1 Introduction to Climate Change Mitigation

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Climate Change

There has been a heated discussion on climate change in recent years, with a particular focus on global warming.

Instrumental recording of temperatures has been available for less than 200 years. Over the last 100 years, a temperature increase of 0.5°C could be measured [1] with rather different regional patterns and trends [2]. Over the last several million years there have been warmer and colder periods on Earth, and the climate fluctuates for a variety of natural reasons, as data from tree rings, pollen, and ice core samples have shown. However, human activities on Earth have reached an extent that they impact the globe in potentially catastrophic ways.

In [3], Bruce D. Smith is quoted as saying: "The changes brought over the past 10,000 years as agricultural landscapes replaced wild plant and animal communities, while not so abrupt as those caused by the impact of an asteroid as the Cretaceous-Tertiary boundary some 65 million years ago or so massive as those caused by advancing glacial ice in the Pleistocene, are nonetheless comparable to these other forces of global change." At the Earth Summit in Rio de Janeiro in 1992, over 159 countries signed the United Nations Framework Convention on Climate Change (FCCC, also called "Climate Convention"), in order to achieve "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" [4]. In 2001, the Intergovernmental Panel on Climate Change (IPCC) [30] wrote: "An increasing body of observations gives a collective picture of a warming world and other changes in the climate system... There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities."

In its fourth assessment report of 2007, the IPCC stated that human actions are "very likely" the cause of global warming. More specifically, there is a 90% probability that the burning of fossil fuels and other anthropogenic factors such as deforestation and the use of certain chemicals have already led to an increase of 0.75° in average global temperatures over the last 100 years, and that the increase in hurricane and tropical cyclone strength since 1970 also results from man-made climate change. The position of the IPCC has been adopted by several renowned scientific societies, and a consensus has emerged on the causes, and partially on the consequences, of climate change. The history of climate change science is reviewed in [5]. There are researchers who oppose the scientific mainstream's assessment of global warming [6]. However, the public seems to be unaware of the high degree of consensus that has been achieved in the scientific community, as elaborated in a 2009 World Bank report [7]. In [8], there is a treatment of the mass media's coverage of the climate change discussion with a focus on rhetoric that emphasizes uncertainty, controversy, and climate skepticism.

The Greenhouse Effect

A greenhouse, also called a glass house, is a structure enclosed by glass or plastic which allows the penetration of radiation to warm it. Gases capable of absorbing the radiant energy are called the greenhouse gases (GHG). Greenhouses are used to grow flowers,

vegetables, fruits, and tobacco throughout the year in a warm, agreeable climate. On Earth, there is a phenomenon called the "natural greenhouse" effect, or the Milankovitch cycles.

Without the greenhouse gas effect, which is chiefly based on water vapor in the atmosphere (i.e., clouds that trap infrared radiation), the average surface temperature on Earth would be 33°C colder [9]. The natural greenhouse effect renders Earth habitable, since the temperature which would be expected from the thermal equilibrium of the irradiation from sun and radiative losses into space (radiation balance in the blackbody model) is approximately −18°C.

On the moon, for instance, where there is hardly any atmosphere, extreme surface temperatures range from −233°C to 133°C [10]. On Venus, by contrast, the greenhouse effect in the dense CO_2-laden atmosphere results in an average surface temperature in excess of 450°C [11, 12].

The current discussion about global warming and climate change is centered on the anthropogenic greenhouse effect. This is caused by the emission and accumulation of greenhouse gases in the atmosphere. These gases (water vapor, CO_2, CH_4, N_2O, O_3 and others) act by absorbing and emitting infrared radiation. The combustion of fossil fuels (oil, coal and natural gas) has led mainly to an increase in the CO_2 concentration in the atmosphere. Preindustrial levels of CO_2 (i.e., before the start of the Industrial Revolution) were approximately 280 ppm, whereas today they are above 380 ppm with an annual increase of approximately 2 ppm. According to the IPCC Special Report on Emission Scenarios (SRES) [13], by the end of the twenty-first century, the CO_2 concentration could reach levels between 490 and 1,260 ppm, which are between 75 and 350% above the preindustrial levels, respectively.

CO_2 is the most important anthropogenic greenhouse gas because of its comparatively high concentration in the atmosphere. The effect of other greenhouse-active gases depends on their molecular structure and their lifetime in the atmosphere, which can be expressed by their greenhouse warming potential (GWP). GWP is a relative measure of how much heat a greenhouse gas traps in the atmosphere. It compares the amount of heat trapped by a certain mass of the gas in question to the amount of heat trapped by a similar mass of CO_2. With a time horizon of 100 years, the GWP of CH_4, N_2O, and SF_6 with respect to CO_2 is 25, 298 and 22,800, respectively [14]. But CO_2 has a much higher concentration than other GHGs and it is increasing at a higher rate due to burning of fossil fuels. Thus, while the major mitigating emphasis has mainly been placed on CO_2, efforts on mitigating CH_4, N_2O, and SF_6 have also been active.

