global surface temperature was 13.42 °C [14], but in the twentieth century the measured global average land and ocean surface temperature was only 12.7 °C, which, by 2020, had risen to 13.86 °C [15]. However, others suggest that the average temperature over the last century was 13.9 °C, which, by 2019, had increased to 14.85 °C [16]. Such differences could be construed as unhelpful, but illustrate the difficulties met when trying to be definitive about average absolute⁵ temperatures and probably explains why climate scientists prefer to use temperature anomalies i.e., differences between average temperatures over a given period, compared to a baseline average computed over another specific time span. Defining a baseline is therefore important when defining temperature anomalies, so when the members of the UNFCCC formulated the 2015 Paris Agreement on climate change the chosen baseline was the *pre-industrial* period and the goal was to limit global warming in this century by achieving a temperature anomaly “*to well below 2, preferably to 1.5 °C*” compared to this period [17].

³ There appears to be some disagreement about the exact date.

⁴ After a quoted year, CE stands for the *common era*, while BCE stands for *before the common era*.

⁵ Not in the thermodynamic sense using the Kelvin scale.

So, why not add this targeted anomaly to the actual average temperature of the chosen baseline to provide the public with a definitive and understandable mean global temperature limit? Is this because the strength of messaging on climate change would be diluted by saying the temperature must be limited by 2100 to less than 1% higher than 1750, perhaps using the Kelvin temperature scale? The most likely answer is yes, but, in general, the Kelvin scale is only regularly used by engineers and scientists. A stronger message could be communicated if the Celsius (centigrade) scale were used as 15.42/13.42 would yield a 14% higher temperature limit, albeit the difference between a Celsius and Kelvin increase being a quirk of definition. Perhaps then the temperature anomaly approach is more efficacious if the baseline is clearly defined? But here again there can be problems, since there are contradictions in exactly *what is the pre-industrial period*. The IPCC have defined this period as being “*prior to the onset of large-scale industry activity around 1750*” [18] although both the IPCC and UNFCCC have chosen the 51-year period, 1850–1900, “to approximate the pre-industrial *global mean surface temperature (GMST)*”. The preferred 1.5 °C increase limit is based on this latter baseline. However, the NASA global temperature website base their anomaly charts from 1880 onwards on a baseline of 1951–1980 [19].

For the IPCC’s *Special Report on Global Warming of 1.5 °C* a more detailed working definition of the target anomaly was adopted, i.e., a limiting increase of 1.5 °C warmer than 1851–1900 period or 0.87 °C more than 1986–2005 or 0.67 °C above the 2006–2015 average, likely to give more perspective to the mitigation targets [20]. Therefore, in assessing how much mitigation is needed, there is no target average global temperature, but only temperature anomaly targets based on differing baselines, which are probably not known or taken cognisance of by the public. Given that it can be somewhat tricky to measure mitigation success using surface and ocean temperatures, actual or anomalous, is there a more convincing yardstick? There is global acceptance of the CO₂ concentration data from the Mauna Loa observatory in Hawaii [21], and as there are often published correlations between average surface temperatures and atmospheric CO₂ levels, then reductions in GHG levels should be followed by temperature declines. Would CO₂ measurements then supply a better benchmark for mitigation success? Maybe, but it is also true that there are regional and historic instances where temperature rises happen before CO₂ concentration growth, but, even in these circumstances, the higher CO₂ levels can eventually amplify the temperature increases [22]. So, what does all this mean? If mitigation is the strategy to combat UNFCCC climate change, then authoritative measures of strategic success will be tenuous until universally accepted data becomes available. But can we wait until the end of the century? Perhaps the best that can be done is to use the continually improving hundred or so climate change models to predict the impacts of mitigation under various *what-if* scenarios? However, the accuracy of climate models’ projections to-date has not been wholly encouraging, although, with the inclusion of some climate variabilities, they do appear to be improving [6].

Irrespective of the scale of success that mitigation strategies may achieve, at present there is measurable proof that changes in climate are taking place in many

global regions, especially as measured by sea-level rises, albeit that *sea-level* is a surprisingly difficult concept to define. If the trends in such rises are well documented and substantiated, then it would be remiss not to construct suitable and proper sea-wall defences around the impacted population centres. Such an approach would be an obvious example of adaptation. But, if eventually mitigation were to prove successful, would immediate or short-term adaptation be necessary solely as a *band-aid* solution until ample mitigation successes are achieved? Conceivably, a parallel modern context could be whether face masks, social distancing, and lock-downs will suffice until efficacious vaccines for all become available in combating a global pandemic. However, not all vaccines provide lifelong immunity and further booster shots may be needed to eradicate the cause of a particular disease. In many cases, while pandemics can be avoided by global vaccination strategies, total elimination of harmful diseases has proved to be exceptionally challenging⁶ and seasonal epidemics regularly occur.

In likening *mitigation* to immunization, and *adaptation* to mask-wearing, physical distancing etc., the contention is that mitigation *alone* will not eradicate the impacts of climate change and that more focus on adaptation will be necessary, not only as part of the continual human attempts to avoid the harmful effects of climate variability, but also to complement mitigation. This contention is explored in this chapter, while appreciating that with both approaches the interminable nuances are likely to be *costs*, human, societal, political, and economic. Subsequently, after discussing, in Sect. 1.2, exactly what is meant by mitigation and adaptation as defined by the IPCC [5, 16], in Sect. 1.3, the historical context and current approaches to mitigation, including the prospects and risks of using *geoengineering* are described. The approaches to adaptation of climate variabilities and the possible advantages and disadvantages of conjointly using mitigation and adaption are examined in the proceeding sections. Final remarks are given in Sect. 1.6.

1.2 Mitigation and Adaptation

As the climate debates began in earnest with the UNFCCC declarations of the 1990s, and the later IPCC Assessment Reports (ARs) which underpin the Paris Agreement, in any discussion of mitigation and adaptation it is arguably valuable to consider how these strategies are defined in these documents. It also needs to be emphasised, especially for post-secondary students, that IPCC reports incorporate a wealth of information and encyclopedic literature reviews and that individual chapters are multi-authored. It would be neglectful for any scholar or researcher to take no account of these publications in their climate studies. Unfortunately, the sections known as *Summaries for Policymakers* (SPM) do not always fully reflect the content of the individual chapters and this can lead to cavalier and misleading

⁶ To date, only small-pox has been eradicated in the past two centuries.

Table 1.1 IPCC AR5 [16], working group main report statistics

AR5 working group number	Description	Number of pages of main report	Lead and contributing authors	Number of references/citations	Reviewers
1	Physical science basis	1552	809 (209 Lead/600 + contributing)	>9200	1089
2	Impacts, adaption, vulnerability	1846 (1150-Part A; 696 Part B)	678 (242 Lead/436 contributing)	>12,000	1729
3	Mitigation of climate change	1454	411 (235 Lead/176 contributing)	~ 10,000	1046
	Synthesis ^a	169			
All		5021	1898	~ 31,000	3864

^aDistils and Integrates the findings of AR5 Working Groups 1–3 and incorporates the findings of IPCC Special Reports (a) *Renewable Energy Sources and Climate Change Mitigation* and (b) *Managing the Risks of Extreme Events and Disasters to Advanced Climate Change Adaptation*

quotations in the media. In the author’s opinion, SPMs tend to be as much political and agenda-driven as scientific, but the peer reviewed main chapters present high-calibre, scientific, studies, even if, at times, the stated confidence and certainty levels may be revealed, ultimately, as somewhat inflated. The scale of the recent AR studies on adaptation and mitigation can be gauged by the details of AR5 as summarized in Table 1.1. It would be sensible for post-secondary students, their teachers, and researchers not to ignore such a comprehensive collection of peer-reviewed material.

The precise wording of the definitions of Mitigation and Adaptation has changed since the first UNFCCC and IPCC statements, almost 3 decades ago. In AR5 the reason for the amendments to adaptation is *progress in science* while for Mitigation, substances other than GHGs are included in the definition [23]. These added substances have long been named as criteria air pollutants by many countries. Shortened forms of these definitions are,

Adaptation: *The process of adjustment to actual or expected climate and its effects.*

Mitigation: *A human intervention to reduce the sources or enhance the sinks of greenhouse gases. [The AR5 report] also assess human interventions to reduce the sources of other substances which may contribute directly or indirectly to limiting climate change.*

Throughout the IPCC AR5 report the virtues of both Adaptation and Mitigation are emphasized, but global financial investments and strategies have, almost without exception, firmly focused on mitigation activities. These activities attracted \$537 Billion US (93%) of total finance in both 2017 and 2018, which represents over 50% more, in US\$ terms, than in 2010/11, but with a slightly smaller proportion, 93% versus 96% [24, 25]. This level of financial investment is a clear

demonstration, perhaps, of the ‘*prevention is better than cure*’⁷ approach, which underpins the medical and health sciences approach to disease control, as embedded in many national government policies [e.g., 26]. One dictionary explanation of the phrase is, “*It is better to stop something bad from happening than it is to deal with it after it has happened*” [27]. Could this philosophy be used to clarify the differences between mitigation and adaptation? The answer is both yes and no. Mitigation is aimed at preventing something bad from happening i.e., anthropogenic climate change, but many climate scientists assert that something bad has already happened and the situation is likely to get worse. If this is the case, then, arguably, any mitigation measures could be viewed as a form of adaptation, at least until the anthropogenic climate change situation stabilizes. But how will it be known when this condition is achieved? As already noted, there are uncertainties surrounding global mean surface temperature estimates and precise CO₂ correlations. Indeed, a targeted CO₂ concentration level does not necessarily create a specific mean global temperature, or temperature anomaly, which can be used by politicians as a measure of mitigation success [28]. For now, there is only general political agreement that the average global temperature rise *should be* limited to no more than 2 °C, and preferably lower, by 2100. Any increase above 2 °C is depicted as being climatically dangerous. Yet, by some estimates the global temperature had already increased 1.1 °C by 2020 [29].

Whether or not the *should-be* limit can be achieved is a matter of intense discussion and analysis. If the use of fossil fuels were banned, it is hypothesised that global warming would continue and take at least four decades for the global temperature to stabilize, but at a higher level than experienced at the time of the prohibition [30]. As cutting fossil fuels is a cornerstone of mitigation strategies, then the consequent time-lags palpably reinforces the need to adapt to continually rising temperatures. Whatever the issues associated with defining targets and benchmarks it is obvious that both mitigation and adaptation strategies will be necessary to address the 2015 Paris Agreement goals. It can also be argued that adaptation improvements will need to be continual, even after mitigation is believed to be a success, so that adverse, albeit relatively temporary, natural changes in climate, floods, droughts, and so on, can be tackled as the need arises. The challenge will be how to fund these improvements to account for all eventualities. But what if the *eventuality* is an annual, or a 10-year, or a 100-year, or even a 500-year *occurrence*? The likelihood of these occurrences, and their impact, should be a key element of adaptation. Normally adaptation infrastructure designs are based on a 100-year occurrence but that is not to say that two such events could not be experienced in consecutive years. There are several *eventualities* or *occurrences* indices which are used for analysing and assessing changing climate and weather patterns. These are regularly updated as discussed in Sect. 1.4.1.

⁷ A tenet attributed to the Dutch philosopher Desiderius Erasmus at the start of the sixteenth century.

