Introduction to Climate Change Mitigation

Maximilian Lackner, Wei-Yin Chen, and Toshio Suzuki

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Abstract

Since the first edition of the Handbook, important new research findings on climate change have been gathered. The handbook was extended to also cover, apart from climate change mitigation, climate change adaptation as one can witness increasing initiatives to cope with the phenomenon. Instrumental

M. Lackner (✉)
Institute of Advanced Engineering Technologies, University of Applied Sciences FH Technikum Wien, Vienna, Austria
e-mail: maximilian.lackner@tuwien.ac.at

W.-Y. Chen
Department of Chemical Engineering, The University of Mississippi, Oxford, MS, USA
e-mail: cmchengs@olemiss.edu

T. Suzuki
National Institute of Advanced Industrial Science and Technology (AIST), Nagoya, Japan
e-mail: toshio.suzuki@aist.go.jp

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recording shows a temperature increase of 0.5 °C Le Houérou (J Arid Environ 34:133–185, 1996) with rather different regional patterns and trends (Folland CK, Karl TR, Nicholls N, Nyenzi BS, Parker DE, Vinnikov KYA (1992) Observed climate variability and change. In: Houghton JT, Callander BA, Varney SDK (eds) Climate change, the supplementary report to the IPCC scientific assessment. Cambridge University Press, Cambridge, pp 135–170). 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. This chapter is an introduction to climate change.

Climate Change

There has been a heated discussion on climate change in recent years, with a particular focus on global warming. 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. For instance, in the Pleistocene, the geological epoch which lasted from about 2,588,000 to 11,700 years ago, the world saw repeated glaciations ("ice age"). More recently, "Little Ice Age" and the "Medieval Warm Period" (IPCC) occurred. Several causes have been suggested such as cyclical lows in solar radiation, heightened volcanic activity, changes in the ocean circulation, and an inherent variability in global climate. Also on Mars, climate change was inferred from orbiting spacecraft images of fluvial landforms on its ancient surfaces and layered terrains in its polar regions (Haberle et al. 2012). Spin axis/orbital variations, which are more pronounced on Mars compared to Earth, are seen as main reasons. As to recent climate change on Earth, there is evidence that it is brought about by human activity and that its magnitude and effects are of strong concern.

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 (Le Houérou 1996) with rather different regional patterns and trends (Folland et al. 1992). In (Ehrlich 2000), 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 Ma 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" (United Nations (UN) 1992). In 2001, the Intergovernmental Panel on Climate Change (IPCC) (Intergovernmental Panel on Climate Change (IPCC) 2007) 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.

In its fifth assessment report of 2013, the IPCC confirms their findings as *"Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased"* (IPCC 2013).

Figures 1 and 2 show some details of IPCC's findings.

In Fig. 2, natural and man-made (anthropogenic) radiative forcings (RF) are depicted. RF, or climate forcing, expressed in W/m^2, is a change in energy flux, viz., the difference of incoming energy (sunlight) absorbed by Earth and outgoing energy (that radiated back into space). A positive forcing warms up the system, while negative forcing cools it down.

(Anthropogenic) CO_2 emissions, which have been accumulating in the atmosphere at an increasing rate since the Industrial Revolution, were identified as the main driver.

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 (Miller et al. 2009). There are researchers who oppose the scientific mainstream's assessment of global warming (Linden 1993). 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 (Worldbank 2009). In (Antilla 2005), 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 scepticism. Climate change skeptic films were found to have a strong influence on the general public's environmental concern (Greitemeyer 2013).

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.

