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A review of climate change, mitigation and adaptation

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ABSTRACT

Global climate change is a change in the long-term weather patterns that characterize the regions of the world. Scientists state unequivocally that the earth is warming. Natural climate variability alone cannot explain this trend. Human activities, especially the burning of coal and oil, have warmed the earth by dramatically increasing the concentrations of heat-trapping gases in the atmosphere. The more of these gases humans put into the atmosphere, the more the earth will warm in the decades and centuries ahead. The impacts of warming can already be observed in many places, from rising sea levels to melting snow and ice to changing weather patterns. Climate change is already affecting ecosystems, freshwater supplies, and human health. Although climate change cannot be avoided entirely, the most severe impacts of climate change can be avoided by substantially reducing the amount of heat-trapping gases released into the atmosphere. However, the time available for beginning serious action to avoid severe global consequences is growing short. This paper reviews assessing of such climate change impacts on various components of the ecosystem such as air, water, plants, animals and human beings, with special emphasis on economy. The most daunting problem of global warming is also discussed. This paper, further reviews the mitigation measures, with a special focus on carbon sequestration and clean development mechanism (CDM). The importance of synergy between climate change mitigation and adaptation has been discussed. An overview of the relationship between economy and emissions, including Carbon Tax and Emission Trading and the policies are also presented.

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1. Introduction

Climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external forcing, or to persistent anthropogenic changes in the composition of the atmosphere or in land-use. Climate change has long-since ceased to be a scientific curiosity, and is no longer just one of many environmental and regulatory concerns.

Ever since the Industrial Revolution began about 150 years ago, man-made activities have added significant quantities of green house gases (GHGs) to the atmosphere. According to the Third Assessment Report on climate change 2001 of the Intergovermental Panel on climate change, the atmospheric concentrations of carbon dioxide, methane, and nitrous oxide have grown by about 31%, 151% and 17%, respectively, between 1750 and 2000. An increase in the levels of GHGs could lead to greater warming, which, in turn, could have an impact on the world's climate, leading to the phenomenon known as climate change. Indeed, scientists have observed that over the 20th century, the mean global surface temperature increased by 0.6 °C. They also observed that since 1860 (the year temperature began to be recorded systematically using a thermometer), the 1990s have been the warmest decade. It is a growing crisis with economic, health and safety, food production, security, and other dimensions. Shifting weather patterns, for example, threaten food production through increased unpredictability of precipitation, rising sea levels contaminate coastal freshwater reserves and increase the risk of catastrophic flooding, and a warming atmosphere aids the pole-ward spread of pests and diseases once limited to the tropics. The news to date is bad and getting worse. Ice-loss from glaciers and ice sheets has continued, leading, for example, to the second straight year with an ice-free passage through Canada's Arctic islands, and accelerating rates of ice-loss from ice sheets in Greenland and Antarctica. Combined with thermal expansion – warm water occupies more volume than cold – the melting of ice sheets and glaciers around the world is contributing to rates and an ultimate extent of sea-level rise that could far outstrip those anticipated in the most recent global scientific assessment. There is alarming evidence that important tipping points, leading to irreversible changes in major ecosystems and the planetary climate system, may already have been reached or passed. Ecosystems as diverse as the Amazon rainforest and the Arctic tundra, for example, may be approaching thresholds of dramatic change through warming and drying. Mountain glaciers are in alarming retreat and the downstream effects of reduced water supply in the driest months will have repercussions that transcend generations. Climate feedback systems and environmental cumulative effects are building across Earth systems demonstrating behaviors which cannot be anticipated.

The Earth's climate has changed throughout history. Just in the last 650,000 years there have been seven cycles of glacial advance and retreat, with the abrupt end of the last ice age about 7000 years ago marking the beginning of the modern climate era – and of human civilization. Most of these climate changes are attributed to very small variations in Earth's orbit that change the amount of solar energy our planet receives.

The evidence for rapid climate change (*IPCC Fourth Assessment Report*) is compelling:

(1) Sea-level rise: Global sea-level rose about 17 cm (6.7 in.) in the last century. The rate in the last decade, however, is nearly double that of the last century.
(2) Global temperature rise: Most of this warming has occurred since the 1970s, with the 20 warmest years having occurred since 1981 and with all 10 of the warmest years occurring in the past 12 years.
(3) Warming oceans: The oceans have absorbed much of this increased heat, with the top 700 m (about 2300 ft.) of ocean showing warming of 0.302° Fahrenheit since 1969.
(4) Shrinking ice sheets: The Greenland and Antarctic ice sheets have decreased in mass. Data from NASA's Gravity Recovery and Climate Experiment show Greenland lost 150–250 km^3 (36–60 cubic miles) of ice per year between 2002 and 2006, while Antarctica lost about 152 km^3 (36 cubic miles) of ice between 2002 and 2005.
(5) Declining Arctic sea ice: Both the extent and thickness of Arctic sea ice has declined rapidly over the last several decades.
(6) Glacial retreat: Glaciers are retreating almost everywhere around the world – including in the Alps, Himalayas, Andes, Rockies, Alaska and Africa.
(7) Ocean acidification: Since the beginning of the Industrial Revolution, the acidity of surface ocean waters has increased by about 30%. The amount of carbon dioxide absorbed by the upper layer of the oceans is increasing by about 2 billion tons per year.

The increasing trend of CO_2 emissions, Arctic sea Ice, CO_2 concentration, sea level and global surface temperature is shown in Figs. 1–5 respectively.

September Arctic ice is now declining at a rate of 11.5% per decade. Arctic sea ice reaches its minimum in September. The September 2010 extent was the third lowest in the satellite record.

There are lots of initiatives taken by different countries and organizations like United Nations Framework Convention on Climate Change (UNFCCC), United Nations Environment Programme (UNEP) and Intergovermental Panel on Climate Change (IPCC), in mitigating and adapting to the global climate change. The most important mitigation measures include carbon sequestration, clean development mechanism, joint implementation and most

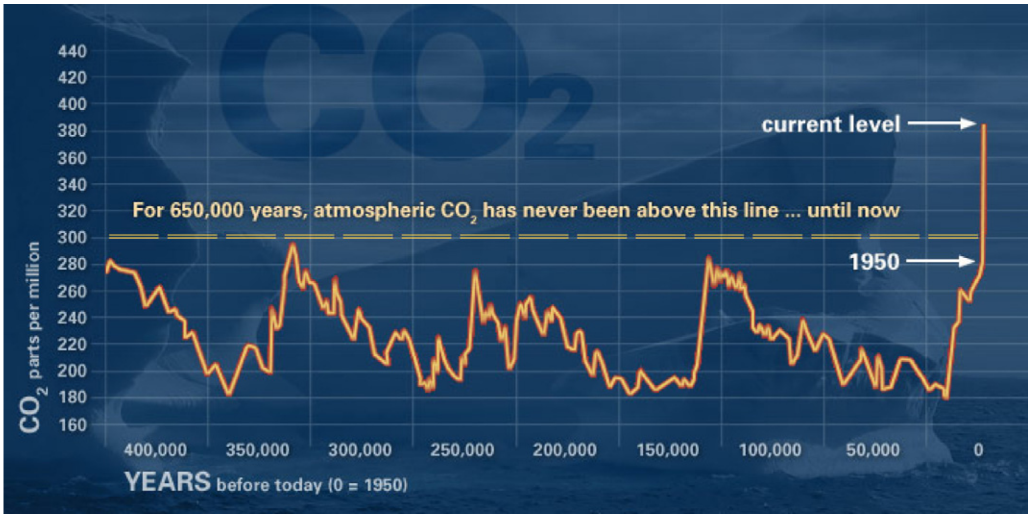

Fig. 1. CO_2 (ppm) trend over years.

Source: NASA satellite data.

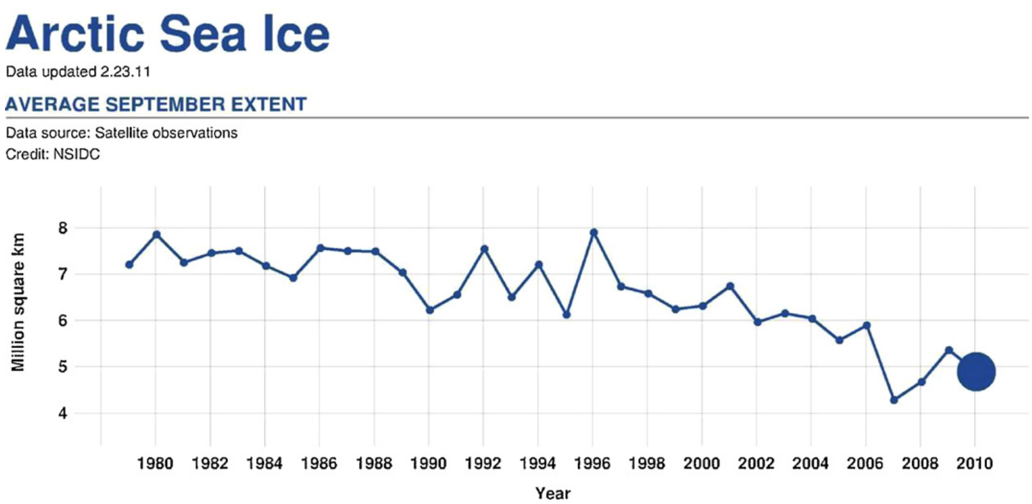

Fig. 2. Arctic sea-ice level.

Source: NASA satellite observations.

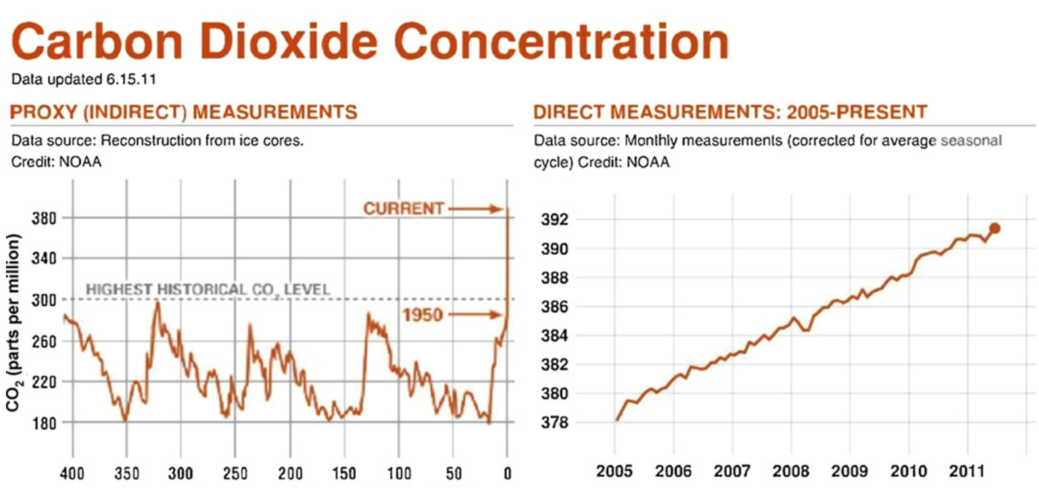

Fig. 3. Carbon dioxide concentration level.

Source: NASA satellite observations.