As will be seen, the approaches to mitigation and adaptation are not necessarily mutually exclusive, although their individual aims, as defined in Sect. 1.2, could be interpreted as requiring separate mind-sets. But if there is legislated mitigation to the use of non-carbon fuels, will that not require societal adjustment to the adaptation of the *new* energy sources? Moreover, some advocated mitigation methodologies require that people adapt their diet to reduce their meat and dairy product consumption by up to a half by 2050 [31], raising millennia old philosophical questions, which legal and political science scholars still grapple with, such as *obey or persuade*, and whether *political obligation* is the same as a duty *to obey the law* [32]? Difficult questions which, while they cannot be wholly ignored when considering the differing approaches to defeating the impact of adversely changing climates, even cursory attempts to answer are somewhat beyond the scope of this chapter.

1.3 Approaches to Mitigation

1.3.1 Historical Context

Mitigation was not a commonly used term, or even a major discussion topic, among scientists until the last two decades of the twentieth century. Therefore, it could be valuable, to appreciate how mitigation became a such a global scientific and law-maker focus. The dictionary definition of Mitigation simply means *the act of mitigating* which in turn means to make something less harmful or cause the consequences of a bad or unpleasant situation to be less severe. The IPCC have used these basic meanings to define what mitigation entails in terms of combating anthropogenic climate change. The AR5 report definition of Mitigation was quoted in Sect. 1.2, the preceding IPCC AR4 report gave a more economical definition, “*mitigation means implementing policies to reduce GHG emissions and enhance sinks*”, substituting the phrase *anthropogenic intervention* of the Second Assessment Report (SAR) with implementing policies [33, 34]. In the updated and expanded AR5 definition the effects of the internationally acknowledged *criteria air pollutants and contaminants* have been added to the GHG concerns. Mitigation, then, has an ever-evolving meaning. Prior to the increasing popularity of the term Mitigation from the IPCC’s second report, terms such as weather modification and climate modification were often used [35]. The notion of weather modification, principally rain-making, was known to, and practised by, ancient indigenous peoples using shamans, priests, and rain-dances thousands of year ago and in some regions continue [36]. By the mid-twentieth century, at the end of the 2nd World War, some scientists claimed that human activity was changing local weather and, with a post-war weapons race on the horizon, a small group of leading scientists agreed, at a meeting at Princeton University, that it might be possible to deliberately change weather patterns [35]. In the United States, this led to the funding of

research projects investigating *climatological warfare* but, by 1977, the United Nations had created a *convention* banning the use of weather-warfare, although less than 20% of members have so far ratified the convention [37].

However, the original initiatives led to climate scientists investigating the causes of climate change and the modelling of the changes. Apart from the potential weaponization of weather and climate, there were also concerns that the average terrestrial surface temperatures in the northern hemisphere had fallen by 1.5 °C (2.7 °F) between the mid-1940s and early 1970s, so was the Earth entering a new ice age? If that were the case, and some scientists believed it was, could the climate be stabilized and changed to prevent further *global cooling* [38]? *Engineering schemes* were suggested to counteract the cooling and control climate change, including (a) removing Arctic sea-ice using *clean* nuclear bombs, (b) covering the ice with soot to reduce the reflectivity, (c) cutting down tropical forests in South American and Africa and (d) damming the Bering Straits, as shown on Fig. 1.1 [38]. All these proposals were aimed at *warming* the Earth and it is now known that reducing the extent of Arctic sea-ice does indeed lead to increased surface temperatures, albeit in the absence of nuclear weapons!

Clearly, the concept of defeating climate change is not new, but the proposition that the Earth was experiencing global cooling and that the climate was entering a new ice age, although it garnered a few media headlines, was revisited by scientists almost as soon as it had been announced. Using different model assumptions, although the same basic models and data, and amended forcing factors for the

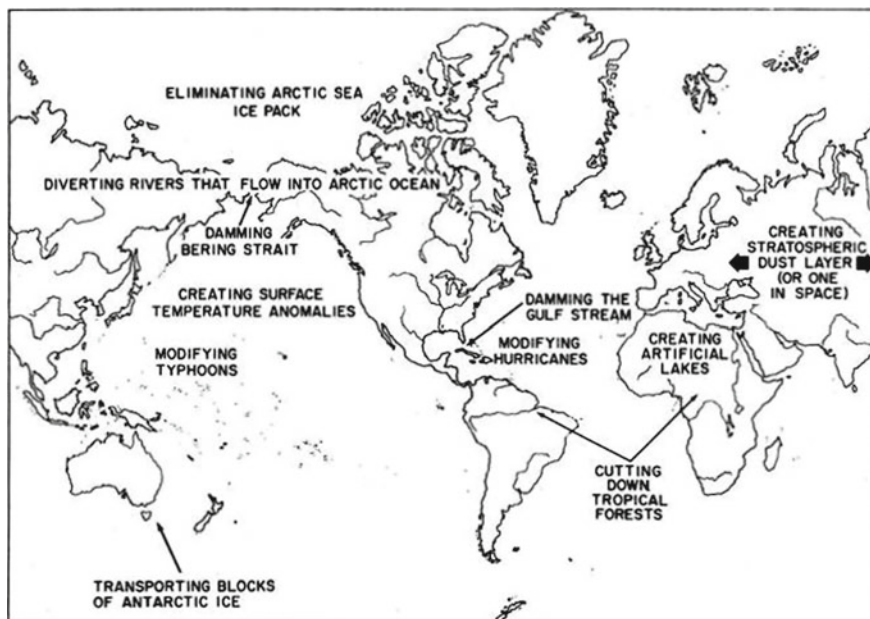


Fig. 1.1 Proposals to combat global cooling [38]

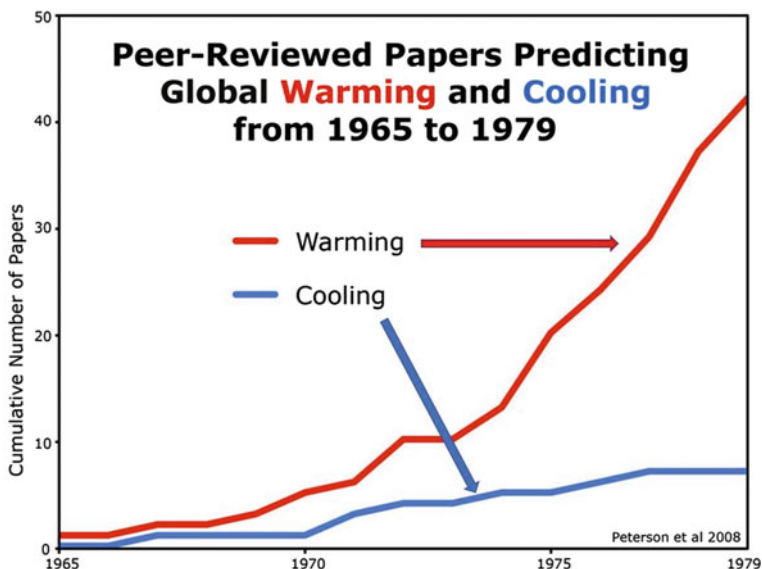


Fig. 1.2 Global cooling and warming publications 1965–1979 [39]

effects of GHG, the global cooling conclusions were changed to global warming conclusions in an increasing number of publications, Fig. 1.2 [39]. In the same decade, following the *Oil Crises* in many countries outside the Middle East and the fear that oil production had reached its peak and would soon run-out, the then United States President, Jimmy Carter, gave an address to the nation in 1977 on the 10 principles of his national energy plan. He said, “*we could use up all the proven reserves of oil in the entire world by the end of the next decade*” and thus advocated starting the development of new, unconventional energy sources to be used in the twenty-first century [40]. Although, one of President Carter’s targets was to increase coal production by 66% by 1985. The combination of increased alertness to global climate change and the need for future energy transitions, in all probability, were the likely drivers for two UN agencies, the World Meteorological Organization (WMO) and the UN Environment Program (UNEP) to propose the formation of the IPCC, which the full UN General Assembly endorsed in 1988 [41]. The IPCC were tasked with producing a climate report including (a) a comprehensive review of the state of knowledge of climate change science, (b) the possible socio-economic impact of climate change, and (c) potential response strategies to climate change.

The IPCC report—the First Assessment Report (FAR)—laid the foundation for the UNFCCC, the seminal international convention/treaty aimed at reducing global warming and coping with its consequences. In the SAR, as previously mentioned, the terms *adaptation* and *mitigation* entered IPCC lexicon, while increasing carbon dioxide levels and deforestation were named as the chief causes of climate change.

Following the SAR, the *Kyoto Protocol* was set up [42]. The Third Assessment Report's (TAR) focus was the impact of climate change and the need for adaptation, while the Fourth Assessment Report (AR4) considered both Mitigation and Adaptation, and the last assessment report (AR5), as summarized in Table 1.1, provided an encyclopedic scientific assessment of the associated strategies. Throughout these reports, extensive and transparent, use is made of the results of climate change computer models, although this is not always acknowledged in the media or in policymakers' commentaries, which means that large swaths of the public likely assumed they were being presented with proven facts and observations. The IPCC reports, especially from the scientific working groups, invariably tried to present a more balanced interpretation, although some of their resulting opinions are prone to scientific and technological debate. For example, in the FAR, one of the key conclusions was that "*The size of this {global} warming is broadly consistent with predictions of climate models, but it is also of the same magnitude as natural climate variability*" [43]. However, the models at that time concentrated more on anthropogenic effects, such as rises in CO₂ emissions from human activities, rather than natural impacts such as volcanic emissions.

The next steps in the IPCC's assessments were to quantify exactly what proportions of global warming were anthropogenic and which were natural, and which human activities were the root causes of anthropogenic climate change. This work continues, and in the next assessment report (AR6) the computer models will include factors derived from both anthropogenic climate change and climate variability analyses. What the modelling results will show, and how well they will compare with the growing database of actual observations, is obviously uncertain. However, while it may be expected that the findings could result in a revision of mitigation targets, either more or less severe, it needs to be remembered that, over the last thirty years, the two main advocated mitigation approaches have been energy transitions, to address the desired reduction of sources of GHG, and reforestation, to deal with the enhancement of the sinks.

1.3.2 *Current Mitigation Approaches*

Of the 900 or so Mitigation strategies, along with the 300 baseline energy-use scenarios, reviewed in AR5, the core themes are still the same as the original SAR recommendations, i.e., reduce GHG emissions by energy transitions and increase GHG sinks by reforestation and *afforestation*.⁸ These are evidenced based approaches since carbonaceous energy use accounted for around 65% of all global GHG emissions in 2016, with hydrocarbon fuel production and storage adding about another 6% [44]. Land-use and forestry change, and agriculture, impart a

⁸ Afforestation is the establishment of forests, through planting and/or deliberate seeding, on land that, until then, was not classified as forest.

further 18% of GHG emissions [44]. Thus, as almost 90% of GHG emissions involve the types of energy sources currently used and how humans use, or misuse, land, it can be wholly appreciated why mitigation strategies focus on these two issues, especially energy use transitions. However, the temporal target for the hoped for replacement of fossil fuels is within a decade from now, or at least by 2050, although it should be noted that the strategic pathways outlined in AR5 for mitigating atmospheric CO₂ do not extend beyond the end of the century [45]. Moreover, as there continues to be uncertainty regarding the physical relationship between surface temperature and GHG concentrations it may not be possible for these temperatures to return to the IPCC defined pre-industrial levels, but a *never to be exceeded* temperature level could be defined as an indicator associated within target bounds of CO₂ concentration levels [46, 47]. Therefore, it appears inevitable that mitigation pathways will continue into the twenty-second century, although the future actual strategies may be amended from those of this century.