Anthropogenic Climate Change

The climate is governed by natural influences, yet human activities have an impact on it as well. The main impact that humans exert on the climate is via the emission of greenhouse gases. Deforestation is another example of an activity that influences the climate [15]. *Figure 1.1* shows the share of greenhouse gas emissions from various sectors, taken from [16]. The energy sector is the dominant source of GHG emissions.

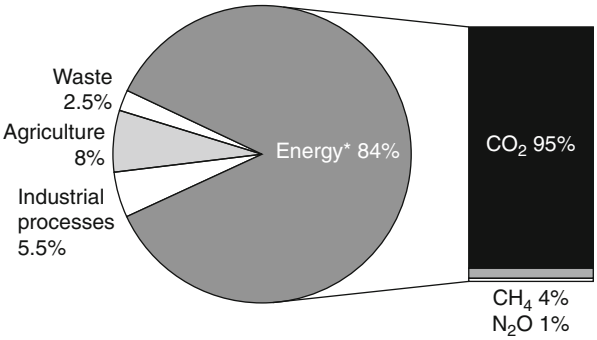

Fig. 1.1
Shares of global anthropogenic greenhouse gas emissions (Reprinted with permission from [16])

According to the International Energy Agency (IEA), if no action toward climate change mitigation is taken, global warming could reach an increase of up to 6° in average temperature [17]. This temperature rise could cause devastating consequences on Earth, which will be discussed briefly below.

Effects of Climate Change

Paleoclimatological data show that 100–200 million years ago, almost all carbon was in the atmosphere as CO_2, with global temperatures being 10°C warmer and sea levels 50–100 m higher than today. Photosynthesis and CO_2 uptake into the oceans took almost 200 million years. Since the Industrial Revolution, i.e., during the last 200 years, this carbon is being put back into the atmosphere to a significant extent. This is a rate which is 10^7 times faster, so there is a risk of a possible "runaway" reaction greenhouse effect.

Figure 1.2 shows the timescales of several different effects of climate change for the future.

Due to the long lifetime of CO_2 in the atmosphere, the effects of climate change until a new equilibrium has been reached will prove long term. A global temperature increase of 6°C would be severe, so the IEA has developed a scenario which would limit the temperature increase to 2°C [17] to minimize the effects.

Sea level rise will indeed be the most direct impact. Other impacts, including those on weather, flooding, biodiversity, water resources, and diseases are discussed here.

Climate Change – What Will change?

An overall higher temperature on Earth, depending on the magnitude of the effect and the rate at which it manifests itself, will change the sea level, local climatic conditions, and the

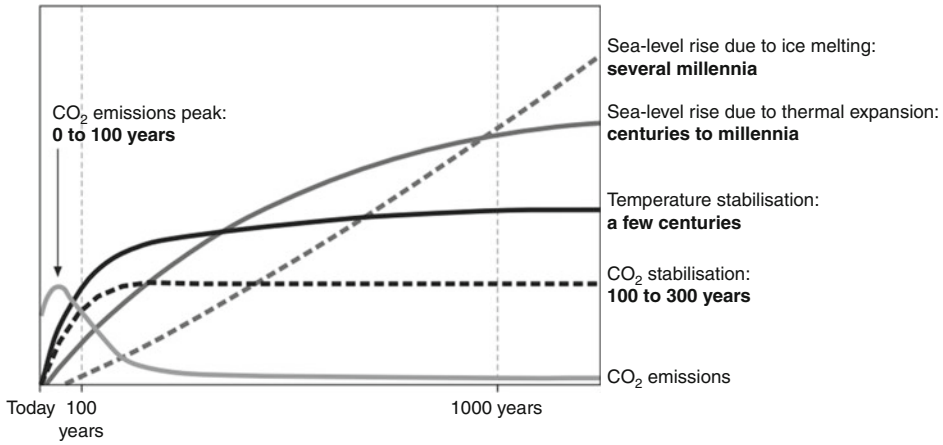

Fig 1.2

Time scales of climate change effects based on a stabilization of CO_2 concentration levels between 450 and 1,000 ppm after today's emissions (Reprinted with permission from [16])

proliferation of animal and plant species, to name but a few of the most obvious examples. The debate on the actual consequences of global warming is the most heated part of the climate change discussion.

Apart from changes in the environment, there will be various impacts on human activity. One example is the threats to tourism revenue in winter ski resorts [20] and low-elevation tropical islands [21]. Insurance companies will need to devise completely new business models, to cite just one example of businesses being forced to react to climate change.

Impact of Climate Change Mitigation Actions

The purpose of climate change mitigation is to enact measures to limit the extent of climate change. Climate change mitigation can make a difference. In the IEA reference scenario [17], the world is headed for a CO_2 concentration in the atmosphere above 1,000 ppm, whereas that level is limited to 450 ppm in the proposed "mitigation action" scenario. In the first case, the global temperature increase will be 6°C, whereas it is limited to 2°C in the latter [17].