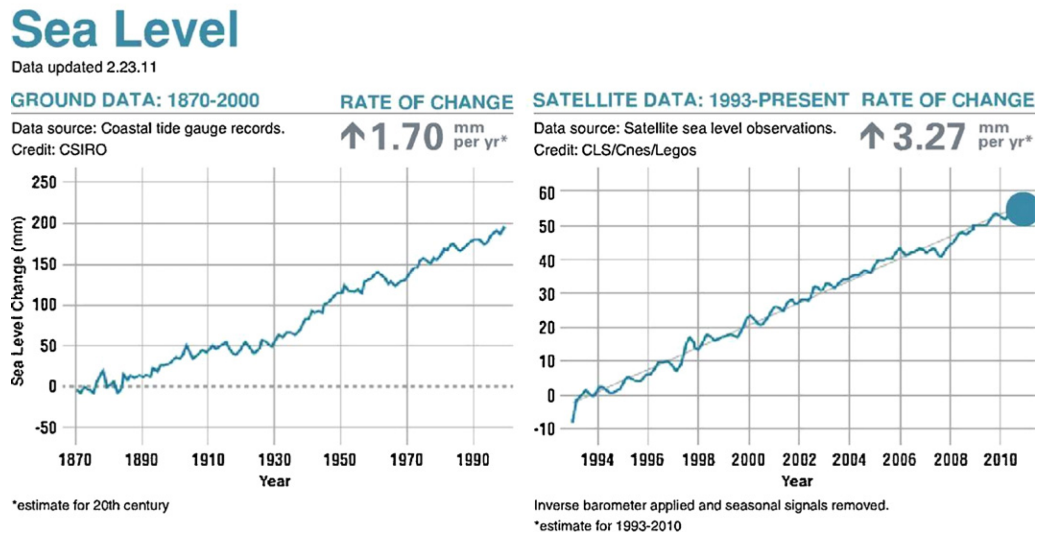

Fig. 4. Sea level.

Source: NASA satellite observations.

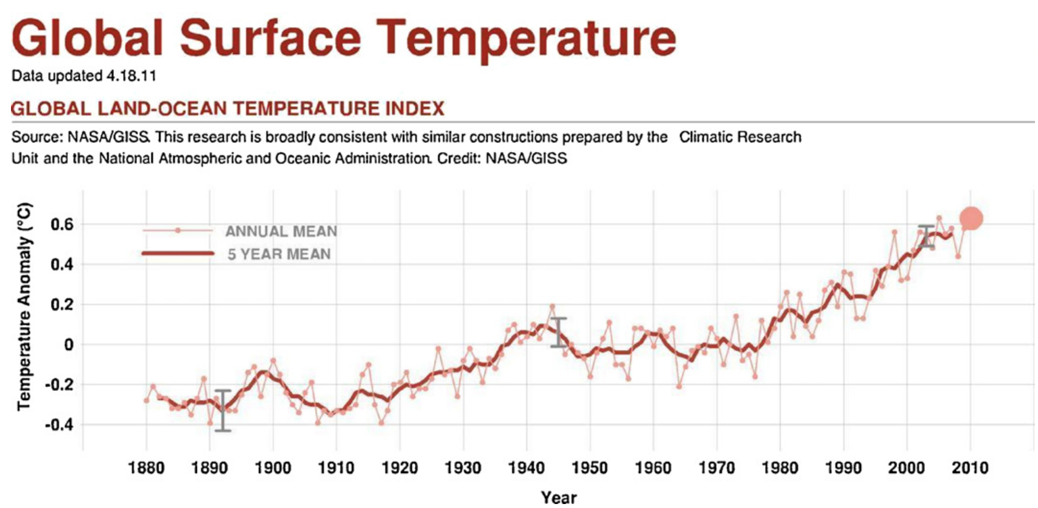

Fig. 5. Global temperature variation.

Source: NASA satellite observations.

importantly use of renewable and non-polluting sources of energy like solar, wind and geothermal energy sources.

2. Assessing the impacts of climate change

The ever-increasing emissions of greenhouse gases from various sources has led to catastrophic climate changes including the well pronounced 'global warming'. Serge Planton et al. gives an overview of the expected change of climate extremes during this century due to greenhouse gases and aerosol anthropogenic emissions like decreasing number of days of frost, increasing growing season length, trends for drought duration and change of wind-related extremes [1]. The dramatic change that the arctic has undergone during the past decade including atmospheric sea-level pressure, wind fields, sea-ice drift, ice cover, length of melt season, change in precipitation patterns, change in hydrology, change in ocean currents and watermass distribution were studied by Macdonald et al. [2]. The near-surface thermal regime in permafrost regions could change significantly in response to anthropogenic climate warming [3]. A scenario of chain of transitions in the solar convective zone was suggested by Bershadskii, in order to explain the observations of increase in sunspots number and a forecast for global warming was also suggested on the basis of this scenario [4]. With 15 case studies in the catchments of UK, Nigel W. Arnell found that the effects of climate change on average annual runoff depend on the ratio of average annual runoff to average annual rainfall, with the greatest sensitivity in the driest catchments with lowest runoff coefficients [5]. Hirst examined the response of the Southern ocean to global warming, for a transient greenhouse gas integration using the Commonwealth Scientific and Industrial Research Organisation (CSIRO) coupled ocean–atmosphere model [6]. Global warming caused by enhanced greenhouse effect is likely to have significant effects on the hydrology and water resources of the GBM (Ganges, Brahmaputra, Meghna) basins and might ultimately lead to more serious floods in Bangladesh, India [7]. Mohammed Fazlul Karim and Nobuo Mimura used a calibrated numerical hydrodynamic model to stimulate surge wave propagation through the rivers and overland flooding, to describe the impacts of climate change namely the sea surface temperature and sea-level rise on cyclonic storm surge flooding in western Bangladesh, India [8]. The Asian Pacific Integrated Model (AIM) is a large-scale model for scenario analyses of greenhouse gas emissions and the impacts of global warming in the Asian Pacific region. Yuzuru Matsuoka et al. categorized the scenarios that have been written so far in relation to global warming and then, given fixed inputs, simulates the effects of global warming taking in to account various uncertainties using AIM [9]. van Minnen et al. presented a new methodology called the "critical climate change" approach for evaluating the policies for reducing climate change impacts on natural ecosystems [10].

2.1. Air, water, plants and animals

The future evolution of the concentration of near-surface pollutants determining air quality at a scale affecting human health and ecosystems is a subject of intense scientific research. Robert Vautard and Didier Hauglustaine, based on this thematic issue, reviewed the current scientific knowledge of the consequences of global climate change on regional air quality and its related impact on the biosphere and on human mortality. The changes in the global atmospheric composition, changes in the regional air quality and the organization of the thematic issue of near-surface pollutants that determines the air quality [11]. Mooij et al. hypothesized that climate warming and climate-induced eutrophication will increase the dominance of cyanobacteria and climate change will also affect shallow lakes through a changing hydrology and through climate change-induced eutrophication, using two models namely the full ecosystem model PCLake and a minimal dynamic model of lake phosphorus dynamics [12]. Delpla et al. explained the climate change impacts on water quality by reviewing the most recent interdisciplinary literature and concluded that a degradation trend of drinking water quality in the context of climate change leads to an increase of at risk situations related to potential health impact [13]. Wright et al. used the MAGIC model to evaluate the relative sensitivity of several possible climate-induced effects on the recovery of soil and surface water from acidification and suggests that the future modeling of recovery from acidification should take in to account possible climate changes and focus especially on the climate-induced changes in organic acids and nitrogen retention [14]. A simple methodology for assessing the salination risk for any water management situation and under global warming conditions was presented by Angel Utset and Matilde Borroto, where the physically based SWAP (Soil–Water–Atmosphere–Plant environment) model was used to predict future water table depths after irrigation begins and under global warming conditions [15]. Estimating the impacts of climate change on ground water represents one of the most difficult challenges faced by the water resource specialists. Pascal Goderniaux et al. provided an improved methodology for the estimation of the impacts of climate change on groundwater reserves, where a physically based surface–subsurface flow is combined with advanced climate change scenarios for the Geer basin, Belgium using finite element model 'HydroGeoSphere' [16]. The change in climate is likely to have a profound effect on hydrological cycle viz. precipitation, evapotranspiration and soil moisture, evapotranspiration (ET) being the major component of hydrological cycle will affect crop water requirement and future planning and management of water resources. An attempt has been made by Goyal to study the sensitivity of ET to global warming for arid regions of Rajasthan, India. Weekly reference evapotranspiration was calculated using the Penman–Monteith method and the study revealed that even as small as 1% increase in temperature from base data could result in an increase in evapotranspiration by 15 mm, which means an additional water requirement of 34.275 mcm for Jodhpur district alone and 313.12 mcm for whole arid zone of Rajasthan. The increased evapotranspiration demand due to global warming can put tremendous pressure on existing overstressed water resources of this region and since this region is devoid of any perennial river system, any increase in water demand requires careful planning for future water resource development in this region. The study provided a contemporary view on future water requirement of this region in context of global warming [17]. With the global climate change data provided by the IPCC from the first version of the Canadian Global Coupled Model (CGCMI), GIS based EPIC is run by Guoxin Tan and Ryosuke Shibasaki, for scenarios of future climate in the year of 2010, 2020, 2030, 2040 and 2050 to predict the effects of global warming on main crop yields and the results showed that the global warming will be harmful for most of the countries and an efficient adaptation to alternative climates tends to reduce the damages [18]. Goudie outlined that future global warming has a number of implications for 'fluvial geomorphology' because of changes in such phenomena as rates of evapotranspiration, precipitation characteristics, plant distributions, plant stomatal closure, sea levels, glacier and permafrost melting and human responses [19]. Saving tropical forests as a global warming counter – measure has become one of the environment's most divisive issues, according to Fearnside [20]. The impacts of GHG emissions on forest ecosystems have been traditionally treated separately for air pollution and climate change. Andrzej Bytnerowicz et al. reviewed the links between air pollution and climate change and their interactive effects on northern hemisphere forests [21]. Range limits of many plant species are expected to shift dramatically if climate warming, driven by the release of GHG, occurs in the next century. Simulation models are presented by Dyer, which incorporate two factors, land-use pattern and means of dispersal, to assess potential responses of forest species to climate warming [22]. Wildlife managers face the daunting task of managing wildlife in light of uncertainty about the nature and extent of future climate change and variability and its potential adverse impacts on wildlife. Tony Prato developed a conceptual framework to manage wildlife under such uncertainty, which uses a fuzzy logic to test hypotheses about the extent of the wildlife impacts of past climate change and variability and fuzzy multiple attribute evaluation to determine best compensatory management actions for adaptively managing the potential adverse impacts of future climate change and variability on wildlife [23].