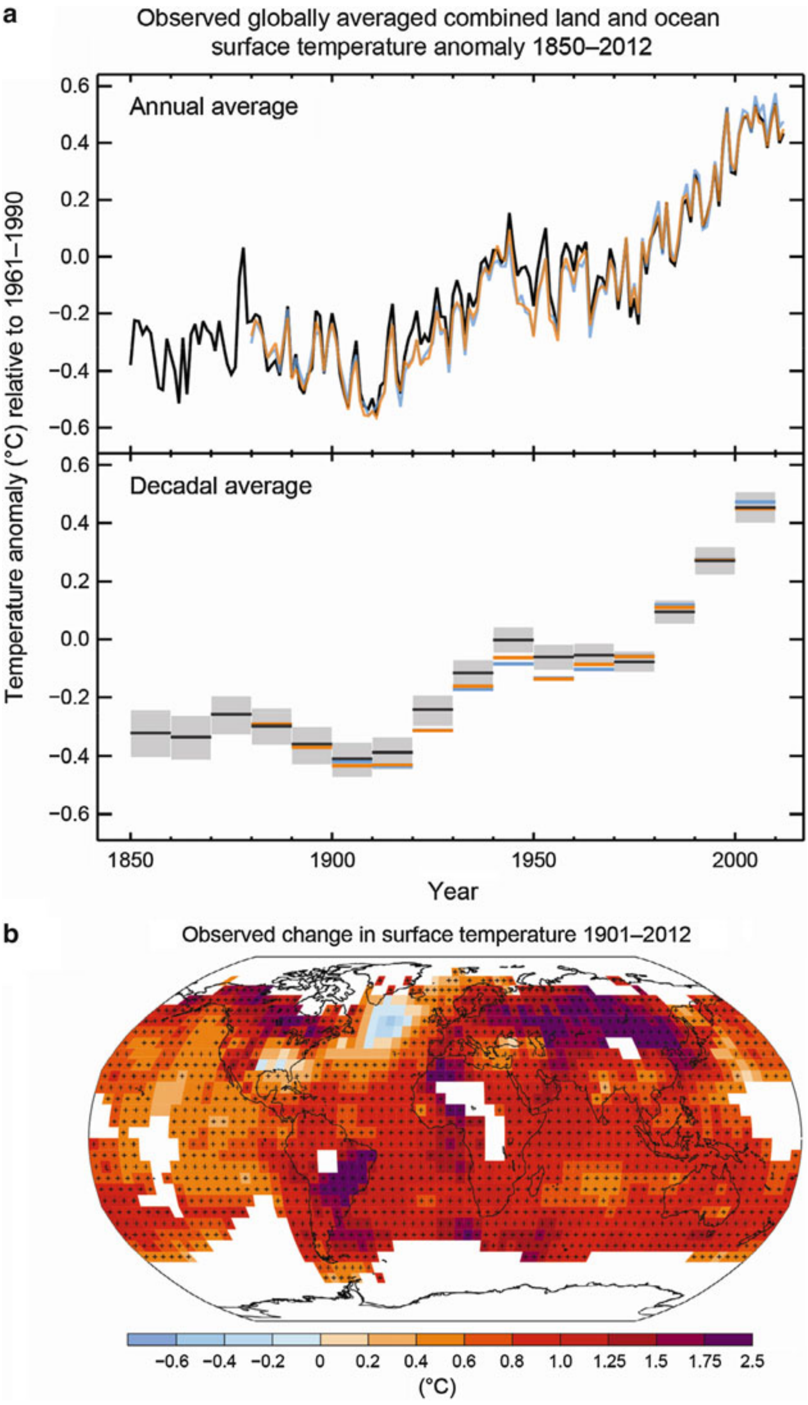


Fig. 1 (continued)

Without the greenhouse gas effect, which is chiefly based on water vapor in the atmosphere (Linden 2005) (i.e., clouds that trap infrared radiation), the average surface temperature on Earth would be 33 °C colder (Karl and Trenberth 2003). The natural greenhouse effect renders Earth habitable since the temperature which would be expected from the thermal equilibrium of the irradiation from the 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 (Winter 1967). 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 (Sonnabend et al. 2008; Zasova et al. 2007).

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) (IPCC 2010a), 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 (IPCC 2010b). 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.

Fig. 1 (**a**) Observed global mean combined land and ocean surface temperature anomalies, from 1850 to 2012 from three data sets. *Top panel*: annual mean values. *Bottom panel*: decadal mean values including the estimate of uncertainty for one dataset (*black*). Anomalies are relative to the mean of 1961–1990. (**b**) Map of the observed surface temperature change from 1901 to 2012 derived from temperature trends determined by linear regression from one dataset (*orange line* in panel a). Trends have been calculated where data availability permits a robust estimate (i.e., only for grid boxes with greater than 70 % complete records and more than 20 % data availability in the first and last 10 % of the time period). Other areas are white. Grid boxes where the trend is significant at the 10 % level are indicated by a + sign (Source: IPCC (IPCC 2013))