1.3.2.1 Mitigation by Energy Transition—Substitution of Fossil Fuels

There is a long history of human energy transitions but, until the *Age of Coal*, changes in energy sources were slow to arrive and gain dominance, as shown in Fig. 1.3 [48, 49]. The combustion of fossil and other carbonaceous fuels, such as wood, emits the largest quantities of CO₂ and produces a sizable proportion of Particulate Matter (PM), the former being considered the major contributor to global warming, the latter a significant cause of both hazardous indoor and outdoor air pollution. The basic strategy is to substitute fossil fuels with renewable energies, e.g., solar, wind, and water-power. Water-power meaning hydroelectric systems including oceanic tidal and wave powerplants. However, hydroelectric power plants using dams and reservoirs now have nationally specified output limitations if they are to be classified as renewable sources, although the specified sizes are somewhat arbitrary. Why these restrictions? There is indisputable evidence that the dams and reservoirs and other large bodies of freshwater emit two GHGs, namely CO₂ and Methane, although, in the United States, less than 4% of the over 91,000 dams are used for hydroelectric installations [50]. Wholly attributing GHG emissions from freshwater sources, natural or purpose built, to hydropower is therefore problematic. Moreover, if the site of the hydroelectric plant was cleared of plant life prior to the flooding of the land and the creation of the dam there should be no GHG emissions from decaying vegetation.

However, GHG production is not the only environmental concern associated with hydropower installations since, depending on how much land area is appropriated, its topology, and location, there will be wildlife habitat destruction and unavoidable human displacement. To address these issues, and to diminish the GHG emission problems, thereby causing less harm to the existing ecological systems and the environment at a selected site, many regions and countries have imposed size restrictions on new hydropower projects. But why is there no universally accepted size requirement? Partial answers are likely, (a) *geography*, in that

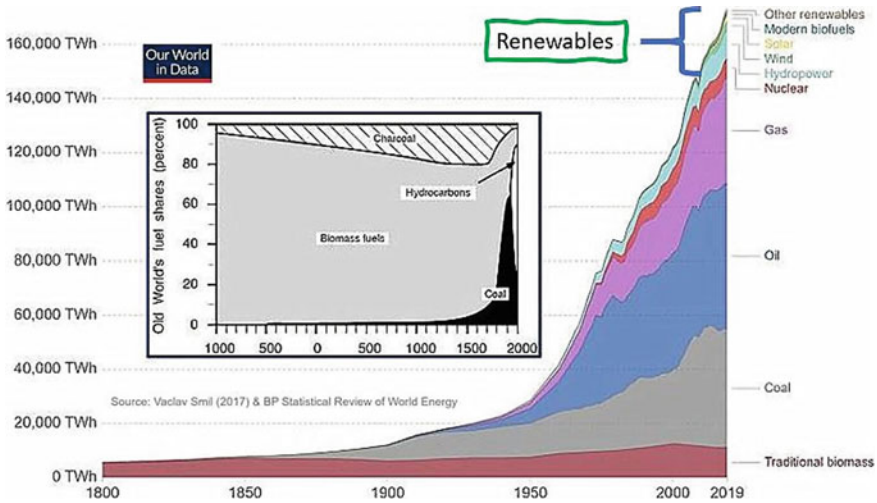


Fig. 1.3 Energy transitions 1000 CE to 2019 CE [48, 49]

installation locations having more mountainous terrains involving valleys and canyons will have a smaller surface footprint than in *flatter* areas for the same volume of water, and (b) *land-use management* of the surrounding areas as water run-offs from agricultural activity will adversely impact pollutant formation [45]. Nevertheless, if all hydropower electricity production were considered renewable, as in China, then many jurisdictions would have already met their Paris Agreement targets. Perhaps of more concern, is not the renewable energy accounting schemes, but how adaptation to droughts, floods, and water scarcity can be supported without dams and reservoirs?

As the main criteria of mitigation is to eliminate, or substantially reduce, anthropogenic CO₂ emissions, nuclear energy may seem an obvious replacement for fossil energy. However, there is a wide-spread public and media aversion to the use of nuclear sources because of safety concerns, which are largely gratuitous, and the fear of the proliferation of thermonuclear weapons leading to their uncontrolled use. Nevertheless, advances in nuclear fusion, as opposed to the conventional nuclear fission technique, and the plans to develop small community size nuclear reactors may eventually repair the negative perceptions of nuclear energy, but this is unlikely to happen in sufficient time to meet the 2050 climate change GHG goals [51, 52]. So, as hydropower and nuclear power are not going to be major enablers of the transition to renewable energy and the desired scale of mitigation, what will? A great deal of faith, and funding, is being placed in solar and wind power. Unfortunately, in addition to the proverbial epithet of what happens *when the sun don't shine and the wind don't blow*, there are also local and regional challenges in places lacking sufficient natural solar and wind energy densities and, moreover, where there are abundances, the ability to store overproduction is very limited [53, 54]. Maybe global, national, or regional transmission grids and networks could

be constructed to carry solar and wind energy produced in abundant areas to those partially or wholly lacking such advantages? Thus, geography will play an increasing role if the spread of solar and wind energy is to increase, let alone replace all carbonaceous fuels, but intranational and international cooperation, including cost sharing on an unprecedented scale, will likely be needed.

Another alternative *fuel*, especially for use in the land and marine transportation sectors, is hydrogen [44, 55]. There have been occasional periods of interest in its application for the powering of prime movers since at least 1820 and, once again, hydrogen in the late 1990s and currently is being promoted as a fuel of the future [56, 57]. There have been varying reasons for this interest by the last quarter of the twentieth century. The oil supply crises, fears of diminishing fossil fuel reserves, and efforts to improve air quality provided the impetus for the consideration of hydrogen use, together with technological breakthroughs in membrane materials and manufacture, which made Fuel Cells more competitive. Today, the focus has become the contributions hydrogen use could make to reducing the impacts of anthropogenic climate change. If used in a fuel cell to generate electrical energy the process is emission-free except for the production of the GHG water vapour, which, because of its short lifetime, is not considered to be a factor in global warming. If used in an air-breathing combustion engine, no CO₂ is emitted, but there could be some NO_x production in the same way as a Hydrogen-Air fuel cell. However, methods for removing nitrogen oxides from exhaust streams are technically mature and very effective. Moreover, hydrogen is the world's most abundant element. So, why is hydrogen not yet a dominant primary energy source?

The answer is, because there is almost no naturally occurring sources of gaseous hydrogen, and it is produced largely by synthesizing conventional fossil fuels and biomass, although it can also be generated by water electrolysis and there is continuing research and development on microbiological and photobiological hydrogen generation [57]. If the electrolysis process is powered by a renewable energy source, then the resulting hydrogen is called *Green-Hydrogen*, while if made from carbonaceous raw materials it is named *Grey Hydrogen*. However, the form of manufactured hydrogen attracting increasing attention is *Blue Hydrogen*, which involves the combination of grey hydrogen production processes together with carbon capture, utilization, and storage (CCUS). Blue hydrogen can be produced in large, off-site facilities, and transported to its destination by pipeline or a suitable vehicle, or smaller, filling station sized, on-site installations. Germany, Japan, South Korea, and the United States already have some on-site hydrogen filling stations [58]. Many of the safety and material degradation issues, particularly steel embrittlement, have been addressed using highly sensitive detectors and non-metallic materials [58].

Could the use of hydrogen become significant over the next three decades to 2050? Yes, according to the multinational company, BP p.l.c., but only if particular energy-use scenarios are adopted. The company publishes a series of reports each year dealing with energy topics and possible global outlooks for the future. In their forecasts they use defined transition and energy use scenarios, like those found in IPCC Assessment Reports and the United States Energy Information

Table 1.2 BP energy outlook scenarios [44]

Scenario term applied to energy use	Paraphrased from full descriptions
Business-as-usual	Government policies, technologies and social preferences continue to evolve in a manner and speed seen over the recent past, but in 2050 carbon emissions are only 10% less than 2018 levels
Rapid	Conceives a series of policy measures, led by a significant increase in carbon prices and supported by more-targeted sector specific measures, such that carbon emissions are reduced by about 70%, limiting the rise in global temperatures by 2100 to well below 2 °C above pre-industrial levels
Net zero	The policy measures embodied in Rapid are both added to and reinforced by significant shifts in societal behaviour and preferences, which further accelerate the reduction in carbon emissions, in line with limiting temperature rises to 1.5 °C

Administration's (USEIA) International Energy Outlook publications. In BP's case, for their 2020 outlook publications, they used 3 scenarios: *Business-As-Usual*; *Rapid*; and *Net Zero* [44]. Analogous, if not always identical, terms and descriptions are used in various forms in the IPCC, USEIA reports, and others from *bone fide* international agencies. A précis of the BP descriptions is given in Table 1.2.

If future energy use is in harmony with, or closely approximates, the BP Rapid and Net Zero scenarios, then especially in the land and marine transportation sectors, but also as a contributor to total global energy consumption in a low carbon transition, hydrogen will become a common, if not a dominant, fuel by 2050, as shown in Fig. 1.4a, b [44]. But what type of hydrogen? It is forecast that by 2035 all three forms, grey, green, and blue could share the hydrogen market but by 2050 it would be equally shared between green and blue. Nevertheless, there are many challenges and uncertainties to overcome such as (a) if green hydrogen is to be produced then even more renewable energy may be needed within the various energy-use scenarios although such an issue could be tempered by utilizing any solar and wind power overproduction to produce green hydrogen and in effect become a renewable energy storage system and (b) the production of blue hydrogen is wholly reliant on the efficacy and economic viability of CCUS.

CCUS will also play a pivotal role in the use of biomass and biofuels [59]. These energy sources are considered carbon-neutral in many global jurisdictions, such as the EU, but the fact of the matter is that if their use involves combustion then CO₂ will be emitted. Those lawmakers and scientists, in favour of applying the carbon-neutral label, argue that the stored carbon in biomass, which is released quickly after the harvested product is burned and its CO₂ emitted, will be gradually removed—sequestered—from the atmosphere by new plant and tree growth. However, depending upon the genus and species choice of the new replacements, the emission generated-sequestration process could take from decades to centuries, which is hardly the desired timeframe for addressing twenty-first century mitigation [60–62].