2.2. Economy

The impacts of GHG emissions and the resulting climate change have a serious impact on the global economy. The Futures of Global Interdependence (FUGI) global modeling system has been developed as a scientific policy simulation tool of providing global information to the human society and finding out possibilities of policy coordination among countries in order to achieve sustainable development of the global economy under the constraints of rapidly changing global environment. The FUGI global model M200 classifies the world into 200 countries/regions where each national/regional model is globally interdependent through oil prices, energy requirements, international trade, export/import prices, financial flows, ODA, private foreign direct investment, exchange rates, stock market prices and global policy coordination, etc. Akira Onishi studied the futures of global economy under the constraints of energy requirements and CO_2 emissions up to 2020 as well as strategy for sustainable development of the interdependent global economy. In order to cut back global CO_2 emissions, it is necessary to confront dilemma of sustainable development of the global economy. A surprising proposal made by limits to growth (1972) is zero growth of the global economy. If the global economy will confront with zero growth, it seems likely to induce global crises such as Great Depression in 1930s. Zero growth may cutback CO_2 emissions but could not solve trade-off between environment issues and desirable development of the global economy.

Alternative simulation by FGMS (FUGI global modeling system) revealed that cutbacks of global CO_2 emissions should be prerequisite against global warming. In order to cutback global CO_2 emissions, it should be needed for international co-operation and co-ordination of development strategy. Even if EU and Japan will co-operate and co-ordinate the policies toward cut back of CO_2 emissions by technology innovations for developing alternative energy and energy savings, it could not achieve the global targets without co-operation with the major CO_2 emission nations such as US, China, Russian Federation. In order to decrease global CO_2 emissions, the developing countries should join as a group and should promote official development assistance (ODA), in particular, technical co-operation to the developing countries. Technology transfer from the advanced to developing countries are pre-requisite for achieving the target of cut back global CO_2 emissions. Advanced economies should make utmost efforts to increase R&D as well as investments for alternative energy and energy savings. The FUGI global model simulations affirmed that not only increased R&D together with investments will increase rates of development of global economy but also decrease global CO_2 emissions [24]. Evidence of the impacts of anthropogenic climate change on marine ecosystems is accumulating, but must be evaluated in the context of the "normal" climate cycles and variability which have caused fluctuations in fisheries throughout human history. The impacts on fisheries are due to a variety of direct and indirect effects of a number of physical and chemical factors, which include temperature, winds, vertical mixing, salinity, oxygen, pH and others. The direct effects act on the physiology, development rates, reproduction, behavior and survival of individuals. Indirect effects act via ecosystem processes and changes in the production of food or abundance of competitors, predators and pathogens. Keith Brander reviewed the recent studies of the effects of climate on primary production and evaluated the consequences for fisheries production through regional examples namely North Atlantic, Tropical Pacific Antartic and Lake Tanganyika. Regional examples namely North Sea, Baltic and North Atlantic are also used to show changes in distribution and phenology of plankton and fish, which are attributed to climate. The role of discontinuous and extreme events (regime shifts, exceptional warm periods) was also discussed [25]. Harle et al. made a study on the implications of climate change on the Australian wool industry, principally through on forage and water resources, land carrying capacity and sustainability, animal health and competition with other sectors, particularly cropping [26]. Maria Berrittella et al. studied the economic implications of climate change-induced variations in *tourism* demand, using a world Computable General Equilibrium (CGE) model. The model was first re-calibrated at some future years, obtaining hypothetical benchmark equilibria, which were subsequently perturbed by shocks, simulating the effects of climate change. The impact of climate change on tourism was portrayed in this study by means of two sets of shocks, occurring simultaneously. The first set of shocks translates predicted variations in tourist flows into changes of consumption preferences for domestically produced goods. The second set reallocate income across world regions, simulating the effect of higher or lower tourists' expenditure. The analysis highlights that variations in tourist flows will affect regional economies in a way that is directly related to the sign and magnitude of flow variations. At a global scale, climate change will ultimately lead to a welfare loss, unevenly spread across regions. Despite the crude resolution of the analysis made, which hides many climate change-induced shifts in tourist destination choices, it was found that climate change may affect GDP by −0.3–0.5% in 2050. Economic impact estimates of climate change are generally in the order of −1–2% of GDP for a warming associated with a doubling of the atmospheric concentration of carbon dioxide, which is typically put at a later date than 2050. As these studies exclude tourism, this implies that regional economic impacts may have been underestimated by more than 20%. The study indicates that the global economic impact of a climate change-induced change in tourism is quite small, and approximately zero in 2010, but in 2050, climate change will ultimately lead to a non-negligible global loss [27]. Susanne Becken analyzed the adaptation to climate change by tourist resorts in Fiji, as well as their potential to reduce climate change through reductions in CO_2 emissions [28]. Koetse and Piet Rietveld presented a survey of empirical literature on the effects of climate change on the transport sector and the net impact on generalized costs and economy of various transport modes are discussed [29]. Radu Zmeureanu and Guillaume Renaud presented a method for the estimation of climate change on the economy of the heating energy use of existing houses [30].

2.3. Agriculture

Robert Mendelsohn examined the likely impact on agriculture of the climate change which has already taken place between 1960 and 2000, when the global temperature rise was 0.25 °C, causing the precipitation patterns to shift and the cross-sectional and crop simulation evidence, temperature, precipitation and CO_2 response functions are used to calculate the impacts on agriculture [31]. The implications for agriculture of mitigating GHG emissions and by when and by how much are the impacts reduced was investigated by Tubielloa and Gunther Fischera and it was found that mitigation could positively impact agriculture [32]. Bernard Tinker et al. addressed the questions of to what extent slash and burn of agriculture is responsible and how land conversion of this type will affect the climate system, including its impact on local and regional hydrology [33]. Rivington et al. argued that an Integrated Assessment (IA) approach, combining simulation modeling with deliberative process involving decision makers and other stakeholders, has the potential to generate credible and relevant assessments of climate change impacts on farming systems [34]. Chakraborty et al. found that, despite the significance of weather on plant diseases, comprehensive analysis of how climate change will influence plant diseases that impact primary production in agricultural systems is presently unavailable and improvements to assess disease impacts is mandatory [35]. Trudie Dockerty et al. explored the possibility of interpreting climate change impacts information of agricultural landscape in Norfolk through GIS based visualizations [36]. Gunther et al. investigated the potential changes in global and regional agricultural water demand within a new socio-economic scenario, A2r, developed at the International Institute for Applied System Analysis (IIAS) with and without climate change, with and without mitigation of GHG emissions [37]. Despite the importance of livestock to poor people and the magnitude of the changes that are likely to befall livestock systems, the intersection of climate change and livestock in developing countries is a relatively neglected research area. Little is known about the interactions of climate and increasing climate variability with other drivers of change in livestock systems and in broader development trends. In many places in the tropics and subtropics, livestock systems are changing rapidly, and the spatial heterogeneity of household response to change may be very large. Thornton et al. briefly reviewed the literature on climate change impacts on livestock and livestock systems in developing countries. The impact of climate change on livestock in terms of quantity and quality of feeds, heat stress, water, livestock diseases and vectors, biodiversity and systems and livelihoods were studied. For instance, while the response of livestock to known increases in temperature is predictable, in terms of increased demand for water, attempts to quantify the impacts of climate change on water resources in the land-based livestock systems in developing countries are fraught with uncertainty, particularly in situations where groundwater accounts for a substantial portion of the supply of water to livestock, which is the case in many grazing systems. In addition to the direct impacts of a changing climate on many aspects of livestock and livestock systems, there are various indirect impacts that can be expected to impinge on livestock keepers in developing countries. One of the most significant of these is the impact on human health. As with livestock diseases, the changes wrought by climate change on infectious disease burdens may be extremely complex, which was also studied briefly [38].

2.4. Health

The potential impacts of climate change on human health are significant, ranging from direct effects such as heat stress and flooding, to indirect influences including changes in disease transmission and malnutrition in response to increase competition for crop and water resources. Huntingford et al. addressed this issue by arguing that closer collaboration between the climate modeling and health communities is required and the climate–health model simulations will provide the needed estimates of the likely impacts of climate change on human health [39]. Khasnis and Nettleman studied that global warming will cause changes in the epidemiology of infectious diseases and the vector-borne diseases will become more common as the earth warms [40]. The economic impacts of climate change-induced change in human health, viz. cardiovascular and respiratory disorders, diarrhea, malaria, dengue fever and schistosomiasis were studied by Francesco Bosello et al. [41]. The global increase in surface temperature (global warming) was found to impact on mortality through ill health, particularly among the elderly, in summer and Preti et al. explored the impact of global warming on suicide mortality, using the data from Italy [42].

3. Global warming

Global warming is a problem in which the combustion of coal, oil and other fossil fuels causes the atmospheric concentrations of GHGs such as carbon dioxide, to increase. This results in mounting global air temperatures that lead to climate change. Specifically, global warming will cause a rise in sea levels, changes in the rainfall patterns and other problems.

There are concerns that the rapid development of the developing countries will hasten global warming and exacerbate resource problems. But Yasuhiro Murota and Kokichi Ito attempted to show that, on the contrary, the fast development of these countries might very well bring about a long-term solution of the global warming problem [43]. Dutta and Roy modeled the global warming process as a dynamic commons game in which the players are countries, their actions at each date produce emissions of GHGs and the state variable is the current stock of GHGs and a complete theoretical characterization is provided for the best equilibrium and it is shown that it has a very simple structure, involving a constant emission rate through time [44]. Alessio Alexiadis used the control theory to study the connection between human activities and global warming. A feedback mechanism is proposed and tested against temperature and CO_2 concentration historical data, considering four scenarios and the results showed that even in the case of dramatic reduction of the anthropogenic CO_2 emission, the temperature will not decrease for a certain time and although the system at the moment is stable, it is very close to becoming unstable with unpredictable consequences on climate change [45]. Honjo recommended that in addition to energy related R&D, also important are the R&D for CO_2 absorption and fixation for fundamental solution to global warming [46]. Evaluation methods of global warming are presented by Akira Sekiya, considering the direct warming effect of chemical compounds and of decomposed compounds, warming effect due to the formation of troposphere ozone and the cooling effect due to the decomposition of stratosphere ozone [47]. Kumar et al. assessed the methane emission inventory from municipal solid waste disposal sites and expressed that there is a need to study the ever-increasing contribution of solid waste to the global GHG effect [48].

3.1. Global warming potential

In order to quantitatively compare the greenhouse effect of different greenhouse gases, a global warming potential (GWP) index has been used which is based on the ratio of the radioactive forcing of an equal emission of two different gases, integrated either overall time or up to an arbitrarily determined time horizon. The GWP index is analogous to the Ozone Depleting Potential (ODP) index.

An alternative GWP index was proposed by Danny Harvey, which explicitly takes in to account the duration of capital investments in the energy sector and is less sensitive to uncertainties in atmospheric lifespans and radiative heating than usual GWP index for time horizons longer than the lifespan of capital investment and the effect of this alternate GWP index proposed here is that, compared with previous indices, is to shift attention away from short lived gases such as methane and toward CO_2 [49]. The Intergovernmental Panel on Climate Change (IPCC) used GWPs to standardize inputs of different gases with differing radiative forcings and atmospheric lifetime. An alternative unified index was proposed by Fearnside that assigns explicit weights to the interests of different generations [50]. A simple model was used by Ko et al., to illustrate the methodology for determining the time variations of the radiative forcing and temperature changes attributable to the direct greenhouse effect from potential emissions of the halocarbons, used extensively as an alternate to CFCs [51]. Tapscott and Douglas Mather proposed that incorporation of certain molecular features in to fluoro carbons can decrease the tropospheric lifetime, providing commercially applicable chemicals with low global warming and stratospheric ozone impacts [52]. Drage et al. measured the high resolution (0.03/cm) absolute infrared photo absorption cross-sections of bromotrifluoromethane (CF3Br) and tetrafluoroethylene (C2F4) using Fourier – transformed infrared (FTIR) spectroscopy at temperatures between 213 and 296 K and the measured cross-sections were subsequently used to estimate the radiative forcings and the GWPs of these two species [53]. Tatsuru Shirafugi et al. prepared low dielectric constant fluorinated amorphous carbon films from the low GWP gas of C5F8 by a capacitively coupled plasma enhanced chemical vapor deposition method [54].