The Intergovernmental Panel on Climate Change has projected that the financial effect of compliance through trading within the Kyoto commitment period will be limited at between 0.1 and 1.1% of GDP. By comparison, the Stern report estimated that the cost of mitigating climate change would be 1% of global GDP and the costs of doing nothing would be 5 to 20 times higher [14, 22].

Climate Change Adaption Versus Climate Change Mitigation

Individuals [23], municipalities [24, 25], businesses [20], and nations [26, 27] have started to adapt to the ongoing and expected state of climate change. Climate change adaptation and climate change mitigation face similar barriers [29]. To best deal with the situation, there needs to be a balanced approach between climate change mitigation and climate change adaptation [21, 24, 29]. This will prove to be one of mankind's largest modern challenges.

Handbook of Climate Change Mitigation

Motivation

The struggle in mitigating climate change is not only to create a sustainable environment, but also to build a sustainable economy through renewable energy resources. "Sustainability" has turned into a household phrase as people become increasingly aware of the severity and scope of future climate change. A survey of the current literature on climate change suggests that there is an urgent need for a comprehensive handbook introducing the mitigation of climate change to a broad audience.

The burning of fossil fuels, such as coal, oil, and gas, and the clearing of forests, has been identified as the major sources of greenhouse gas emissions. Reducing the 24 billion metric tons of carbon dioxide emissions per year generated from stationary and mobile sources is an enormous task that involves both technological challenges and monumental financial and societal costs with benefits that will only surface decades later. The Stern Report (2007) provided a detailed analysis of the economic impacts of climate change and the ethical ground of policy responses for mitigation and adaptation.

The decline in the supply of high-quality crude oil has further increased the urgency to identify alternative energy resources and develop energy conversion technologies that are both environmentally sound and economically viable. Various routes for converting renewable energies have emerged – including energy conservation and energy-efficient technologies.

The energy industry currently lacks an infrastructure that can completely replace fossil fuels in the near future. At the same time, energy consumption in developing countries like China and India is rapidly increasing as a result of their economic growth. It is generally recognized that the burning of fossil fuels will continue until an infrastructure for sustainable energy is established. Therefore, there is now a high demand for reducing greenhouse gas emissions from fossil fuel–based power plants.

The pursuit of sustainable energy resources has become a complex issue across the globe. The *Handbook on Climate Change Mitigation* is a valuable resource for a wide audience who would like to quickly and comprehensively learn the issues surrounding climate change mitigation.

Why This Book Is Needed

There is a mounting consensus that human behaviors are changing the global climate and that its consequence, if left unchecked, could be catastrophic. The fourth climate change report by the Intergovernmental Panel on Climate Change (IPCC 2007) has provided the most detailed assessment ever on climate change's causes, impacts, and solutions. A consortium of experts from 13 US government science agencies, universities, and research institutions released the report *Global Climate Change Impacts in the United States* (2009), which verifies that global warming is primarily human induced, and climate changes are underway in the USA and are only expected to worsen.

From its causes and impacts to its solutions, the issues surrounding climate change involve multidisciplinary sciences and technologies. The complexity and scope of these issues warrants a single, comprehensive survey of a broad array of topics, something which the *Handbook on Climate Change Mitigation* achieves by providing readers with all the necessary background information on the mitigation of climate change. The handbook introduces the fundamental issues of climate change mitigation in independent chapters, rather than directly giving the detailed advanced analysis presented by the IPCC and others. Therefore, the handbook will be an indispensable companion reference to the complex analysis presented in the IPCC reports. For instance, while the IPCC reports give large amounts of data concerning the impacts of different greenhouse gases, they contain little discussion about the science behind the analysis. Similarly, while the IPCC reports present large amounts of information concerning the impacts of different alternative energies, the reports rarely discuss the science behind the technology. There is currently not a single, comprehensive source that enables the readers to learn the science and technology associated with climate change mitigation.

Audience of the Handbook

Since the handbook covers a wide range of topics, it will find broad use as a major reference book in environmental, industrial, and analytical chemistry. Scientists, engineers, and technical managers in the energy and environmental fields are expected to be the primary users. They are likely to have an undergraduate degree in science or engineering with an interest in understanding the science and technology used in addressing climate change and its mitigation.

Scope

This two-volume handbook offers a comprehensive collection of information on climate change and how to minimize its impact. The chapters in this handbook were written by internationally renowned experts from industry and academia. The purpose of this book

is to provide the reader with an authoritative reference work toward the goal of understanding climate change, its effects, and the available mitigation strategies with which it may be tackled:

- Scientific evidence of climate change and related societal issues
- The impact of climate change
- Energy conservation
- Alternative energy sources
- Advanced combustion techniques
- Advanced technologies
- Education and outreach

This handbook presents information on how climate change is intimately involved with two critical issues: available energy resources and environmental policy. Readers will learn that these issues may not be viewed in isolation but are mediated by global economics, politics, and media attention. The focus of these presentations will be current scientific technological development, although societal impacts will not be neglected.

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