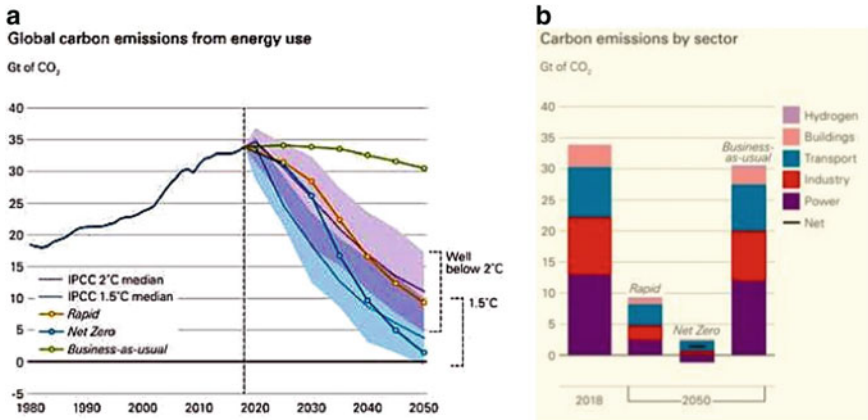


Fig. 1.4 a Total carbon emissions [44]. b Carbon emissions by energy sector [44]

Biomass could be thought of as a renewable energy, as harvested plants and trees can be directly replaced but the carbon-neutral moniker is less palatable to scientists, and both the IPCC and the EU have revisited the 2006 assessment of biomass emissions not counted as contributing to GHG, at least not being included in national GHG inventories [63]. In 2019, a major 5 volume refinement to the 2006 guidelines was published [64]. Both sets of guidelines have many proposals on how to calculate CO₂ emissions from Harvested Wood Products (HWP) and their removal using so-called *carbon-stocks*, i.e., a count of trees and plants existing in any one year. The emissions and removals are not reported in the energy or waste GHG inventories but in the Agriculture, Forestry, and Other Land-Use (AFOLU) category. The methodologies used are open to interpretation, as the IPCC acknowledges, and that “[i]n practice, physically measuring either actual carbon stocks in the HWP pool, or actual fluxes between HWP and the atmosphere, can be technically challenging” [65]. The overall situation on the carbon-neutrality of biomass is somewhat muddled, but for lawmakers there is literally a *get-out-of-jail-free* card as the guidelines state that “The HWP Contribution can be reported as zero if the inventory compiler judges that the annual change in carbon in HWP stocks is insignificant” [64].

So, can biomass be considered as part of an energy transition mitigation strategy? Analysts and scientists continue to debate the issue of whether biomass burning can be counted as a net zero contributor to anthropogenic climate change and suggest that its use may worsen rather than reduce global warming [66–68]. Despite the GHG inventory revisions and ongoing discussions about the use of biomass as an energy source, it will continue as part of the energy mixes for now and in the foreseeable future and CCUS could strength its acceptability. But if carbon capture can be used with one type of carbonaceous fuel, why not others? Other than economics, political ideologies, and maybe some technical challenges associated with size of the capturing devices, there appears no show stopping

obstacles to the wider use of carbon capture [69, 70]. To complete the CCUS systems approach, it will be necessary not only to capture the CO_2 but also to store it. In North America this should not prove to be a problem because the United States National Energy Technology Laboratory (NETL) has reported that there is sufficient capacity to store 900 years or more of CO_2 at the current rates of production [62].

Whatever the scientific-political tensions about the use of biomass, there are still over 2.5 Billion people using it for basic domestic needs and, in doing so, producing the criteria pollutant PM in sufficient quantities to cause the premature deaths of millions, particularly in the regions where it is widely used for such purposes, but PM dispersal, especially the health-damaging PM 2.5 is not confined by national or international borders [71]. However, to attribute PM emissions solely to biomass burning and on-road diesel fuelled international combustion engines can be misleading, as illustrated in Fig. 1.5, which shows the sources of PM in the contiguous United States [72]. The planned elimination, by some governments, e.g., the UK [70], of fossil fuelled engines between 2030 and 2040 will reduce the amount of anthropogenically generated PM in the atmosphere but just modestly in comparison with the current contributions of coal-fired and biomass fuelled power stations, industry, and building HVAC systems. Yet, if the use of hydrogen and electricity are to be the dominant energy sources for the transportation, building, and power generation sectors, then far more renewable energy generation will be needed. As this is unlikely in the sought-after UK timeframe, nuclear and carbonaceous fuelled energy production, using CCUS, will also have to be part of the

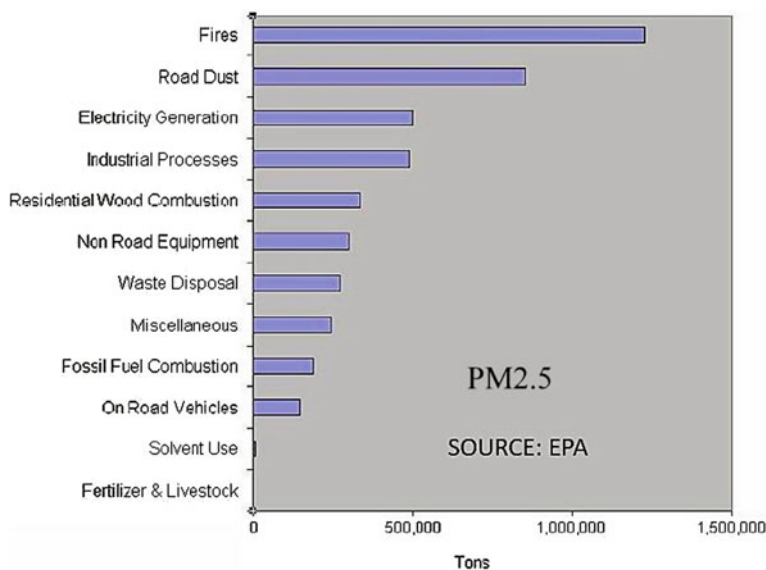


Fig. 1.5 United States sources of $\text{PM}_{2.5}$ [72]

energy mix. This scenario will doubtless be repeated in other countries but, for some, hydropower will also play a part, especially if used in *pumped storage* mode with solar and wind power installations [73].

Arguably, the mitigation measures discussed so far are reasonably pragmatic approaches which societies, even if reluctantly in some cases, will accept. However, when elected governments try to change societal behaviours based on their known ideologies, even with good intent, will they be as readily accepted, or lead to dissension [32, 74, 75]? For example, the imposition of carbon taxes is an increasingly common strategy for manipulating socio-economic behaviour towards the use of non-polluting energy sources. Is this approach indicative of a country's *Nationally Determined Contribution* (NDC) to the 2015 Paris Agreement targets, global leadership bragging rights, or sincere attempts to persuade their own society of the seriousness of anthropogenic climate change [76]? If persuasion is only partially successful does legislation and litigation have to be invoked? Perhaps, an exemplar of such a situation is Canada's carbon tax. The Federal Government of Canada's 2018 *Greenhouse Gas Pollution Pricing Act*, passed by a then majority government, was not greeted with overwhelming societal enthusiasm and, indeed, three of the ten Provincial governments, representing over 53% of the country's population, challenged the legality of the Act. In March 2021, the Supreme Court of Canada (CSS-CSA) in a 6–3 decision decided that the Act was legal and constitutional and noted that “*global warming causes harm beyond provincial boundaries*” [77]. On that basis, most of the justices decided that global warming was “*a matter of national concern under the “peace, order and good government” clause of the Canadian Constitution*” [77].

At the time of the passing of the Act, 72% of the country's most populous province believed it was more of a tax grab than a sincere attempt to mitigate global warming [78]. Will legal enforcement now change attitudes? Whatever, the underlying rationale for imposing a carbon tax, which is the path taken by over 40 countries, there is evidence to show that carbon taxes do lead to GHG emissions reductions, but these taxes are also *regressive*, in that they impose a disproportionate burden on those with lower incomes as a higher percentage of their income will need to be used to obtain the basic necessities of life and, for such individuals, the transition to an electric vehicle could prove unattainable [79, 80]. However, in Canada, the government has sought to ease the carbon tax burdens by using a gradual increase annually, from \$16US per tonne of CO₂ equivalent to \$136 US by 2030 [81], which is still less than the lowest rate that the *New York Times*TM estimates the UN appears to believe is necessary to keep surface temperature increases to only 1.5 °C above the defined pre-industrial levels by the end of the century, and far less than the over \$5000 US per tonne recommended by the UN, according to the same source [80].

Presumably, once the carbon-tax mitigation approach succeeds, it will no longer be needed as there will be no anthropogenic carbon to tax and hence no further revenues to generate, but when and if this happens are unequivocal suppositions. There are also exemplars for more profound behaviour-shaping strategies, the latest being recommendations to reduce meat and dairy consumption by 35%, and

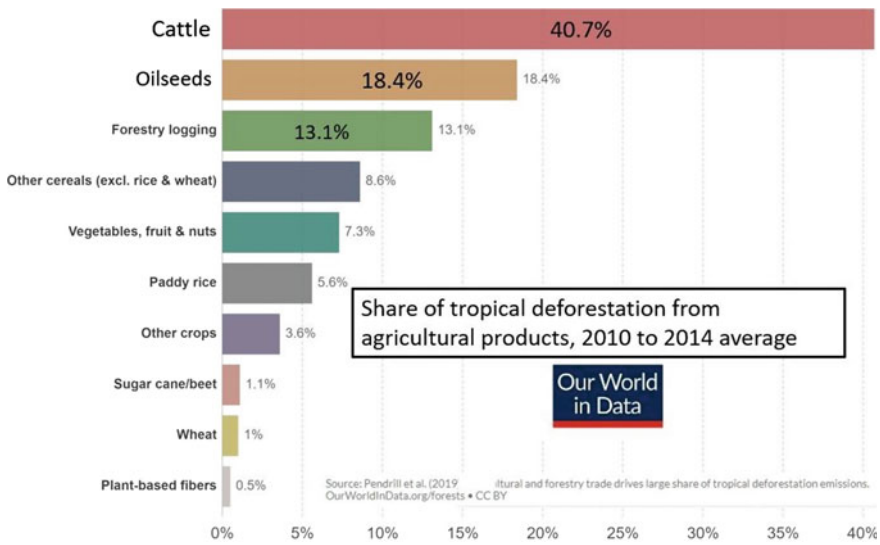


Fig. 1.6 Deforestation from agricultural products (tropical) [85]

agricultural land use by 21%, for the UK to achieve zero-carbon by 2050 [31]. Will these recommendations be endorsed as a concession to lobbyists or as a bone fide approach to mitigation [82, 83]? Is the diet changing approach an example of adaptation as much as mitigation? Can agricultural land be reduced, but simultaneously the plant food supplies increased, to replace meat and dairy products for a growing population? It would be thoughtless for governments not to address these questions in clear, precise, and unambiguous ways before embarking on a legislated approach to enforcing human diet changes, but that is not to say it could not happen or that reducing meat consumption, particularly *red* meat, would have negative health effects [84]. Maybe the claims of ideological maneuvering are somewhat over-blown? There are elements of climate change pragmatism in advocating for a reduction in red meat consumption as cattle grazing is the single largest contributor to land being deforested for agricultural purposes, as shown in Fig. 1.6, for the period 2010–2014 [85]. However, it needs to be stressed that the chart is for tropical regions and that in terms of net forest change, i.e., forest expansion minus deforestation, the UK has experienced no change over the period 1990–2015 [84].