3.2. Economy

In-Tae Jeonga and Kun-Mo Lee proposed an assessment method for ecodesign improvement options using global warming and economic performance indicators, the global warming performance indicator as the external cost which converts the external effect of global warming in to a monetary value, in order to measure the performance of the GHG reduction of the product and the life cycle cost of the product was chosen as the economic performance indicator, with LCD panel as a case study [55]. Economic analyses of global warming have typically been grounded in the theory of economic efficiency. Woodward and Bishop developed a simple economic model which demonstrated that an efficient economy is not necessarily a sustainable economy and then considered the policy alternatives to address global warming in the context of economies with the dual objectives of efficiency and sustainability, with particular attention to carbon based taxes [56]. Alfred Greiner and Willi Semmler presumed a simple endogenous growth model where global warming affects economic growth and analyzed the dynamics of the competitive economy and of the social optimum [57]. Using the topical issue of global warming as an illustration, it was argued that the ecologicalisation of the economics discipline challenges the foundations of the strategy that “continued reliance on an unreconstructed neo-classical economic model for human progress is largely responsible for an economic development path which is both unsustainable and undemocratic", among other benefits, a more democratic global economic organization [58]. Larry Karp analyzed the time-consistent Markov Perfect equilibrium in a general model with a stock pollutant and the solution to the linear quadratic specialization illustrated the role of hyperbolic discounting in a model of global warming [59].

4. Mitigation

The Triptych approach is a method for allocating future GHG emission reductions among countries under a post-2012 international climate mitigation regime based on technological criteria at the sector level and accounting for structural differences. A new Triptych approach was presented by Michel den Elzen et al., which is a refinement of an earlier version in terms of an increased transparency and allowing a delayed participation for developing countries [60]. The doubling of atmospheric methane over the last two centuries may contribute to global warming, enhance formation of tropospheric ozone, suppress OH and affect stratospheric ozone but the calculations done by Thompson et al. showed that stabilization of CH_4 could reduce projected temperature increases and possibly mitigate background tropospheric ozone increases due to increasing levels of CH_4 [61]. Michel den Elzen et al. presented a set of technically feasible multi-gas emission pathways (envelopes) for stabilizing GHG concentration at 450, 550 and 650 ppm CO_2 equivalent and their trade-offs between direct abatement costs and probabilities to meet temperature targets [62]. Tim Jackson presented a methodology for comparing the cost-effectiveness of different technical options for the abatement of GHG emissions and this methodology allows a determination of the extent to which each technology can contribute to abatement by a specified date [63]. Keigo Akimoto et al. developed an integrated assessment model, DNE21, composed of three sub-models viz an energy system, a macro economic and a climate change model and the simulation results indicated that the optimal mitigation strategy against global warming should be comprehensive implementation of the various options, among which energy saving in the end-use sectors is important throughout the 21st century and CO_2 sequestration is after the middle of the century [64]. Preining concluded from his study that climate modeling requires the full inclusion of aerosols, taking in to account the annual carbon emissions of the same [65]. Van Vuuren and de Vries developed two different mitigation scenarios for stabilizing carbon dioxide concentration at 450 ppmv $\times$ 2100, based on the recently developed B1 baseline scenario (part of the IPCC Special Report on Emission Scenarios) and predicted that in the first/second quarter of this century most of the reduction will come from energy efficiency and fuel switching options and later on the introduction of carbon-free supply options will account for the bulk of the required reductions [66]. Jos Sijm et al. presented a new sector-based framework, called the *multi-sector convergence approach* (MSC), for negotiating binding national GHG mitigation targets after the first budget period defined by the Kyoto Protocol (2008–2012) and the methodology and major characteristics of the MSC approach was outlined, followed by some numerical illustrations [67]. Sanna Syri et al. assessed the achievement possibilities of the EU 2 °C climate target with the ETSAP TIAM global energy systems model and calculated the cost-effective global and regional mitigation scenarios of carbon dioxide, methane, nitrous oxide and F-gases with alternative assumptions on emissions trading and predicted that in the mitigation scenarios, a 85% reduction in CO_2 emissions is needed from the baseline and very significant changes in the energy system towards emission-free sources take place in this century [68]. Mitigating global climate change requires not only government action but also cooperation from consumers and the qualitative data analyzed by Semenza et al. indicated that there are a number of cognitive, behavioral and structural obstacles to voluntary mitigation [69]. The findings of Stoll-Kleemann et al. suggested that more attention needs to be given to the social and psychological motivations as to why individuals erect barriers to their personal commitment to climate change mitigation, even when professing anxiety over climate futures [70]. Dalia Streimikiene and Stasys Girdzijauskasa analyzed the post-Kyoto climate change mitigation regimes and their impact on sustainable development. Wide range of post-Kyoto climate change mitigation architectures have different impact on different groups of countries, therefore sustainability assessment was performed for four main group of countries: EU and other Annex-I countries, USA, advanced developing countries and least developed countries. The post-Kyoto climate change mitigation regimes were evaluated based on their economical, environmental, social and political impact for different groups of countries and scoring was applied for assessment. The architectures including Targets and Time tables, harmonized domestic policies and measures, resource transfer from developed countries to developing, sustainable development policies in developing countries, were further ranked according to the best results or highest score obtained during assessment according to all criteria and for all groups of countries. The analysis concluded that at present most assessments of climate change measures are partial and incomplete. A more holistic assessment against economic, social and environmental dimensions of sustainable development called 3A's (acceptability, availability and accessibility) developed by World Energy Council would not only ensure that the measures were likely to be more effective in a wider sense in promoting sustainable development, but would also help make them more viable in a narrower sense, that is, more acceptable to those affected and therefore easier to introduce and get supported and thus more likely to achieve their goals. Based on the analysis of international post-Kyoto climate change mitigation regimes according to 3A's the most suitable future regime would be flexible emission reduction targets via continuing Kyoto approach. This approach provides the highest advantages relative to the critical criteria of sustainable energy development: acceptability, accessibility and availability for all groups of countries [71].

4.1. Economy of mitigation

The debate over the costs of GHG emission mitigation has become more complex recently as disagreements over the existence of economic and environmental double dividends have been added to discussions over the existence of a negative cost potential.

Industrialized countries may reduce their costs of meeting carbon constraints if they penalize fuels not only on the basis of their carbon intensity but also on the basis of their import–export [72]. Hadi Dowlatabadi used simple representations of endogenous and induced technical change to explore the sensitivity of mitigation cost estimates to how technical change is represented in energy economics model [73]. Chandler et al. summarized selected studies of the potential and cost of carbon emissions mitigation strategies in the post-planned economies [74]. Alexander Roehrl and Keywan Riahi analyzed the long-term GHG emissions and their mitigation in a family of high economic and energy demand growth scenarios in which technological change unfolds in alternative path dependant directions [75]. Kristen Halsnaes discussed methodological lessons and empirical results of climate change mitigation assessment for developing countries with a special emphasis on economic studies. National study resuits were discussed in relation to expected general international development trends in greenhouse gas emissions. It was concluded that greenhouse gas emissions from developing countries certainly will increase in the future due to economic development needs. There is however a large and relatively cheap potential for emission reductions connected to efficiency improvements in industrial production and general energy efficiency improvements in the countries. The implementation of greenhouse gas mitigation strategies is interrelated with general national economic development policies. The macroeconomic impact of implementing climate change mitigation strategies was assessed on the basis of two case studies for Zimbabwe and Venezuela and it is concluded that project implementation and economic welfare improvement in some cases can be achieved simultaneously. The methodological basis for macroeconomic assessment and for the establishment of baseline scenarios were critically discussed in relation to the specific planning context of developing countries and recommendations were also given on research requirements. Despite differences in methodological approaches bottom–up CO_2 emission reduction costing studies carried out for the energy sector of developing countries exhibit some common results namely (i) the 30–40 year reference scenario projections show a tendency to decreasing energy/GDP intensity, but increasing CO_2/energy intensity, (ii) the potential for a 30–40% emission reduction from baseline over a 40-year time frame has been estimated. However, even after such a reduction is realized, emissions will on average be two or three times greater than present levels because of economic growth and (iii) the emission reduction potential includes low/negative cost options relating to end use and conventional supply technologies in the short to medium term. In the 30–40 year time frame, the UNEP country studies have estimated average emission reduction costs to be below US$14/tonne of CO_2 [76]. Valentina Bosetti et al. investigated the best short-term strategies that emerging economies can adopt in reacting to OECD countries' mitigation effort, given the common long-term goal to prevent excessive warming without hampering economic growth [77]. Harri Laurikka and Urs Springer presented a framework for evaluating the risks of investments in climate change mitigation projects to generate emission credits and also proposed a methodology for quantifying risk and return of such investments, discuss data requirements and illustrate it using a sample of voluntary projects [78]. Urs Springer used a mean-variance approach to compute the international portfolios of carbon abatement activities that balance low abatement costs and investment risks [79]. Jean-Charles Hourcade and John Robinson underlined the importance of the timing of decisions for determining the costs of GHG emissions mitigation [80].

5. Carbon sequestration

Carbon sequestration is an important technology for the maintenance of optimum CO_2 level in the atmosphere, which in turn results in the climate change mitigation. Atushi kurosawa had done a sensitivity analysis of the costs of carbon sequestration and the relative importance of sequestration technology was assessed in a long-term carbon management framework and suggested that carbon recovery with ocean and geological sequestration could be included among the available carbon abatement technologies and its abatement potential is sensitive to the carbon transport and storage cost assumption [81]. David Gerard and Wilson explored a particularly dicey issue – how to ensure adequate long-term monitoring and maintenance of the carbon sequestration sites, with a special mention of bonding mechanisms [82]. Lionel Ragot and Katheline Schubert modeled the asymmetry of the sequestration/de-sequestration process at a micro level and of its consequences at a macro level, taking explicitly in to account the temporality of sequestration and showed that with these assumptions sequestration must be permanent [83].