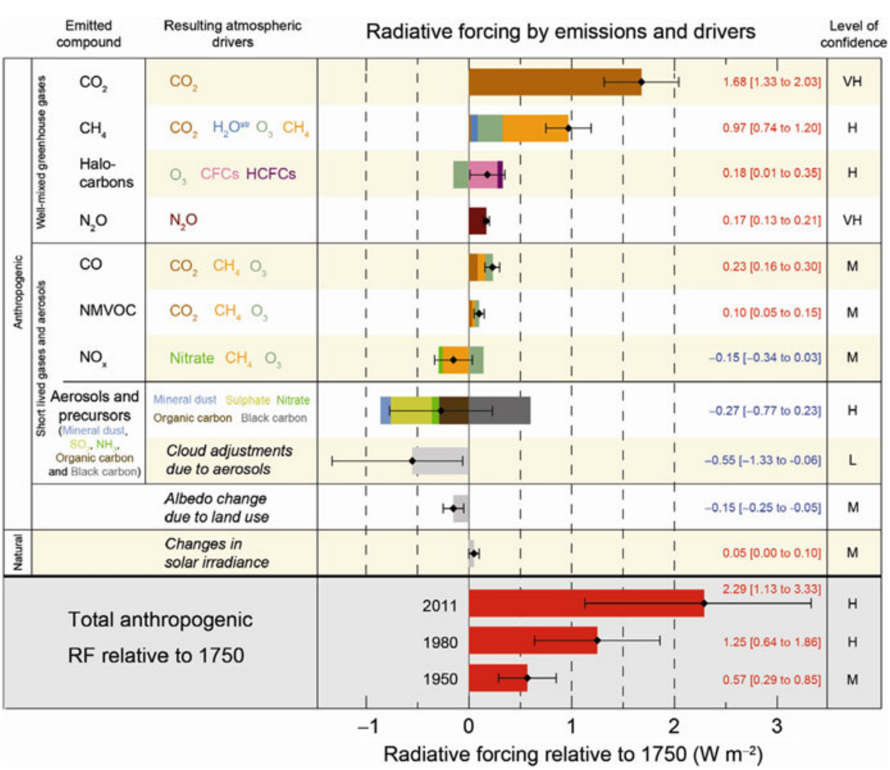
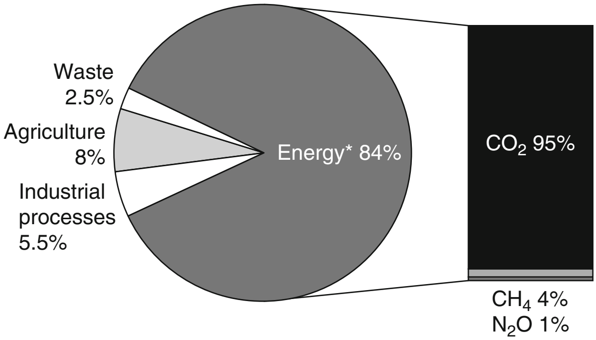


Fig. 2 Radiative forcing estimates in 2011 relative to 1750 and aggregated uncertainties for the main drivers of climate change. Values are global average radiative forcing (*RF*), partitioned according to the emitted compounds or processes that result in a combination of drivers. The best estimates of the net radiative forcing are shown as *black diamonds* with corresponding uncertainty intervals; the numerical values are provided on the *right* of the figure, together with the confidence level in the net forcing (*VH* very high, *H* high, *M* medium, *L* low, *VL* very low). Albedo forcing due to black carbon on snow and ice is included in the black carbon aerosol bar. Small forcings due to contrails (0.05 W m^{-2}, including contrail induced cirrus), and HFCs, PFCs and SF6 (total 0.03 W m^{-2}) are not shown. Concentration-based RFs for gases can be obtained by summing the like-coloured bars. Volcanic forcing is not included as its episodic nature makes is difficult to compare to other forcing mechanisms. Total anthropogenic radiative forcing is provided for three different years relative to 1750 (Source: IPCC (IPCC 2013))

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 (McMichael et al. 2007). Figure 3 shows the share of greenhouse gas emissions from various sectors taken from (Quadrelli and Peterson 2007). The energy sector is the dominant source of GHG emissions.

Fig. 3 Shares of global anthropogenic greenhouse gas emissions (Reprinted with permission from (Quadrelli and Peterson 2007))



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 (International Energy Association IEA 2009). 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 Ma 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 Ma. 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 4 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 (International Energy Association IEA 2009) 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 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.