Other large contributors to agricultural deforestation, see Fig. 1.6, are oilseeds, especially palm-oil, and food crops. With the use of *healthy* non-meat protein products gaining momentum, global soya-bean production has tripled over the last three decades with the United States and Brazil leading the way, although not all soya-beans are used exclusively for food [85, 86]. The same level of increase has also been experienced with palm oil, but more than 80% of global production comes from just two countries, Indonesia and Malaysia, while India and China are the biggest importers of palm oil [85], Fig. 1.7. Palm oil is mainly used in food

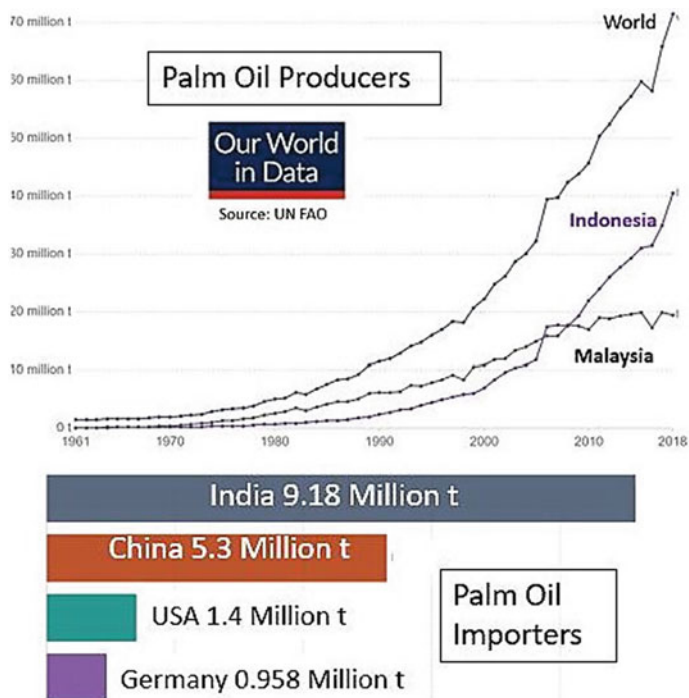


Fig. 1.7 Palm oil producers and importers (exemplars) [85]

products and industrial applications, but 5% is used for biofuels with some importing countries, e.g., Germany using more for biofuel production than food [87]. As these products have positive health effects, to reduce their dietary use in the same way as red meat would be problematic, as would be the rejection of their contributions to biofuel production.

1.3.2.2 Reforestation and Afforestation—AFOLU (Agriculture, Forestry, and Other Land-Use)

Despite the contentious issue of diet change, the accompanying zero-carbon advice to the Government of the UK is to reduce agricultural land to enable increased forestation and wetlands, and make peat beds tree-free, i.e., changing land-use, and this is in harmony, to a large extent, with the IPCC’s Mitigation strategy of enhancing the sinks of GHGs [23]. But does this mean simply planting more trees? Yes, and no. Globally, since approximately the beginning of the present inter-glacial period between 10 and 11 millennia ago, about a third of forest cover has vanished, almost all of which has occurred since the eighteenth century industrial revolution and, especially, in the twentieth century, see Fig. 1.8 [85, 88].

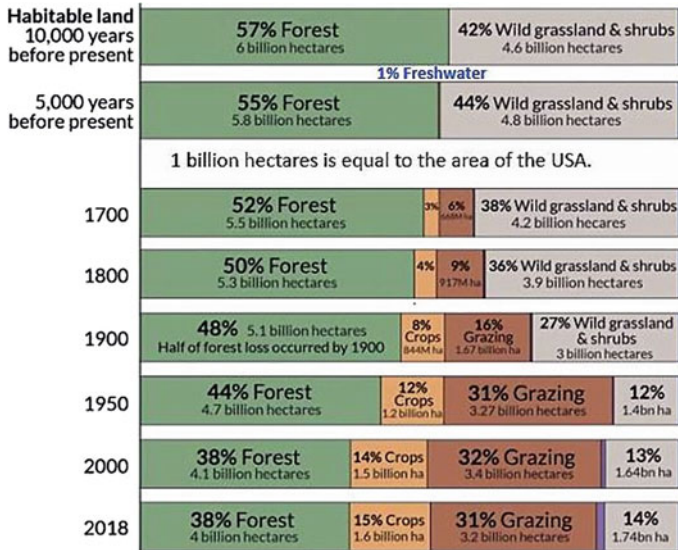


Fig. 1.8 Increasing deforestation from 10,000 BCE to 2000 CE [85, 88]

Planting more trees, some advocate 1 trillion could address this issue, but the IPCC, in their 2019 report on Climate Change and Land, highlight that afforestation and using biomass for bioenergy can also have adverse side-effects and risks including food insecurity and land degradation [89, 90]. Nevertheless, as frequently quoted in several UN publications and communications: “Forests are a major, requisite front of action in the global fight against catastrophic climate change”... “Stopping deforestation and restoring damaged forests could provide up to 30% of the climate solution” [91].

Consequently, is the scale of deforestation declining and reforestation and afforestation increasing? *Yes*, according to the UN’s Food and Agriculture Organization (UNFAO) *Global Forest Resources Assessment* (FRA), but the World Resource Institute’s *Global Forest Watch* (GFW) say *No* [92]. GFW reports that tree cover has declined by 50% since 2015, the FRA by about 11%, the differences being that annual forest regrowth is hard to quantify from GFW’s satellite data and, if tree cover is lost, it is not clear whether the loss is permanent or temporary. FRA, on the other hand, is mainly reliant on nations reporting how *registered* land is used [92]. In the twentieth century it appears that the FRA and GFW were in reasonable harmony, but this is no longer the case, and the differences are marked, so while one system may report that certain countries have increased their forests, the other system reports the same countries have massive deforestation. This unhelpful situation is leading to a cacophony of articles about this important topic and the sooner a scientifically acceptable remedy is found the better. However, in this

sub-section, as in other sections, since the data used in the discussions so far was largely extracted from UN published sources, the UNFAO data is used mainly in the form presented by the trusted and reputable organization, *Our World in Data* [93].

The many national efforts, such as those by India and China which together account for over 36% of the global population, to encourage more tree planting are having positive effects in expanding forests. But global deforestation continues, so the expansion results are not as reassuring as may be anticipated, as shown in Fig. 1.9a, b, where exemplars of deforestation and increasing forest cover are presented in juxtaposition [85]. Notwithstanding the current situation, there is little doubt that having more trees and vegetation can provide an increasing scale of carbon sinks which, if sustainable and well-managed, could help defeat the adverse impacts of anthropogenic climate change and simultaneously contribute to cleaner air and increased food supplies. In other words, reforestation, afforestation, and reduced deforestation are inherently attractive climate change mitigation strategies provided that anthropogenic CO₂ is unequivocally confirmed as the main change agent.

1.3.3 *Is Mitigation Working?*

There are some problems, as already highlighted, with assessing the AFOLU affects on climate change, not because of CO₂ data, but because of the unresolved issues surrounding the contradictions of AFOLU source data. However, can the efficacy of the other mitigation strategies be measured, which started with the Kyoto Protocol in 1997, but took almost 8 years to come into effect, or, its successor, the 2015 Paris Agreement [94]? If CO₂ is used as the indicator, then, using the general atmospheric measurements, like those taken at the renowned Hawaiian Mauna Loa observatory, or the emissions due to fossil fuel burning and cement production alone, as illustrated on Fig. 1.10, the mitigation strategies do not appear to have had the desired effect and, indeed, CO₂ levels have continued to rise during the COVID pandemic [95, 96]. This situation is not wholly surprising as it is only 16 years since Kyoto came into force, but without the agreement of China and the United States, and latterly Canada, and the United States formally withdrew from the Paris Agreement in 2020—although it is set to rejoin [94, 97]. Perhaps a reasonable temporal benchmark for the possible success of mitigation is the first International environmental treaty, the universally agreed, *Montreal Protocol* [98]. This protocol is aimed at repairing the damage to the ozone-layer and it has been estimated that the repairs will be *almost complete* by the middle of this century, over 60 years since the protocol came into force [94, 99].

If the Montreal benchmark is applied to the progress of mitigation, and given that the Paris Agreement came into force in 2016, then even optimistically, it could be the last quarter of this century before the average surface temperature anomalies stabilize and, by then, the target *never to be exceeded* average surface temperature

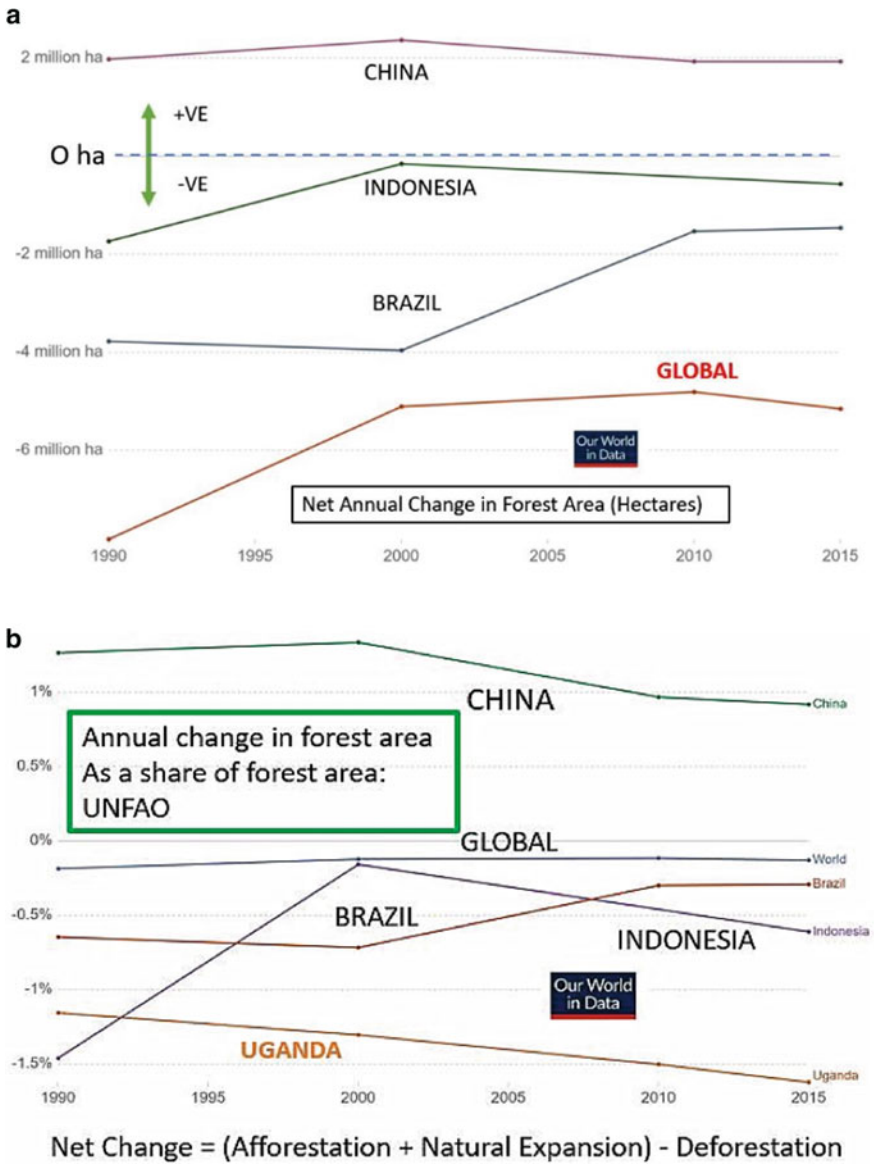


Fig. 1.9 a Change in forest areas (exemplars) [85]. **b** Percentage net change in forest area (exemplars) [85]

anomaly level of 2.0 °C could well have been surpassed, which for climatologists, is the tipping point. Moreover, as previously discussed in this section, it is likely that mitigation will have to continue well into the twenty-second century before atmospheric CO₂ concentrations and average global surface temperatures return to