5.1. Ocean and geological sequestration

Although, it has received relatively little attention as a potential method of combating climate change in comparison to energy reduction measures and development of carbon-free energy technologies, sequestration of carbon dioxide in geologic or biospheric sinks has enormous potential. Grimston et al. reviewed the potential for sequestration using geological and ocean storage as a means of reducing carbon dioxide emissions. There are concerns about possible environmental effects of large-scale injection of carbon dioxide especially into the oceans. Available technologies, especially of separating and capturing the carbon dioxide from waste stream, have high costs at present, perhaps representing an additional 40–100% onto the costs of generating electricity. In most of the world there are no mechanisms to encourage firms to consider sequestration. The study indicates that considerable R&D is required to bring down the costs of process, to elucidate the environmental effects of storage and to ensure that carbon dioxide will not escape from stores in unacceptably short time scales [84]. Israelsson et al. evaluated the expected environmental impact of several promising schemes for ocean sequestration by direct injection of carbon dioxide and concluded from the analysis that ocean carbon sequestration by direct injection should not be dismissed as a climate change mitigation strategy on the basis of environmental impact alone and it can be considered as a viable option for further study, especially in regions where geological sequestration proves impractical [85]. Chow et al. presented the strategies for producing negatively buoyant carbon dioxide hydrate composite particles for ocean carbon sequestration [86]. The phytoplankton of the upper ocean remove carbon dioxide from the atmosphere by photosynthesis and this ocean uptake of carbon dioxide is limited by the availability of nitrogen in the upper waters over much of the global ocean. The cost of providing this needed nitrogen to the upper ocean from a pilot plant with a capacity to sequester 2,000,000 tonnes of carbon dioxide per year is examined by Jones and Otaegui [87].

Geologic carbon sequestration is the injection of anthropogenic carbon dioxide in to deep geologic formations where it is intended to remain indefinitely. If successfully implemented, geologic carbon sequestration will have little or no impact on terrestrial ecosystems aside from the mitigation of climate change.

Price and Oldenburg proposed that the regulations for the siting of early geologic carbon sequestration projects should emphasize limiting the consequences of failure because the consequences are easier to quantify than failure probability [88]. A computationally efficient semi-analytical code CQUESTRA has been developed by LeNeveu for probabilistic risk assessment and rapid screening of potential sites for geological sequestration of carbon dioxide and the sensitivity analysis of CQUESTRA indicated that criteria such as siting below aquifers with large flow rates and siting in reservoirs having fluid pressure below the pressure of the formations above can promote complete dissolution of the carbon dioxide during movement toward the surface, thereby preventing release in to the biosphere [89]. The products of forsterite dissolution and the conditions favorable for magnesite precipitation have been investigated by Giammar et al., in experiments conducted at temperature and pressure conditions relevant to geologic C sequestration in deep saline aquifers [90]. The U.S. Environmental Protection Agency has developed a Vulnerability Evaluation Framework (VEF) for the geologic sequestration of carbon dioxide which can be used as a reference to inform site-specific assessments and risk management decisions [91]. Oldenburg et al. have developed a Certification Framework (CF) for certifying the safety and effectiveness of geologic carbon sequestration sites, by relating the effective trapping to carbon dioxide leakage risk which takes in to account both the impact and probability of leakage [92]. Keigo Akimoto et al. analyzed the cost of the geological storage of CO_2

in Japan in order to consider future research, development and deployment [93].

5.2. Agricultural soils

Carbon sequestration in degraded agricultural soils in developing countries to mitigate atmospheric greenhouse gas concentrations is increasingly promoted as a potential win–win strategy [94]. A comprehensive analysis incorporating ecologic, geographic and economic data was used by Thomson et al. to develop the terrestrial carbon sequestration estimates for agricultural soil carbon, reforestration and pasture management, estimating the contribution of terrestrial sequestration over the next century as 23–41 GtC [95]. Pandey suggested that agroforestry systems are a better climate change mitigation option than oceanic and other terrestrial options because of the secondary environmental benefits such as food security, secured land tenure, increasing farm income, restoring and maintaining the above-ground and below-ground biodiversity, maintaining watershed hydrology and soil conservation [96]. Alain Albrecht and Kandji analyzed the carbon storage data in some tropical agroforestry systems and discussed the role they can play in reducing the concentration of CO_2 in the atmosphere [97]. Karen Updegraff et al. designed a system called C-Lock to produce standardized carbon emission reduction credits (CERCs) that minimize litigation risks to purchasers and maximize the potential value to agricultural producers i.e. C-Lock is an online system to standardize the estimation of agricultural carbon sequestration credits [98]. John Antle et al. developed methods to investigate the efficiency of alternate contracts for carbon sequestration in cropland soils, taking in to account the spatial heterogeneity of agricultural production systems and the costs of implementing more efficient contracts [99]. Biospheric carbon sinks and sources can be included in attempts to meet emission reduction targets during the first commitment period of the Kyoto Protocol. Forest management, cropland management, grazing land management and re-vegetation are allowable activities under Article 3.4 of the Kyoto Protocol. Soil carbon sinks (and sources) can, therefore, be included under these activities. The role of croplands in European carbon budget and the potential for carbon sequestration in European croplands and then the global context pertaining to the same were reviewed by Pete Smith. Croplands are estimated to be the largest biospheric source of carbon lost to the atmosphere in Europe each year, but the cropland estimate is the most uncertain among all land-use types. It was estimated that European croplands (for Europe as far east as the Urals) lose 300 Mt C per year. The mean figure for the European Union is estimated to be 78 (S.D. 37) Mt C per year. There is significant potential within Europe to decrease the flux of carbon to the atmosphere from cropland, and for cropland management to sequester soil carbon, relative to the amount of carbon stored in cropland soils at present. The biological potential for carbon storage in European (EU15) cropland is of the order of 90–120 Mt C per year with a range of options available including reduced and zero tillage, set-aside, perennial crops and deep rooting crops, more efficient use of organic amendments (animal manure, sewage sludge, cereal straw, compost), improved rotations, irrigation, bioenergy crops, extensification, organic farming, and conversion of arable land to grassland or woodland. The sequestration potential, considering only constraints on land-use, amounts of raw materials and available land, is up to 45 Mt C per year. The realistic potential and the conservative achievable potentials may be considerably lower than the biological potential due to socio-economic and other constraints, with a realistically achievable potential estimated to be about 20% of the biological potential. As with other carbon sequestration options, potential impacts on non-CO_2 trace gases need to be factored in. Soil carbon sequestration is a riskier long-term strategy for climate mitigation than direct emission reduction and can play only a minor role in closing carbon emission gaps by 2100 [100]. The effect of alternative harvesting practices on long-term ecosystem productivity and carbon sequestration was investigated by Brad Seely et al., with the ecosystem simulation model FORECAST [101].

5.3. Soil organic carbon (SOC)

One of the most important terrestrial pools for carbon storage and exchange with atmospheric CO_2 is soil organic carbon (SOC). Follett felt that in the future, it is important to acquire an improved understanding of SOC sequestration processes, the ability to make quantitative estimates of rates of SOC sequestration and the technology to enhance these rates in energy and input efficiency manner [102]. Yang et al. evaluated the influence of soil depth and sample numbers on SOC sequestration in no-tillage (NT) and moldboard plow (MP) corn and soyabean production systems, with three long-term field trials in humid regions of Canada and USA. The first trial was conducted on a Maryhill silt loam (Typic Hapludalf) at Elora, Ontario, Canada, the second on a Brookston clay loam (Typic Argiaquoll) at Woodslee, Ontario, Canada, and the third on a Thorp silt loam (Argiaquic Argialboll) at Urbana, Illinois, USA. No-tillage led to significantly higher SOC concentrations in the top 5 cm compared to MP at all three sites. However, NT resulted in significantly lower SOC in subsurface soils as compared to MP at Woodslee (10–20 cm, $P = 0.01$) and Urbana (20–30 cm, $P < 0.10$). No-tillage had significantly more SOC storage than MP at the Elora site (3.3 Mg C ha^{-1}) and at the Woodslee site (6.2 Mg C ha^{-1}) on an equivalent mass basis (1350 Mg ha^{-1} soil equivalent mass). Similarly, NT had greater SOC storage than MP at the Urbana site (2.7 Mg C ha^{-1}) on an equivalent mass basis of 675 Mg ha^{-1} soil. However, these differences disappeared when the entire plow layer was evaluated for both the Woodslee and Urbana sites as a result of the higher SOC concentrations in MP than in NT at depth. Using the minimum detectable difference technique, we observed that up to 1500 soil sample per tillage treatment comparison will have to be collected and analyzed for the Elora and Woodslee sites and over 40 soil samples per tillage treatment comparison for the Urbana to statistically separate significant differences in the SOC contents of sub-plow depth soils. Therefore, it is impracticable, and at the least prohibitively expensive, to detect tillage-induced differences in soil C beyond the plow layer in various soils. It is concluded that although NT practices are found to favor SOC gain in the near-surface layers of soil, differences in the amount of SOC between NT and MP practices may also occur in deeper depths (even below the plow layer) [103]. Yadav et al. used the Soil Water Assessment Tool (SWAT) water quality model, the Water Erosion Prediction Project (WEPP) erosion model and the CENTURY 4.0 a soil carbon model, to stimulate the carbon sequestration rates for 160 crop-tillage rotations in 272 sub-basins of the Big Creek watershed and concluded that developing model-based estimates of SOC sequestration rates of field practices at many locations would thus greatly serve the needs of carbon crediting programs [104]. The significance of different variables on GHG production and soil C sink capacity was investigated by Mondini et al., by monitoring CO_2 and N_2O fluxes from amended soils under laboratory conditions and reported that the C conservation efficiency of organic residues, calculated by the combined loss during composting and after land application was higher for the less transformed organic materials [105]. Afforestation of agricultural ecosystems and forest plantations can enhance SOC stock through C sequestration [106]. Parr and Sullivan examined the role of the organic carbon occluded within phytoliths (referred as phytOC) in carbon sequestration in some soils and the process followed offers the opportunity to use plant species that yield high amounts of phytOC to enhance terrestrial carbon sequestration [107]. Hutchinson et al. explored the global potential of aerable soils by using the data from selected regions especially the Canadian Prairies and the Tropics, considering the fact that soil C sequestration is a significant mitigation option [108]. Shrestha and Lal worked on the restoration of the depleted SOC pools of reclaimed mine soil (RMS), which can be done through the conversion to an appropriate land-use and adoption of recommended management practices (RMPs) [109].

5.4. Forests

One strategy for mitigating the increase in atmospheric carbon dioxide is to expand the size of the terrestrial carbon sink, particularly forests, essentially using trees as biological scrubbers. The Kyoto protocol to the framework convention on climate change includes many provisions for forest and land-use carbon sequestration projects and activities in its signatories' overall GHG mitigation plans.

Kenneth and Krister explained the difficulty that even impartial analysts have in assessing the carbon offset benefits of projects, which when combined with self-interest, asymmetries of information and large numbers, prevents to a project-based forest and land-use carbon credit program may be insurmountable [110]. Sofia Backeus et al. presented an optimization model for analysis of carbon sequestration in forest biomass and forest products at a local or regional scale and concluded that assigning carbon storage a monetary value and removal of carbon in forest products as a cost increases the carbon sequestration in the forest [111]. Information on soil carbon sequestration and its interaction with nitrogen availability is rather limited, since soil processes account for the most significant unknowns in the C and N cycles. On account of this, Mol Dijkstra et al. compared three completely different approaches to calculate carbon sequestration in forest soils namely limit-value concept (annual litter fall × recalcitrant fraction of the decomposing plant litter), N-balance method (N retention in the soil × present soil C/N ratio) and dynamic SMART2 model [112]. Timo Karjalainen et al. studied different scenarios for carbon sequestration in the forest sector in Finland and demonstrated that C sequestration assessments should include not only C in the biomass of trees, but also C in the soil and in the wood products [113]. Using the institutional mechanisms provided by community based forest management (CBFM), Preet Pal Singh predicted that 833.8 Tg carbon can be sequestered by enhancement of forest carbon stocks in low biomass Indian forests [114]. Hashimoto et al. discussed the potential carbon sequestration in wood products and the impacts of three accounting approaches (IPCC default, stock-exchange and atmospheric-flow) on net carbon emissions of 16 industrialized countries [115]. Riitta Korhonen et al. illustrated that the use of bioenergy from the reforested areas to replace fossil fuels can in the long term contribute more effectively to the control of carbon dioxide concentrations than permanent sequestration of carbon to forests [116].