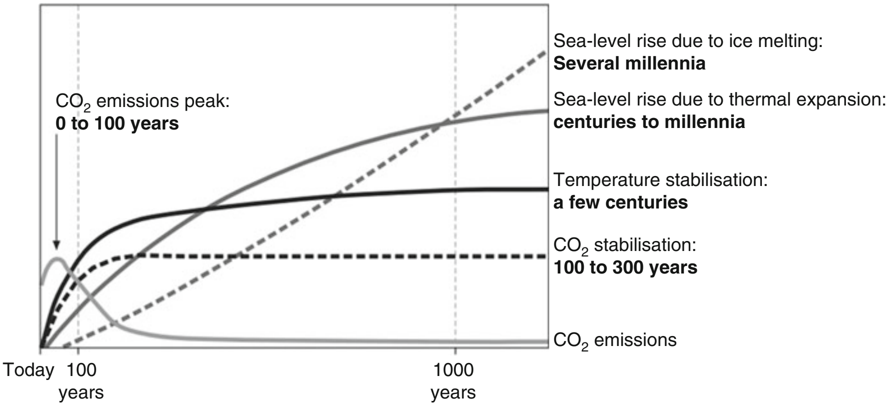


Fig. 4 Time scales of climate change effects based on a stabilization of CO_2 concentration levels between 450 and 1,000 ppm after today's emissions (Reprinted with permission from (Quadrelli and Peterson 2007))

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 (Hoffmann et al. 2009) and low-elevation tropical islands (Becken 2005). 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 (International Energy Association IEA 2009), 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 (International Energy Association IEA 2009).

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 5–20 times higher (IPCC 2010b; Stern 2007).

Climate Change Adaptation Versus Climate Change Mitigation

Individuals (Grothmann and Patt 2005), municipalities (Laukkonen et al. 2009; van Aalst et al. 2008), businesses (Hoffmann et al. 2009), and nations (Næss et al. 2005; Stringer et al. 2009) have started to adapt to the ongoing and expected state of

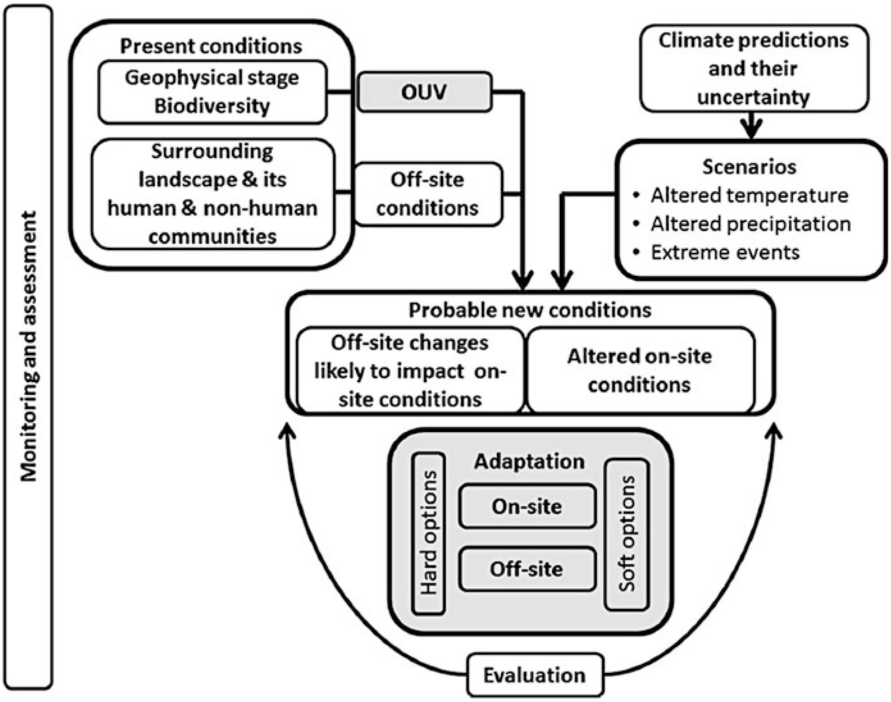


Fig. 5 Conceptual framework for developing a climate change adaptation strategy. *OUV* Outstanding Universal Values (each World Heritage (*WH*) site has one or more such OUV. According to UNESCO, WH represent society's highest conservation designation (Source: Jim Perry (2015))

climate change. Climate change adaptation and climate change mitigation face similar barriers (Hamin and Gurran 2009). To best deal with the situation, there needs to be a balanced approach between climate change mitigation and climate change adaptation (Becken 2005; Laukkonen et al. 2009; Hamin and Gurran 2009). This will prove to be one of mankind's largest modern challenges. Figure 5 shows a conceptual framework for developing a climate change adaptation strategy. Details are presented in this Handbook.

Handbook of Climate Change Mitigation and Adaption

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 source 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.

Adaptation is a pragmatic approach to deal with the facts of climate change so that life, property, and income of individuals can be protected.

The pursuit of sustainable energy resources has become a complex issue across the globe. The *Handbook on Climate Change Mitigation and Adaptation* 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 and Adaptation* 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 multivolume 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 *and adaptation* 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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