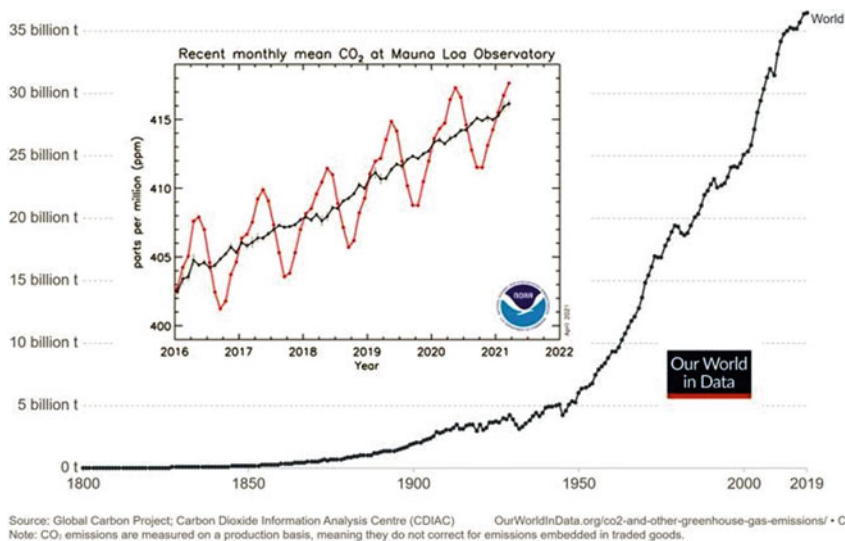


Fig. 1.10 CO₂ emissions: recent concentrations [95] and amounts since 1800 CE [96]

pre-industrial levels. Arguably, while the mitigation strategies, advocated since the 1997 Kyoto protocol, should address the vagaries of CO₂-driven anthropogenic climate change, the long delays in their implementation, coupled with the perceived lethargic transitions away from fossil fuels, mean that more radical approaches to changing the climate are needed, even if only to allow *breathing room* for Mitigation to take effect. Traditional adaptation can hardly be considered revolutionary, but so-called *Geoengineering* techniques can, and may offer an interim solution [100].

Using the AR5 definitions given in Sect. 1.2, a case for classifying geoengineering as both mitigation and adaptation could be made, as it is an intervention in Earth’s natural systems aimed at impeding the impacts of anthropogenic climate change, but also a method of adjusting to current or future climate change. However, because the geoengineering approach is probably a better fit to mitigation discussions, it is addressed in this section.

1.3.4 *Geoengineering*

The term *geoengineering* can be used as shorthand for Geological Engineering, or to describe some aspects of Civil Engineering, when referring to tunnel and bridge construction, for example. However, over the last decade it has been used in climate change discussions, almost wholly replacing the term Climate Engineering. In this context, what is its precise meaning? Different national and international agencies,

as well as authoritative dictionaries, have different definitions but are very similar in intent if not words. In this section the definition, ‘*Geoengineering is the deliberate large-scale intervention in the Earth’s natural systems to counteract climate change, particularly the World’s temperature*’, will be used, which was extracted and merged from two respected sources [101, 102].

However, it was concluded in the 2007 IPCC AR4 report that geoengineering proposals were “*largely speculative and unproven, and with the risk of unknown side-effects*” [33]. A somewhat bleak and partly impulsive conclusion, but at the time there was a great deal of hope that fossil fuels would be replaced promptly by renewable sources. So, perhaps suggestions, such as geoengineering, were considered a distraction from the main thrust of ensuring speedy energy transitions, which would make any geoengineering effort redundant? Given that the main aim of geoengineering is to lower surface and ocean temperatures to pre-industrial levels, numerous proposals have since been studied on how this could be achieved. These include imitating *natural* phenomena, such as volcanic eruptions, which, if their ash-plumes are of sufficient scale, are known to reduce global temperatures and result in harmful side-effects, or by capturing more CO₂ using better land-use management, i.e., increasing forestry cover [103]. Moreover, another possible class of geoengineering is weather or *climate modification*, e.g., firing or spraying specific chemicals into the clouds to make them give up their moisture, a technique used by the People’s Republic of China prior to the 2008 Olympics to ensure that the upcoming games would be rain-free [104]. In Germany, such techniques using planes, so-called *Hail Fliers*, to deliver the chemicals, have long been used to cause thunderclouds to release their water vapor as rain before damaging hail is formed [105]. However, usually such approaches can be considered as more of a local adaptation rather than large-scale intervention but, by 2025, China, following declared technical research and development breakthroughs, has plans to deploy *weather modification systems* to generate rain and snow over an area of 5.5 Million square kilometers, about 60% of its total land area; a similar land area as the United States, over 1.5 times larger than India, and 20 times larger than the UK! [104].

There are two primary approaches to geoengineering; (a) Carbon Dioxide Removal (CDR), and (b) Solar Radiation Management (SRM) [100, 102, 106]. These approaches involve various methodologies which are summarized in Table 1.3. The burning of biomass combined with CCUS and burying cut-down trees or turning them into charcoal (bio-char) are considered by some to be forms of geoengineering, but these approaches are usually categorized as part of mitigation by energy transition.

The cirrus cloud approach is only at the theoretical stage, but most of the other methodologies are scientifically and technically possible, if not yet ready for universal deployment, except *avoided* deforestation and afforestation. This situation is mainly the result of, laboratory-scale only, experimental data being available due to a general lack of significant funding because of governments’ hesitancy [102].

Table 1.3 Geoengineering methodologies [100, 102, 106]

Carbon dioxide removal	Solar radiation management
Capturing CO ₂ from ambient air, not emission sources	Stratospheric aerosol injection
Fertilization of the Ocean using iron Compounds to increase capture of more atmospheric CO ₂	Reducing solar radiation reaching the earth by shields, deflectors, mirrors in space
Ocean alkalinity enhancement to increase ocean CO ₂ storage ability	Albedo enhancement —increasing surface, unused desert, and marine cloud reflectivity, e.g., painting the roofs of urban structures and pavements of urban environments white; use low altitude seawater/acid sprays to encourage greater cloud formation over the oceans
Geochemical weathering , the acceleration of natural geological weathering processes by injecting CO ₂ into certain types of rock	
Avoided deforestation and afforestation	Dissipation and prevention of cirrus clouds , i.e., high altitude heat-trapping clouds

However, super-rich philanthropists, such as Bill Gates the co-founder of *Microsoft*TM, have started to invest significant amounts in both CDR and SRM [e.g., 107]. Moreover, the Government of the United States is now investing in *Climate Intervention* research [108]. Yet, whatever the viability of geoengineering, there is a mountain of concerns associated not only with the AR4’s “*the risk of unknown side-effects*”, but also the global ethics and politics of instituting the methodologies [33]. For example, one of the major unknown effects of reducing Earth’s surface temperatures and decreasing its heat energy absorption is how will agricultural food crops productivity be influenced at a time when global populations are increasing? Until far more research data becomes available, for the moment geoengineering should only be viewed as an approach of last resort, an *emergency* brake, to be used if mitigation does not flatten the rising temperature curve. However, many countries and jurisdictions have already proclaimed *climate emergencies* and, following China’s announcement of their large-scale weather modification plans, others may take unilateral geoengineering actions in the absence of a global treaty.

The concept of using mitigation to circumvent the potentially damaging impacts of human-driven climate change is a relatively new phenomenon which has gained credence since the start of this century. Nonetheless, in the absence of harmful human influences for almost all the Holocene era, global climates have continued to change. Humans have learned, often painfully, to combat these changes using strategies which are now labelled *adaptation*. In the next section the approaches to adaptation, old and new, are discussed along with insights into the causes of climate variabilities.

1.4 Approaches to Adaptation and Causes of Climate Variability

Adapting to changing climates is a challenge that has existed since living things first inhabited the Earth. Scientists believe that these challenges have led to 99.9% of all species that ever existed becoming extinct and even trees disappeared for at least 10 millennia because of one of the 5 major mass extinctions that happened over the past 500 million years [109]. A less than outstanding record of adaptation success. However, with the arrival of *homo sapiens*, about 300,000 years ago, and, especially, since the onset of the present interglacial period, adaptation strategies have proved far more successful. The arrival of a globally warmer climate, coupled with learned human abilities for intentionally making fire, building protective shelters, and growing, rather than hunting, food, have been instrumental in this success. Particularly, over the past 2 millennia, humans have taken steps to harvest and store rainwater, build sea rise defences and weather-resistant buildings, and move to more habitable areas. Those who have not made such provisions have usually perished, but global populations have constantly increased, except for relatively short periods following wide-spread pandemics or wars.

On occasions, the traditional approaches to adaptation had to be modified to account for changing climate circumstances, i.e., natural climate variability, but now these changing circumstances are accelerating for reasons mainly attributed to anthropogenic climate change. Will these added climate influences result in more droughts and floods, more extreme weather events such as damaging hurricanes, changes in atmospheric and oceanic circulations, increases in sea-levels, and reductions in ocean alkalinity⁹? Research on all these effects is ongoing and there is uncertainty in some of the findings so far, so terms such as, *generally, more likely, expected to become, can worsen, more prone*, and so on are regularly seen in the climate change literature [e.g., 110–112]. The general theme is largely that *more of the same* adaptation techniques are going to be needed in the future, but that migration will not only impact populations but also agriculture, i.e., where plant-based food is grown. Moreover, urbanization will continue, and, in many instances, there will be a reluctance to move away from coastal areas. The latter means more, and better, sea-defences will be needed. In essence, risk analysis and risk management will play major roles in adaptation strategies and such assessments will rely on diverse forms of evidence, as illustrated in Fig. 1.11 [47].

Anthropogenic climate models are predicting increased global warming, which will cause changing precipitation and weather patterns, which in turn will affect adaptation approaches to local and regional terrestrial and coastal flooding, droughts, and water scarcity. Is there any way that real observations can help in deciding when and where enhanced adaptation will be necessary? Yes, using defined weather and climate indices, which are based more on observations rather

⁹ The term ocean acidification is often used to describe decreasing ocean alkalinity although the oceans still are alkaline.

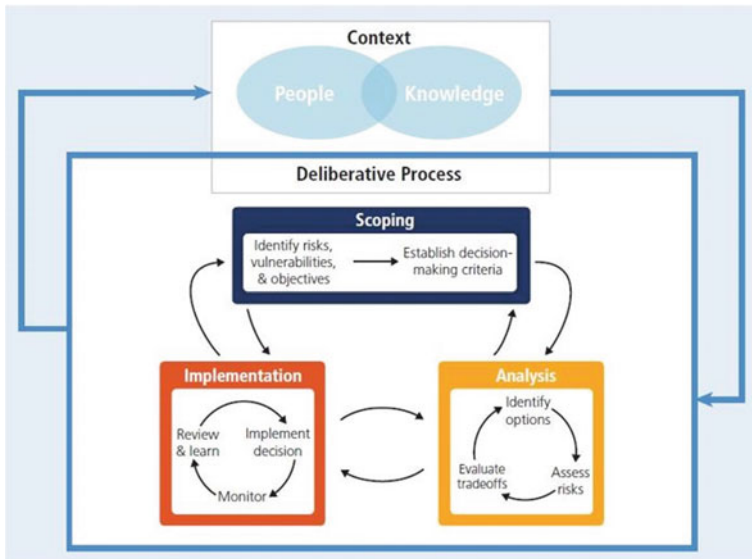


Fig. 1.11 Risks, analysis, implementation framework for adaptation [47]

than modelling results, and which include not only climate change effects but also the influences of climate variabilities. Although the precise contributions of each can be difficult to quantify. As discussed in Sect. 1.2, in the design of flood-prevention adaptation infrastructure, a 100-year occurrence or eventuality usually supplies the benchmark.