5.4.1. Afforestation

Benitez et al. provided a framework for identifying the least-cost sites for afforestation and reforestation and deriving carbon sequestration cost curves at a global level in a scenario of limited information [117]. A scenario generating tool was developed by Niu and Duiker, to detect the hotspots in terms of C sequestration potential (CSP), with the assessment of C sequestration potential by afforestation of marginal agricultural land (MagLand) and identification of hotspots for potential afforestation activities in the U.S Midwest region [118]. Baral and Guha compared the costs and quantity of carbon mitigation by afforestation and fossil fuel substitution based on simple carbon stocks and flows assuming the growth conditions of trees in the southern US and found that C sequestration sequestered through afforestation projects can be used to earn carbon credits to meet carbon reduction targets through Kyoto mechanisms [119]. Yin et al. introduced an integrated assessment (IA) approach for a Canada – China joint research project that linked forest carbon sequestration, forest resource management and local sustainability enhancement, which stresses the importance of IA [120].

5.5. Miscellaneous

Liu and Smirnov recorded that carbon dioxide sequestration in a coal bed is a profitable method to reduce GHGs in the atmosphere and to recover byproduct methane from the coal seam [121]. A variable saturation model was developed by Guoxiang Liu and Smirnov to predict the capacity of carbon dioxide sequestration and coal bed methane recovery and the results of their study and the developed models can provide the projections for the CO_2 sequestration and methane recovery in coal beds with different regional specifics [122]. Garg and Shukla showed that Carbon dioxide capture and storage (CCS) can mitigate CO_2 emissions from coal based large point sources (LPS) clusters and therefore would play a key role in mitigating both energy security risks for India and global climate change risks [123]. An under-researched alternative approach, concerning the application of biomass to reduce global warming gas emissions, is to extract from biomass black (elemental) carbon, which can be permanently sequestered as mineral geomass and may be relatively advantageous in terms of those risks. Malcolm Fowles reviewed the salient features of biomass black (elemental) carbon sequestration and used a high level quantitative model to compare the approach with the alternative use of biomass to displace fossil fuels. Black carbon has been demonstrated to produce significant benefits when sequestered in agricultural soil, apparently without bad side-effects. Black carbon sequestration appears to be more efficient in general than energy generation, in terms of atmospheric carbon saved per unit of biomass; an exception is where biomass can efficiently displace coal-fired generation. Black carbon sequestration can reasonably be expected to be relatively quick and cheap to apply due to its short value chain and known technology. However, the model is sensitive to several input variables, whose values depend heavily on local conditions. Because characteristics of black carbon sequestration are only known from limited geographical contexts, its worldwide potential will not be known without multiple streams of research, replicated in other. The paper concludes that efforts are needed to discover the feasibility and effectiveness of such sequestration in local conditions and suggests that sequestration has more carbon saving potential than electricity generation from biomass, because the latter is not efficient enough, but that the displacement of coal in particular by biomass has more carbon saving potential than sequestration [124]. Carbon sequestration through the formation of carbonate minerals is a potential means to reduce CO_2 emissions. Huntzinger et al. presented the first study examining the feasibility of C sequestration in cement kiln dust (CKD), a byproduct generated during the manufacturing of cement [125]. Celeb Stewart and Mir Akbar Hessami explained the methods of CO_2 capture and sequestration, with the topic of photosynthetic reaction, which has long been known as a natural process that can produce useful byproducts of biomass, oxygen and hydrogen, fixing the CO_2, using a photosynthetic bioreactor approach [126].

5.6. Interrelationship with biodiversity and sustainable development

The economic and legal implications of the interrelationship between carbon sequestration programs and biodiversity are analyzed by Alejandro Caparros and Frederic Jacquemont. The current treatment of this issue under the Framework Convention on Climate Change process was presented; the implications of carbon incentives for existing forests were studied (basing the analysis on an extension of the Hartman model including carbon sequestration and biodiversity values) and then, the expected influence of this policy on decisions about which type of forest to use for afforestation and reforestation was discussed. An optimal control model was used to analyze the choice between two types of forests: (i) one with high timber and carbon sequestration values but lower, or negative, biodiversity values; and (ii) one with lower timber and carbon sequestration benefits, but with high biodiversity values. The relationship between the Kyoto process and the Convention on Biological Diversity was also investigated, to assess whether or not the latter is expected to have any influence on the outcomes obtained in the analysis above. Results showed that creating economic incentives for carbon sequestration may have negative impacts on biodiversity, especially for afforestation and reforestation programs [127]. Rob Bailis discussed the links between sustainable development and carbon sequestration as a climate change mitigation (CMM) strategy, with a focus on Latin America, which has hosted the majority of sequestration activities to date [128]. Regional Carbon Sequestration Partnerships (RCSP) in the U.S. in determining and implementing the technology, infrastructure and regulations most appropriate to promote carbon sequestration in different regions of the nation is reviewed by Litynski et al., indicating the interrelationship between the C sequestration and the regional variations [129].

5.7. Economic aspects

Keywan Riahi et al. analyzed the potentials of carbon capture and sequestration technologies (CCT) in a set of long-term energy–economic–environmental scenarios based on alternative assumptions for technological progress of CCT. In order to get a reasonable guide to future technological progress in managing CO_2 emissions, past experience in controlling sulfur dioxide (SO_2) emissions from power plants were reviewed. By doing so, a "learning curve" for CCT was quantified, which describes the relationship between the improvement of costs due to accumulation of experience in CCT construction. The learning curve was incorporated into the energy-modeling framework MESSAGE-MACRO and greenhouse gas emissions scenarios of economic, demographic, and energy demand development were framed, where alternative policy cases lead to the stabilization of atmospheric CO_2 concentrations at 550 parts per million by volume (ppmv) by the end of the 21st century. Three types of contributors to the carbon emissions mitigation were quantified: (1) demand reductions due to the increased price of energy, (2) fuel switching primarily away from coal, and (3) carbon capture and sequestration from fossil fuels. Due to the assumed technological learning, costs of the emissions reduction for CCT drop rapidly and in parallel with the massive introduction of CCT on the global scale. Compared to scenarios based on static cost assumptions for CCT, the contribution of carbon sequestration is about 50% higher in the case of learning, resulting in cumulative sequestration of CO_2 ranging from 150 to 250 billion (109) tons with carbon during the 21st century. Also, carbon values (tax) across scenarios (to meet the 550 ppmv carbon concentration constraint) are between 2% and 10% lower in the case of learning for CCT by 2100. The results illustrate that assumptions on technological change are a critical determinant of future characteristics of the energy system, indicating the importance of long-term technology policies in mitigation of adverse environmental impacts due to climate change [130]. Klass van't Veld and Andrew Plantinga showed analytically that if the carbon price increases over time, consistent with projections from integrated assessment models, it becomes optimal to delay certain sequestration projects, whereas the optimal timing of energy-based abatement projects remain unchanged [131]. Gregg Marland et al. described a system whereby emission credits could be rented, rather than sold, when carbon is sequestered but permanence of sequestration is either not certain or not desired and such a rental contract for emission credits would establish continuous responsibility for sequestered carbon [132]. Man-Keun Kim et al. investigated the differential value of offsets in the face of impermanent characteristics by forming a price discount for land-based C sequestration that equalizes the effective price per ton between a perfect offset and one possessing some with impermanent characteristics [133]. Assessment of implications of the carbon sequestration policies is necessary in order to determine whether these sequestration policies contribute significantly to the global portfolio of climate change mitigation options. Dmitry et al. determined whether carbon sequestration policies could present a significant contribution to the global portfolio of climate change mitigation options [134].

6. Clean development mechanism

The Kyoto Protocol's clean development mechanism (CDM) was established in 1997 with the dual purpose of assisting non-Annex I parties in achieving sustainable development and assisting Annex I parties in achieving compliance with their quantified GHG emission commitments.

Erik Haites and Farhana Yamin examined the CDM defined by the Kyoto Protocol, the substantive, procedural and institutional issues raised by the CDM in the light of decisions adopted by the fourth Conference of the Parties to the UN Framework Convention on Climate Change held in Buenos Aires and suggested practical options for the operation and governance of the CDM in a credible, cost-efficient and environmentally effective manner [135]. Jane Ellis et al. analyzed the development of the CDM portfolio as well as achievements of the CDM to date in the context of wider private and public flows of investment in to developing countries and outlined the changes that are needed, to transform the CDM concept to a broader scale after the end of the first commitment period in 2012 [136]. Larry Carp and Xuemei Liu reviewed and evaluated the arguments surrounding the CDM and provided new empirical evidence concerning its potential benefits [137]. Diakoulaki et al. addressed three questions: in which country, what kind of investment, with which economic and environmental return and showed for the full exploitation of the CDM, a multi-faced approach for identifying priority countries and interesting investment opportunities in each priority country, is necessary [138]. Gilau et al. addressed the cost-effectiveness of renewable energy technologies like photovoltaic – diesel (PVDB), wind-diesel (WDB) and photovoltaic wind-diesel (PVWDB) hybrids, in achieving low abatement costs and promoting sustainable developments under the CDM [139]. Duic et al. assessed the possible influence of CDM and by assessing a case of a small island, showed that although the emission reduction on global scale is small, there is a great potential for establishing a strong market presence of renewable energy technologies in developing countries [140]. Miriam Schroeder discussed about how much the CDM can contribute to the deployment of renewable energies in China. While there are at least two general barriers to utilizing CDM finance for RE deployment – namely high project costs and the proof of additionality – this article argues that an appropriate national regulation can lead RE technologies to a stage of commercialisation at which CDM financing can become crucial. For an assessment of the current policy mix in place in China for the deployment of renewable energies, the article compares the national Chinese regulations for renewable energies and China's specific CDM rules for their impact: where do general and CDM-specific regulations for the promotion of renewable energies provide synergies, where does the policy-making on these two levels collide [141]. Timilsina and Shrestha analyzed the general equilibrium effects of a supply side GHG mitigation option – the substitution of thermal power with hydro power in Thailand under the CDM [142]. Malte Schneider et al. analyzed how the CDM contributes to technology transfer and found that the CDM does contribute to technology transfer by lowering several technology-transfer barriers and by raising the transfer quality [143]. The critical issue of whether the CDM can address poverty alleviation and sustainable development in developing countries was discussed by Bob Lloyd and Srikanth Subbara, in the context of existing market principles, transparency of the mechanism, economics and the daunting bureaucratic procedures involved and concluded that the CDM, if suitably modified, can address the above issues [144]. Actual CDM practice has shown that projects are largely initiated by the demand of relatively low-cost certified emission reductions, leading to a series of ad-hoc projects rather than serving the overall host countries' sustainable development needs and priorities. In the above framework, Charikleia Karakosta et al. aimed to direct CDM towards national sustainable development priorities, through the identification of sustainable energy technologies for electricity generation in five examined developing countries, namely Chile, China, Israel, Kenya and Thailand [145]. Funding for GHG mitigation projects in developing countries is crucial for addressing the global climate change problem. By examining the current climate change related financial mechanisms and their limitations, Zhong Xiang Zhang and Aki Maruyama indicated that the CDM, one of the flexibility mechanisms incorporated in to the Kyoto Protocol, could offer great potential in helping foreign direct investment towards climate mitigation, by providing commercial incentives for the private sector to invest in mitigation projects and internalizing externalities associated with mitigation projects [146]. Shrestha and Timilsina argued that while an application of purely economic additionality criterion is essential to ensure the real and long-term mitigation of global GHG emissions, it could also limit the scope of CDM as an effective vehicle for GHG mitigation [147]. Current discussions on the CDM lacks the technical input on which carbon emissions trading could be based and Michael See attempted to present estimates of capital costs of carbon dioxide reductions, addressed more vital issues of equity distribution and illustrated how emissions trading may be conducted via an exchange [148]. Sudhakara Reddy and Balachandra presented a few CDM business cases (for both rural and urban households) and demonstrated their feasibility and profitability from the perspectives of all the stakeholders and concluded that the possibility of earning profits is very high from these small scale CDM project cases, the highest being in the case of shifting from traditional to efficient firewood stoves [149].