However, the USGS (United States Geological Survey) suggest that the term *recurrence interval* is a better description than the sometimes-misleading use of comments about a 100-year flood. Moreover, they underscore that it must be appreciated that two comparable events, e.g., heavy floods, could occur at the same location only a few years apart rather than say a gap of 100 years. To address such issues, the USGS and other agencies use a factor called the *Annual Exceedance Probability* (AEP) in conjunction with a recurrence interval. So, if a 100-year occurrence has an AEP of 0.1 (10%) it means there is a 10% chance of that occurrence in any given year [113]. On a moving average, the AEP value could change because of climate change effects and not only the occurrence probability, but also what height of water is a major flood. The AEP and other weather and climate indices are key parameters which should be included in the design of future adaptation strategies whether, local, regional, or global. Exemplars of such probability indices are given in the next sub-section.

1.4.1 The Use Weather and Climate Indices

The numerical values of these indices are based on historic datasets, but the probability of occurrences is usually calculated using standard modelling techniques assuming normal distributions. The estimated values of the indices, recurrence intervals, and the specific eventually risks, rely to some extent on the chosen benchmarks or the quantity and quality of available data in much same way as with temperature anomaly data [114]. So, for example, as shown in the chart, given at Fig. 1.12, the SPIs for a region in the State of Idaho in the United States are based on a database of 111 years of observations, the *red curve*, based on 60-month timescales and are stated as tracking long-term drought, whereas the *blue curve* is based on 5-month timescales and when $SPI = 0 \pm 1$, the precipitation situation is considered neutral, i.e., no dryer or wetter than usual over the years of observations [115].

If SPI values are above 1 then the climate will be wetter than normal and if below -1 it will be dryer, and the generic SPI distribution curve will be as shown as in Fig. 1.13 [116]. As a mathematical expression SPI, can be written,

$$SPI = (X_{ij} - X_{im})/\sigma \quad (1.1)$$

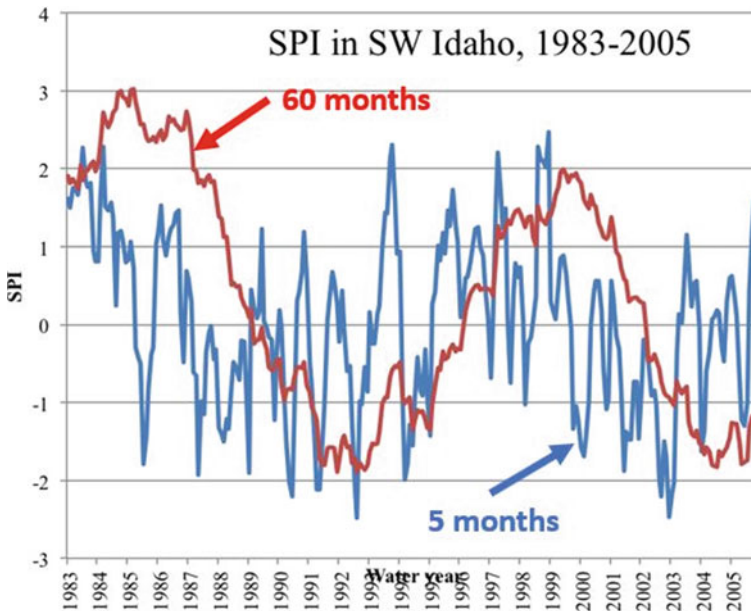


Fig. 1.12 Example of SPI curves in a USA region [115]

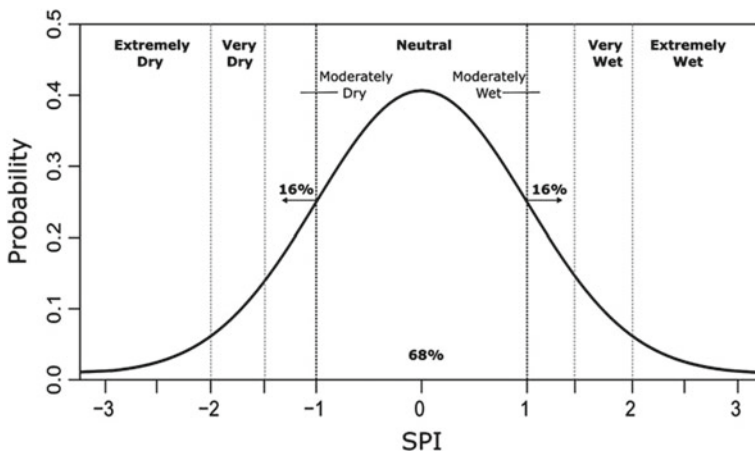


Fig. 1.13 Generic SPI normal distribution curve [116]

where,

X_{ij} Seasonal precipitation in i th rain-gauge station and j th observation

X_{im} long term seasonal mean, and σ is the standard deviation.

Similar expressions, or computer algorithms, can be used to calculate the numerical values of the various indices. These can show what adaptation measures may need to be contemplated, if not already taken, and what adaptation measures are needed to be taken to avoid local, regional, and global disasters, what the United Nations Office of Disaster Risk Reduction (UNDRR) term *disaster risk reduction* [114, 116, 117].

1.4.2 Adaptation, Climate Variability and Climate Change

Since they first appeared as a specie, adaptation has allowed humans to address climate variabilities. But what are the sources of these variabilities? Over the last two centuries scientists, particularly geologists and anthropologists, became aware of current and historic *natural* climate changes and they tried to answer the question, why do they happen? However, awareness is different from understanding and there are still no wholly conclusive explanations for the causes and effects of such variabilities, but they have found several factors that are associated with natural climate changes. These include *Plate Tectonics*,¹⁰ the idiosyncrasies of the *Carbon Cycle*, and the *Milankovitch cycles*, which are connected to the intricate

¹⁰ Formerly referred to as *continental drift*.

relationships between the amount of solar radiation reaching the Earth at specific locations at any given time and global periods of subsequent climate warming and cooling.

Plate Tectonics. Plate tectonics is the notion that the Earth's outer shell, or *lithosphere*, which is about 100 km thick, consists of slabs of rock, *plates*, which drift around the Earth, their movement being lubricated by an underlying viscous layer, the *asthenosphere* [118]. Plate collisions, and the geological movements along the boundaries of contiguous various plates, can lead to volcanic eruptions, earthquakes, and tsunamis which cause short-lived changes in local, and sometimes global, weather and climates and can have devastating effects on the impacted populations.

Adaptation strategies now include the continued development of scientific *early warning systems* of these events, although there is still a high degree of uncertainty in forecasting the timing and duration of such happenings. However, based on these developments, and using a growing body of accumulated observations and measurements, it is possible to categorize global regions where the likelihood of plate tectonic incidence is much higher. In these regions adaptation measures, such as requiring that buildings are *earthquake-proof* and constructing *sea-defences* (for example, walls, breakwaters, and wave disruptors), are used to reduce the risks from natural disasters [119, 120]. Although, it should be noted, that regions outside the active tectonic zones also use sea-defences to protect communities from the effects of tidal variations.

The Carbon Cycle. Carbon is a key part of all living things, being described in school textbooks as the *backbone* or *foundation* of life on Earth. Carbon compounds are present in various forms in the oceans, sedimentary rocks, soil and organic matter, vegetation, and in the atmosphere as GHGs, i.e., carbon dioxide and methane. Atmospheric carbon dioxide is captured by terrestrial vegetation and oceanic phytoplankton from which it enters both animal and human food chains. Eventually, the sequestered carbon will be returned to the atmosphere by a variety of natural processes, as illustrated in Fig. 1.14 [121]. The Earth's amount of carbon is invariable and its transfer from one source to another is known as the *Carbon Cycle*. Any changes in the stored amounts in one source will alter the amounts in the other *sinks* and possibly the rate of transfer between them. While the atmospheric carbon dioxide and methane store only a trace of the Earth's total carbon, sedimentary rocks such as limestone account for almost all of the total carbon [122]. Volcanic and rock weathering processes are the main pathways for the return of carbon dioxide into the atmosphere. Plate movements can instigate these processes, and while weathering is usually an extremely slow activity, even measured in *geological* time, when volcanoes erupt the effects are immediate. In both cases the Carbon Cycle transfers are altered by plate tectonics [123]. This is not only important for climate variability adaptation but could also have a similar significance for climate change. This is because it appears that excessive tectonic out-gassing of GHGs could affect global warming, but, conversely, such warming could

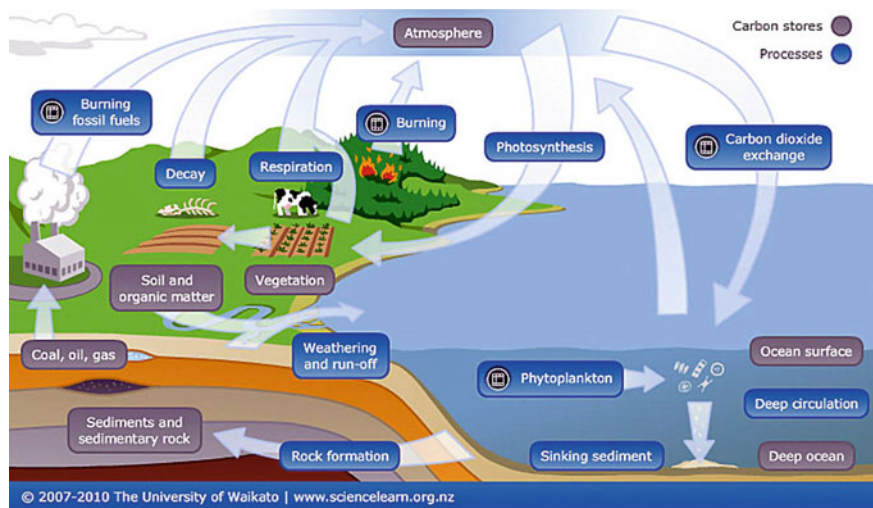


Fig. 1.14 A depiction of the carbon cycle [121]

reduce tectonic activity. The exact correlation between plate tectonics and anthropogenic climate change, and vice versa, are still matters of scientific debate [124, 125].

The Milankovitch Cycles. The final variability factor, and the most important, are the Milankovitch cycles, named after Dr. Milutin Milanković a Serbian civil engineer and mathematician.¹¹ By the early nineteenth century, several leading geologists suggested that abnormal surface rock *boulders*,¹² seen throughout some global regions, were the result of historic glaciation, *Ice Ages*, and hypothesised that the cause was likely to be *astronomical*, involving the amount of *isolation* (incoming solar radiation) from the sun reaching the Earth [126]. Their work intrigued Milankovitch and, after practising as an engineer, he entered academia and published his first paper on climate theory. During the 1914–1918 world war he was a prisoner of war and afterwards an *internee* [127, 128]. He returned to full-time academia after the war and continued his work for another three decades on developing a mathematical theory of how ice ages are caused by isolation. With a growing body of scientific evidence, eventually Milankovitch was able to model the effects for isolation on the Earth’s climate for the 600,000 years before the nineteenth century [129]. He discovered, through modelling using a complex set of equations, that there were 3 orbital cycles involving the Sun and the Earth which triggered climate changes and, by considering the Earth as a *black body*, was able to

¹¹ Milankovitch graduated in Civil Engineer both as an undergraduate and postgraduate student. He is often referred to as a geophysicist, astronomer, scientist and, more recently, a climatologist!

¹² Also known as *erratics*.

calculate the Earth's annual surface temperature variations [130]. He found that there were long periods, *glacial epochs*, when the surface temperatures would cool and glaciation, i.e., the ice cover, would increase. These were interspersed with shorter periods of surface warming, *interglacial periods*, when the glaciers would retreat. His theoretical model predicted when these periods had occurred, but it would be 5 decades before evidence was available to confirm the theory [129].

The three cycles were due to changes in (a) the Earth's orbital path around the sun, from almost circular to slightly elliptical i.e., the orbit's *eccentricity*, (b) the angle of the Earth's rotational axis relative to its plane of orbit around the sun, known as *obliquity* or *axial tilt*, from 22.1° to 24.5° and (c) the wobble, or *precession*, of Earth's spin caused by various combinations of the gravitational forces exerted by both the sun and the moon. An often used analogue is that of the motion of a child's spinning top as the Earth is not a perfect sphere [126–130]. These changes occur in a cyclic manner of varying frequencies, i.e., minimum to maximum eccentricity takes place over an average of about every 100,000 years; axial tilt cycles, from minimum to maximum and back again, take place over about 40,000 years, and significant changes in the precession trend occur about every 26,000 years. There is a lack of synchronicity between the highs and lows of the 3 cycles, but it needs to be stressed that while cyclic changes, albeit over long periods of time, are continuous, they do not suddenly change the climate during a normal human's lifetime. So why should we be interested in Milankovitch cycles?

First, they show that the amount of solar radiation reaching the Earth's geographical regions, especially the Northern Hemisphere, at certain times in the cycles will sooner or later lead to global cooling and the next glacial epoch. Secondly, it is now known that axial tilt is the prime driver of Earth's seasons, e.g., winter and summer. As the tilt changes, the seasons will vary in length, location, timing, and characteristics. So, for example, when the North Pole tilts toward the Sun, it will be summer in the Northern Hemisphere, and when the South Pole tilts toward the Sun, it will be winter in the Northern Hemisphere. Depending upon global location and elevation the seasons have different rates of precipitation, evaporation, and temperature change and while the tilt contributes to the timing and nature of the seasons, it is not the only factor which affects occurrences of floods and droughts, as natural hazards associated with plate tectonics, e.g., earthquakes and volcanic activity, occasional disruptions in atmospheric and oceanic circulations, together with wildfire and destructive hurricane incidences can also influence normal seasonal climates [131].

The type of indices given in Table 1.4 afford some insight into what regional adaptation techniques are needed to address the seasonal changes caused by tilt and then further altered by natural occurrences, i.e., *climate variabilities*. These indices enable infrastructure standards to be formulated, but as the climate has been changing since the 1970s, more up to date benchmarks than a hundred years ago could help to show the possible regional consequences of anthropogenic climate change on future adaptation strategies. In the absence of *climate change*, adaptation will still be necessary because of the climate variabilities involving Plate Tectonics, Milankovitch cycles, and others factors yet to be revealed [132]. However, weather

Table 1.4 Exemplar weather and climate indices [113, 115, 133–140]

Climate index or analysis	Use and definition	References
Annual exceedance probability (AEP)	Probability of a flood event occurring in any year	[113]
Standardized precipitation index (SPI)	Characterizes meteorological drought or abnormal wetness	[115]
Standardized precipitation evapotranspiration index (SPEI)	Combines precipitation and potential evapotranspiration (PET) data	[133, 134]
Standardized streamflow index (SSFI/SSI)	Characterizes hydrological drought from surface run-off water	[135]
Flood frequency analysis/return period	Determination of the statistical potential for floods	[136]
water exploitation index (wei+)	Indicator of water scarcity	[137]
Air quality index (AQI)	Numerical index of five major air pollutants	[138]
The U.S. climate extremes index (CEI)	Overview of climate extremes across continental United States	[139]
Risk of natural catastrophes (cat modelling)	Financial impact on infrastructure	[140]

and climate indices are based on measured data of actual events, not on predictions or projections of future incidences. There could be little, if any, economic and societal benefit from imposing unnecessary adaptation measures. Conversely, if enhanced adaptation approaches, e.g., higher sea-walls prove to be vital because of climate change, and steps have not been taken, there may be insufficient time to construct them and avoid disasters [114, 116, 117].

Mitigation cannot negate the need for adaptation, but it could influence the future scale of adaptation strategies. Moreover, modest enhancements to the current approaches may enable more time for mitigation processes to achieve their desired goals. The shortcoming of such tactics could be reduced public and political anxieties about anthropogenic climate change and reduced global investments in mitigation approaches. Hence, are there ways of constructively addressing both mitigation and adaptation simultaneously to defeat the impacts of changing climates, at least until the inevitable arrival of the next Ice Age? In the next section these matters are discussed.

1.5 Mitigation and Adaptation: Trade-Offs, Conflicts, and Synergies

Mitigation and Adaptation are both aimed at reducing the harm caused by changing climates, mitigation as a permanent global approach with the goal of eventually ending anthropogenic climate change, while adaptation is aimed at reducing the

harm at more *local* levels which can be caused by natural climate variability and, more recently, the possible increasing influences of human-driven climate change. As urbanization continues to increase, albeit somewhat slower because of the COVID-19 pandemic, the discussions about local adaptation in cities and the relationships with national and global mitigation approaches have not abated [141]. Calls for better urban planning and management, with respect to creating friendlier environments through mitigation and adaption, are not new [e.g., 142, 143]. However, an adaption technique for, say, addressing water scarcity, e.g., the building of dams and reservoirs, can lead to conflicts with the mitigation techniques trying to reduce emissions, because of the potential GHG emissions from large bodies of water.

Furthermore, generating more *green infrastructure*, in and around population centers, could lead to the concentration of more people into smaller land areas by building residential and workplace structures vertically as opposed to horizontally, which in turn could enhance, rather than reduce, the climate impacts of urban heat islands. The taller buildings also need more steel and concrete, whose manufacture produces more GHG emissions. There could also be adverse socio-economic consequences for those seeking affordable housing away from urban areas, as demand exceeds supply and city housing costs rise. These individuals will need to travel greater distances to their places of work, and transportation, public or private, will produce more GHG emissions until mitigation strategies become effective. The suburban or rural areas that people must move to, may also be in less well protected flood locations and may have inadequate clean water supplies, at least initially. If this proves to be the case, then eventually, better and more flood prevention measures, and water supply infrastructure, may be necessary which would involve new dams and reservoirs especially as the local population rises. Subsequently, further mitigation versus adaptation conflicts may be created. Conversely, changing land-use from agricultural to reforestation could result in insufficient food production and loss of income.

While these are simple *what-if* examples many such issues have been raised in the climate literature and in place of labelling them as *conflicts*, terms such as *maladaptation* have been coined to describe adaptation strategies that increase GHG levels and *malmitigation* for a mitigation strategy that, while reducing global GHG levels, increases the local or regional vulnerability [144, 145]. There is a growing body of scientific literature dealing with maladaptation and malmitigation in climate change contexts, with the focus being largely, but not exclusively, on the issues that could be experienced in urban communities [e.g., 146–148]. Moreover, concerns about *uncertainty* are often expressed in this literature. However, according to a recent publication survey, there are significantly more articles dealing with trade-offs between mitigation and adaptation, particularly when cities do not have infinite resources [149, 150]. But could there not be a way where mitigation and adaptation could be used together without serious conflicts and enforced trade-offs, i.e., *synergies*? Yes, and such approaches are gaining more scientific attention [143, 151–153]. Possible *sweet-spots* for synergies between mitigation and adaptation have been identified, as shown in Fig. 1.14 [151, 154].

1.6 Concluding Remarks

In this chapter, the main approaches to limiting the average global surface temperature to the 2100 level specified in the ground-breaking Paris Agreement, i.e., the reduction of atmospheric GHG levels, *Mitigation*, were discussed. Aspects of the potentially damaging impacts of anthropogenic global warming on the Earth and its growing number of inhabitants were highlighted. It was emphasized that the Earth has been subject to intrinsically changing climates since its formation and that, since the arrival of homo sapiens, methods of addressing the harmful impact of these changes have evolved, albeit with varying degrees of success. Collectively, these methods are termed *Adaptation*. It is unrealistic to expect that mitigation can prevent natural climate changes, now defined as climate variabilities, so adaptation techniques will always be needed. However, without mitigation, adaptation could become progressively challenging and, in some instances, impractical, which could also be the case when mitigation adversely effects locally applied adaptation infrastructure and thus becomes malmitigation.

Although agencies such as the IPCC have advocated for both mitigation and adaptation, the bulk of government funding on climate research and innovation has been focused on mitigation strategies such as energy transitions [5]. Now, with the apparently growing realization that mitigation alone will not correct anthropogenic climate in the hoped-for timeframe, will governments of all levels, especially national and international, embrace adaptation as a necessary adjunct? After all, local and regional governments have a long record of adaptation actions. However, to avoid maladaptation and malmitigation and promote synergies, constructive frameworks will need to be established, at least, for those *sweet-spot* scenarios identified in Fig. 1.15 [155, 156]. This will require thorough and proper planning

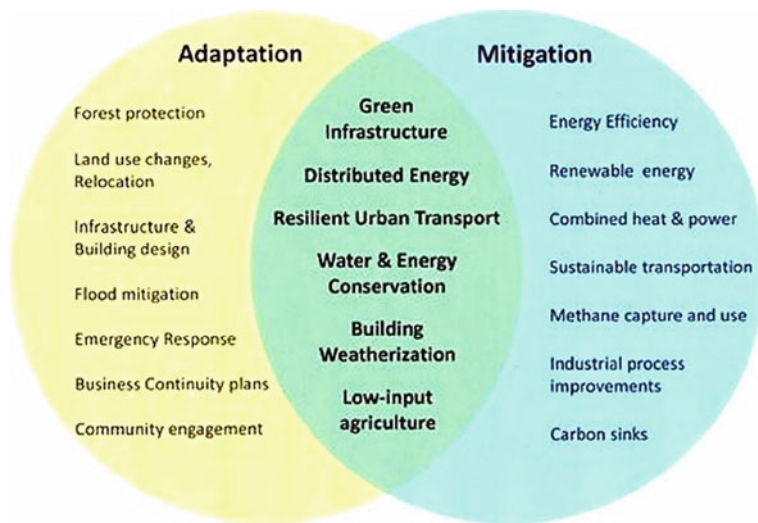


Fig. 1.15 Adaptation and mitigation *sweet-spots* [151, 154]

involving all those directly, or indirectly, taking part in, or impacted by, the proposed solutions. Unquestionably, such processes should include well coordinated rural and urban land management strategies to avoid technical, financial, and social conflicts where possible and practical.

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