6.1. CDM-AR

The CDM allows for a small percentage of emission reduction credits to come from afforestation and reforestation (CDM-AR) projects. Zomer et al. conducted a global analysis of land suitability for CDM-AR carbon sink projects and identified large amounts of land (749 Mha) as biophysically suitable and meeting the CDM-AR eligibility criteria [150]. Small scale afforestation/reforestation under the CDM of the Kyoto Protocol would sequester atmospheric carbon and facilitate carbon trading but they face significant implementation challenges among the rural poor households and communities that are meant to adopt and benefit from them [151]. The implicit hydrologic dimensions of international efforts to mitigate climate change, specifically potential impacts of the CDM-AR provisions of the Kyoto Protocol on global, regional and local water cycles are examined by Antonio Trabucco et al. [152].

7. Mitigation and adaptation

The potential for developing synergies between climate change mitigation and adaptation has become a recent focus of both climate research and policy. There are also increasing calls for research to define the optimal mix of mitigation and adaptation [153]. The diagrammatic representation of climate change, adaptation and mitigation is important in conceptualizing the problem, identifying important feedbacks and communicating between disciplines, with a more refined distinction between adaptation and mitigation [154]. Xinsheng Liu et al. found that emphasis on issue solutions is placed more on mitigation strategies than on adaptation behaviors and that both governmental and non-governmental actions and responsibilities are suggested for dealing with climate change [155]. Pielke Jr discussed the limitations of mitigation responses and the need for adaptation to occupy a larger role in climate policy [156]. Alan Ingham et al. expressed that most of the analysis to date has focused on the case where the actions available to society are just the mitigation of emissions and where there is little or no role for learning [157]. Tol expressed his view that mitigation and adaptation should be analyzed together, as they indeed are, albeit in a rudimentary way, in cost–benefit analysis of emission abatement and recommended that *facilitative adaptation* and mitigation not only both reduce impacts, but they also compete for resources [158]. Katarina Larsen and Ulrika Gunnarsson Ostling discussed the inter-relationships between adaptation and mitigation by examining the processes of citizen participation in constructing scenarios and applying the concepts of resilience, vulnerability and adaptive capacity and argued that tension arising from climate strategies relying on either adaptation or mitigation strategies or combining both, warrant further examination [159]. The results of the analysis done by Nicholls and Lowe suggested that a mixture of adaptation and mitigation policies need to be considered for coastal areas, as this will provide a more robust response to human-induced climate change than either policy in isolation [160]. Julia Laukkonen et al. viewed that it is not sufficient to concentrate on either mitigation or adaptation, but a combination of these results in the most sustainable outcomes and yet, these two strategies do not always complement each other but can be counter productive with case studies of successful adaptation and mitigation strategies suggesting that these successes be translated in to local contexts and communalized with the involvement of local authorities using participatory approaches [161]. Focusing predominantly on cases from US and Australia, Hamin and Nicole Gurran identified whether the policies address adaptation, mitigation or both and whether the practices put mitigation and adaptation in potential conflict with each other and found that half of the actions identified contain potential conflicts to achieving adaptation and mitigation simultaneously [162]. Robbert Biesbroek et al. discussed the origin of the adaptation–mitigation dichotomy and also addressed the relationship between climate change responses and spatial planning, as the spatial planning can function as a switchboard for mitigation, adaptation and sustainable development objectives [163].

8. Economy and emissions

A positive relationship between CO_2 emissions, the most important GHG implicated in global warming and GDP was shown by Michael Tucker, examining the per capita income and CO_2 emissions of 137 countries across 21 years and predicted that higher income levels lead to increase demand for environmental protection [164]. Neha Khanna examined the cost of meeting the Kyoto Protocol commitments under alternative assumptions regarding technology and technical change, by modeling real GDP as a function of the capital, labor and energy inputs and found that the loss in real GDP due to Kyoto commitments is one and a half times higher than obtained under standard assumptions [165]. Ying Fan et al. analyzed the impact of population, affluence and technology on the total CO_2 emissions of countries at different income levels over the period 1975–2000, using the STIRPAT model and the main results showed that at the global level the economic growth has the greatest impact on CO_2 emissions [166]. To date, future change in socio-economic systems has not been sufficiently integrated with an analysis of climate change impacts and climate impact assessment needs to take account of two interrelated processes namely socio-economic change and climate change [167]. Tobey highlighted the critical role of economics in understanding the potential magnitude of global climate change as a problem for human society and for assessing and developing effective responses and felt that much works remain in the application of economic concepts to climate change problems [168].

8.1. Carbon tax

Rolf Golombek et al. studied the optimal design of a carbon tax when a group of countries seeks to maximize its net income minus its environmental costs, which depend on the sum of CO_2 emissions from all countries. When both production and consumption of internationally traded fossil fuels are taxed, a particular combination of producer and consumer taxes exists which is optimal. It was also shown that with this tax the sum of the consumer tax and producer tax should be equal across all fossil fuels per unit of carbon. On the other hand, when the cooperating countries use a tax on consumption (or production) of fossil fuels as the only policy instrument, the tax per unit of carbon should in general be differentiated across fossil fuels. An empirical illustration of the theoretical analysis was also given, assuming that the cooperating countries are those of the OECD [169]. A high carbon tax for carbon intensive tradable sectors in the cooperating countries will reduce the production of good from these sectors and hence the CO_2 emissions in the cooperating countries will also reduce. Michael Hoel showed that a carbon tax should not be differentiated across sectors in the economy, provided one can use import and export tariffs on all traded goods [170]. Zhong Xiang Zhang and Andrea Baranzini assessed the main economic impacts of carbon taxes and based on a review of empirical studies on existing carbon/energy taxes, it was concluded that competitive losses and distributive impacts are generally not significant and definitely less than often perceived [171]. Energy taxes designed to control energy consumption and to assist the achievement of climate change control targets under the Kyoto Protocol, are fairly common in EU countries. Yet many of these taxes bear little resemblance to the design guidance that is given in the economics textbooks. Political economy analysis, in which the interaction of economics and political reality is emphasized, explains the gap between theoretical ideals and practical reality. David Pearce illustrated the above issues in the context of one tax, the UK Climate Change Levy [172].

8.2. Emission trading

Cedric Philibert's study aimed to show how an emission trading system could work if some participating entities are allocated an "emission budget" or non-binding target, as this will allow them to sell allowances if their actual emissions are less than their budget but will not obligate them to buy allowances if their emissions exceed their budget [173]. Marcel Braun recapitulated how emissions trading became a cornerstone of the EU's climate policy and analyzed the development of the European Union Emissions Trading Scheme (EU ETS) [174]. Etan Gumerman summarized the economic and carbon savings sensitivity analysis completed for the *Scenarios for a Clean Energy Future* study and its 19 sensitivity cases provided insight in to the costs and carbon reduction impacts of a carbon permit trading system [175]. Urs Springer gathered results from 25 models of the market for tradable GHG emission permits under the Kyoto Protocol and suggested that these countries can increase their revenues from selling permits by restricting supply, which raises the permit price [176]. The consequences of the Kyoto Protocol for the fossil fuel markets depend on which policy instruments are used in order to reach the emission targets. Bjart Holtsmark and Ottar Maestad assessed the significance of international emissions trading for the oil, coal and gas markets, by using a numerical model. Three different trading regimes namely North America, Asia and Europe including Russia were compared and particular attention is devoted to the EU proposal about limits on acquisitions and transfers of emission permits. It was found that the EU proposal will be non-binding for buyers of emission permits but will significantly constrain the sale of emission permits from Eastern Europe. The EU proposal will increase the level of abatement in Annex B countries and will cause a sharp increase in the price of permits compared to the free trade equilibrium [177].

9. Policies

Katia Simeonova and Harald Diaz-Bone provided an overview of the evolving climate change strategies put in place by industrialized countries to combat climate change and to comply with their quantitative commitments under the Kyoto Protocol and also outlined the portfolios of policy instruments used by the industrialized countries in their evolving climate change strategies and in their approach to widening the scope and increasing the coverage of those policy instruments to all sectors and all gases [178]. Popi Konidari and Dimitrios Mavrakis presented an integrated multi-criteria analysis method for the quantitative evaluation of climate change mitigation policy instruments. The method consists of: (i) a set of criteria supported by sub-criteria, all of which describe the complex framework under which these instruments are selected by policy makers and implemented, (ii) an analytical hierarchy process (AHP) process for defining weight coefficients for criteria and sub-criteria according to the preferences of three stakeholders groups and (iii) a multi-attribute theory (MAUT)/simple multi-attribute ranking technique (SMART) process for assigning grades to each instrument that is evaluated for its performance under a specific sub-criterion. Arguments for the selected combination of these standard methods and definitions for criteria/sub-criteria are quoted. Consistency and robustness tests are performed. The functionality of the proposed method was tested by assessing the aggregate performances of the EU emission trading scheme at Denmark, Germany, Greece, Italy, Netherlands, Portugal, Sweden and United Kingdom [179]. Hal Turton described the development of the energy and climate policy and scenario evaluation (ECLIPSE) model, a flexible integrated assessment tool for energy and climate change policy and scenario assessment [180]. Sovacool and Brown assessed the advantages and disadvantages of fighting the climate change through local, bottom–up strategies as well as global, top–down approaches and concluded that in scaling the policy responses to climate change, local thinking must be coupled with global and national scales of action in order to achieve the levels of CO_2 reductions needed to avoid dangerous climate impacts [181]. Bruce Tonn presented an alternative framework to the approach currently embodied in the Kyoto Protocol for managing global climate change post-2012. The framework has two key provisions. The first is that each person in the world would be allowed an equal amount of GHG emissions, labeled as the equity-first provision and the second provision focuses on incorporating risk concepts in to the setting of GHG emission reductions [182]. International negotiations under the UN Framework Convention on Climate Change could take several different approaches to advance future mitigation commitments. Options range from trying to reach consensus on specific long-term atmospheric concentration targets (e.g. 550 ppmv) to simply ignoring this contentious issue and focusing instead on what can be done in the nearer term. Jan Corfee Morlot and Niklas Hohne argued for a strategy that lays between the two extremes namely the long-term targets and the short-term commitments. Internationally agreed threshold levels for certain categories of impacts or of risks posed by climate change could be translated into acceptable levels of atmospheric concentrations. This could help to establish a range of upper limits for global emissions in the medium term that could set the ambition level for negotiations on expanded GHG mitigation commitments. The paper thus considers how physical and socio-economic indicators of climate change impacts might be used to guide the setting of such targets. In an effort to explore the feasibility and implications of low levels of stabilization, it also quantifies an intermediate global emission target for 2020 that keeps open the option to stabilise at 450 ppmv CO_2. If new efforts to reduce emissions are not forthcoming (e.g. the Kyoto Protocol or similar mitigation efforts fail), there is a significant chance that the option of 450 ppmv CO_2 is out of reach as of 2020. Regardless of the preferred approach to shaping new international commitments on climate change, progress will require improved information on the avoided impacts climate change at different levels of mitigation and careful assessment of mitigation costs [183]. Masami Onoda reported that if we are to use satellite data as a potential global common measurement tool, there is a need to bridge the gaps between observation methods and the policy frameworks [184]. Recent studies on global warming have introduced the inherent uncertainties associated with the costs and benefits of climate policies and have often shown that abatement policies are likely to be less aggressive or postponed in comparison to those resulting from traditional cost–benefit analyses (CBA). Yet, those studies have failed to include the possibility of sudden climate catastrophes. Andrea Baranzini et al. aimed to account simultaneously for possible continuous and discrete damages resulting from global warming and analyzed their implications on the optimal path of abatement policies. The approach is related to the new literature on investment under uncertainty, and relies on some recent developments of the real option in which negative jumps (climate catastrophes) in the stochastic process corresponding to the net benefits associated with the abatement policies were incorporated. The impacts of continuous and discrete climatic risks can therefore be considered separately. The numerical applications led to two main conclusions: (i) gradual, continuous uncertainty in the global warming process is likely to delay the adoption of abatement policies as found in previous studies, with respect to the standard CBA; however (ii) the possibility of climate catastrophes accelerates the implementation of these policies as their net discounted benefits increase significantly [185]. The problem of designing a comprehensive and efficient policy package to reduce emissions of CO_2 and other GHGs is more complicated than suggested in the existing economic literature. Schheraga and Leary examined three different implementation issues. First, the variation of cost-effectiveness of different energy taxes as a function of the level of the market at which they are imposed, secondly the integration of different policy tools in to an efficient policy package and third the focusing on all GHG and not limited to CO_2 and concluded that a piecemeal approach to policy formation that fails to consider these issues is likely to be inefficient and unnecessarily costly [186]. Tony Prato proposed a conceptual framework for assessing and managing the ecosystem impacts of climate change, which can be used by the ecosystem managers to systematically assess the potential adverse impacts of future climate change on ecosystems and identify best adaptation strategies for alleviating those impacts [187]. Policy makers and water resource managers should be aware of the evolving information on climate change impacts to sound decision making on current water resources management actions [188]. Considerable quantities of bio-available nitrogen are released in the production of food and energy. An integrated approach to nitrogen related environmental problems will be more effective on all environmental and geopolitical levels and will therefore make for more efficient and cost-effective policy [189]. Claudia Kemfert investigated the world economic implications of climate change policy strategies and particularly evaluated the impacts of an implementation of CDM, joint implementation and emissions trading with a world integrated assessment model. This study elaborates and compares multi-gas policy strategies and explores the impacts of sink inclusion. The economic impacts on all world regions of the USA's non-cooperative, free rider position resulting from its recent isolated climate policy strategy decision were examined. It turns out that CDM and JI show evidence of improvement in the economic development in host countries and increase the share of new applied technologies. The decomposition of welfare effects demonstrates that the competitiveness effect (including the spill over effects from trade) have the greatest importance because of the intense trade relations between countries. Climatic effects will have a significant impact within the next 50 years, will cause considerable welfare losses to world regions and will intensify if nations highly responsible for pollution like the USA do not reduce their emissions [190]. The anticipated implications of international environmental policy strategies are critical for the success or failure of international negotiations on climate change policies. Peter Nijkamp et al. discussed the complex modeling issues related to the incorporation of international environmental policy measures in one of the popular applied general equilibrium models for international trade, the so-called GTAP model [191]. Approaching the analysis of climate policies from a spatial organization perspective is necessary for realizing both efficient and effective mitigation of GHG emissions. In particular, it allows assessing the potential contribution of specific mechanisms of spatial organization and related spatial planning and policy to climate policy goals. So far, this spatial organization angle of climate policy has hardly received attention in the literature. The main sector significantly contributing to GHG emissions and sensitive to spatial organization and planning is urban transport. Fabio Grazi and van den Bergh provided a qualitative evaluation of the available spatial organization policy options, on the basis of four standard E criteria namely (social) efficiency, effectiveness, equity and enforcement and a decomposition of CO_2 emissions [192]. A multi-sector, multi-region trade model (MS-MRT) was developed by Bernstein et al. that focuses on the international trade aspects of climate change policies [193]. Adam Rose suggested that consideration be given to an equitable sharing of the economic impacts of global warming policy [194]. Customary international law has that countries may do each other no harm. A country violates this rule if an activity under its control does damage to another country and if this is done on purpose or due to carelessness. Impacts of climate change fall under this rule, which is reinforced by many declarations and treaties including the UNFCCC. Tol and Roda Verheyen predicted that state responsibility could substantially change international climate policy [195]. Steinar Andresen and Agrawala illuminated the role of leadership exerted by individuals, institutions and nation-states at various stages of the global climate change regime and four forms of leadership intellectual, instrumental, power-based and directional, were identified [196].

9.1. Influence of science and technology

The recent landmark report by the National Academy of Sciences reviewed the science on which the Kyoto Protocol was based and concluded that the policy choices and the mandatory reductions in GHG by the developed nations were based on incomplete science with significant uncertainties, providing a new framework for consideration of global warming issues [197]. Moss felt from his studies that in future, further interaction is needed between the policy and scientific communities to help policy makers a better understanding of the complexities of the climate system and to assure that the scientific community provides information that is useful to evaluating alternative responses to climate change [198]. Sanden and Christian offered suggestions for the situations when it comes to near-term technology policies for long-term climate targets based on some insights in to the nature of technical change [199]. Khanna and Chapman examined the validity of standard assumptions used in climate economy models and explored the policy consequences of changing them to reflect actual as opposed to postulated trends [200]. Otto et al. studied the cost-effectiveness of climate policy if there are technology externalities and found that cost-effectiveness of climate policy improves if it is differentiated between technologies [201]. Henrik Lund made preliminary recommendations for policies to encourage the use of the Kyoto mechanisms as an acceleration of the necessary technological innovation [202]. Until recently endogenous technical change and uncertainty have been modeled separately in climate policy models. Erin Baker and Ekundayo Shittu reviewed the emerging literature that considers both these elements together and indicated that explicitly including uncertainty has important quantitative and qualitative impacts on optimal climate change technology policies [203].

9.2. Influence of sustainable development

Climate change and sustainable development have been addressed in largely separate circles in both research and policy. Nevertheless, there are strong linkages between the two in both realms. Rob Swart et al. focused on the scientific linkages and discussed the opportunities they provide for integrated policy development and the necessity to consider the risk of trade-offs between the climate change and sustainable development [204]. Bert Metz et al. presented some evidence that shifting emphasis from emission reduction to sustainable development needs in the policy-making can contribute significantly to relieving the threat of human-induced climate change [205]. Adil Najam et al. argued that returning to the basic principles outlined in the UNFCCC in searching for a north–south bargain on climate change could be achieved only if we could realign the policy architecture of the climate regime to its original stated goals of sustainable development [206]. Adil Najam et al. reviewed how sustainable development was treated in prior assessment reports of the IPCC and presented proposals on how it might be integrated in to the forthcoming Fourth assessment Report [207].

10. Conclusion

The Third Assessment Report published by the IPCC in 2001 states, 'there is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities'. Hence, it is possible to mitigate the climate change and GHG emissions to a certain level, though not completely, by human beings. The Climate Change, Mitigation and Adaptation have been reviewed as follows.

- There are proving facts for the impact of climate change on various components of the biosphere like air, water, plants, animals and human beings, which, if not acted upon, may lead to catastrophes. Climate change influences air quality, increases the dominance of cyanobacteria in water bodies, affects quality of drinking water, a change in the hydrological cycle, implications on fluvial geomorphology, range limits of plant species, adverse impacts on wildlife.
- The crucial problem that the world is facing today, the global warming is discussed, including the global warming potential (GWP) and its influence on economy. Climate change has a say on fisheries, which affects the marine economy, wool industry principally on forage, water resources, land carrying capacity and animal health, on tourism affecting the GDP by −0.3–0.5% in 2050 and agriculture based on temperature rise, water quality and availability.
- The potential impacts of climate change on human health are significant, ranging from direct effects such as heat stress and flooding, to indirect influences including changes in disease transmission and malnutrition in response to increase competition for crop and water resources. It changes the epidemiology of infectious diseases and the vector-borne diseases will become more common as the earth warms and impacts on mortality through ill health, particularly among the elderly, in summer.
- In addition to energy related R&D, also important are the R&D for CO_2 absorption and fixation for fundamental solution to global warming.
- Various mitigation strategies along with the economy implications are briefed.
- Carbon sequestration, one of the effective mitigation techniques, is elaborated with its sub-types ocean and geological sequestration and sequestration in agricultural soils and forests. Adequate long-term monitoring and maintenance of the carbon sequestration sites, using bonding mechanisms should be the future research concern.
- The clean development mechanism (CDM), one of the most recommended and promising technology for mitigation, introduced under the Kyoto Protocol is reviewed. Cost-effective and immediate to implement CDM is the need of the hour. Funding for GHG mitigation projects in developing countries is crucial for addressing the global climate change problem.
- The importance of the synergy between mitigation and adaptation is quoted. There are also increasing calls for research to define the optimal mix of mitigation and adaptation. It is not sufficient to concentrate on either mitigation or adaptation, but a combination of these results in the most sustainable outcomes.
- The economic aspects of emissions, including the carbon tax and emission trading, have been studied. The loss in real GDP due to Kyoto commitments is one and a half times higher than obtained under standard assumptions.
- A high carbon tax for carbon intensive tradable sectors in the cooperating countries will reduce the production of good from these sectors and hence the CO_2 emissions in the cooperating countries will also reduce.
- The existing policies and the amendments needed in the framing of new policies have been reviewed. The portfolios of policy instruments used by the industrialized countries in their evolving climate change strategies should be widened, increasing the coverage of those policy instruments to all sectors. In scaling the policy responses to climate change, local thinking must be coupled with global and national scales of action in order to achieve the levels of CO_2 reductions needed to avoid dangerous climate impacts.

- Four forms of leadership intellectual, instrumental, power-based and directional are required for enforcement of global climate change mitigation policies in the society.

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