Forestry Projects under the Kyoto Protocol's Clean Development Mechanism: One Response to the Threat of Global Climate Change

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Acknowledgements 2
Executive Summary 4
1. Introduction 5
  1.1. Humanity's Ecological Footprint 5
2. The Science of Climate Change 7
  2.1. The Intergovernmental Panel on Climate Change 7
  2.2. Scientific understanding of the climate system 8
    2.2.1. Solar Radiation and the Earth's Energy Balance 8
    2.2.2. The Greenhouse Effect: A Natural Process 8
    2.2.3. Anthropogenic Influences on the Climate 9
    2.2.4. Uncertainty and Climate Science: Models 10
  2.3. The Potential Impacts of Climate Change 12
    2.3.1. Ecological impacts 13
    2.3.2. Social and economic impacts 14
3. The International Policy Response to Climate Change 16
  3.1. The Negotiation of the Kyoto Protocol 17
    3.1.1. Legally Binding Commitments to Reduce Greenhouse Gases 17
    3.1.2. The Flexible Mechanism 17
  3.2. The Clean Development Mechanism 19
4. The CDM in Practice 21
  4.1. Carbon Sinks and Photosynthesis 21
  4.2. Measuring the Success of Forestry Projects under the CDM 23
    4.2.1. Carbon Stock Method 23
    4.2.2. Establishing the Baseline 23
    4.2.3. Project Monitoring 24
    4.2.4. Measuring the Sustainability of CDM Forestry Project 25
5. CDM Forestry Projects and the Problem of Uncertainty 26
  5.1. Uncertainties Relating to Carbon Sequestration 26
    5.1.1. Tree Age 26
    5.1.2. Tree Species 26
    5.1.3. The Potential Effect of Climate Change 27
    5.1.4. Nutrients and Water 28
  5.2. Uncertainties Relating to Measuring Sequestration 28
  5.3. Uncertainties Relating to Measuring the Impact of Forestry Projects 29
    5.3.1. Permanence 29
    5.3.2. Additionality 29
    5.3.3. Leakage 29
6. Conclusion 30
Appendix: Glossary of Terms 31

Executive Summary

A large and growing body of evidence suggests that the Earth's climate is changing and that this change is being caused by human activity. Global temperature readings reveal that Earth's surface temperature has risen by 0.6°C during the 20th Century and is projected to continue to increase by an additional 1.4°C to 5.8°C above 1990 levels by 2100. There is some uncertainty associated with the complex science of climate change, especially with regard to the predictive accuracy of climate models. However, there is a near-consensus among scientists that climate change is occurring as a result of increasing concentrations in the atmosphere of several greenhouse gases such as carbon dioxide and methane, which are in turn the result of centuries of energy consumption, land-use change and other human activities.

Climate change models predict severe impacts that pose risks to society, the global economy, and the natural environment. Ecosystem productivity and biodiversity are threatened by the risk of abrupt and non-linear ecological changes, such as fires, droughts, pest infestations, invasion of exotic species, storms, and coral bleaching events. Human populations and the global economy may be directly affected through extreme weather, drought, disease, and migration of species.

The international community has largely agreed that climate change is real and that there is sufficient knowledge upon which to base immediate action. In response to this threat, international governments adopted the Kyoto Protocol in 1997. This treaty established legally binding restrictions on the amount of greenhouse gas emissions below 1990 levels by 2010. A series of market-based "flexible mechanisms" were established to reduce the costs of complying with the Protocol. One of these, the Clean Development Mechanism, allows developed countries to fund projects in developing countries that elad to reductions of greenhouse gases in the host country. Forestry projects are allowed under the CDM, taking advantage of trees' absorption of $CO2$ through photosynthesis. Such projects are controversial because of the difficulty of measuring the amount of carbon that trees sequester and because of concerns that such projects will not lead to sustainable development, one of the key criteria of the CDM. To address these concerns a number of baseline methodologies have been proposed to take into account the uncertainties surrounding the CDM. It will be necessary to observe the effects of individual projects before the success of the CDM can be evaluated.

1. Introduction

The Kyoto Protocol is an international treaty that attempts to address the problem of global climate change. The protocol sets legally binding limits on the anthropogenic emissions of significant “greenhouse gases”, trace gases that trap heat and are thought to be accumulating in the atmosphere at a level sufficient to change the Earth’s atmosphere. The protocol was adopted in Kyoto, Japan, in 1997 but only came into force in 2005, when the required minimum number of countries finally ratified it. Despite the near-consensus that exists about the reality of climate change and the risks it poses to the Earth, ratification of the protocol was difficult because many countries disagreed on how best to address the climate change problem. Indeed, the United States, the world’s largest economy and emitter of greenhouse gases, withdrew from the treaty in February 2001 (along with Australia) due to concerns that implementing the Kyoto Protocol would be unacceptably expensive.

Partly in anticipation of such criticisms, the Kyoto Protocol established an instrument called the Clean Development Mechanism (CDM) that encourages developed countries to invest in greenhouse-gas-reducing projects in developing countries. The purpose of the CDM is to allow developed countries to benefit from the lower-cost opportunities in developing countries to reduce greenhouse gases, whereas the developing countries benefit from the investment that such projects will bring. One type of project allowed under the CDM is forestry, based on the rationale that trees absorb carbon dioxide, one of the main greenhouse gases.

This paper examines the problem that climate change poses, including the scientific basis behind the theory of climate change and the threats associated with it. It describes how the CDM was developed as part of the international response to this problem. It outlines the scientific issues surrounding the inclusion of forests as eligible projects under the CDM and considers some of the controversies that have arisen around the use of forestry as a way of addressing the problem of climate change.

1.1. Humanity’s Ecological Footprint

Humans have been on the Earth for only a fraction of its 3.5 billion-year history. However, humanity’s ecological footprint – the impact on the planet’s ecosystems, biogeochemical processes and natural resources – has been disproportionately large. This impact has become especially pronounced over the past few centuries due to industrialization and agriculture.[1]

The first humans were tribal hunter-gatherers that lived within small family groups with minimal interaction between other groups. These groups maximized resources within their local niche, collecting food and using whatever shelter was available in their locality. On occasion these groups would travel, when the resource potential had expired for their particular area. These early humans were entirely dependant on the environment for food and shelter. This high dependence on the environment has eroded with time. The development of tools led to more efficient techniques for hunting and gathering. As competition for resources became less intense groups of humans began to come together to share knowledge and resources.[2] Some 10,000 years ago humans began to practice agriculture, thereby ensuring surplus food supplies and allowing populations to grow.[3]

The greatest impact came with the Industrial Revolution, a process of great innovation that began three centuries ago in Western Europe and is still continuing. Advances in the fields of physics and engineering led to the production of steam power, a catalyst for the growth of industries and transport. Such growth saw populations shift from rural to urban areas in search of work, hence the formation of large scale industrial cities. Discoveries in biology and chemistry allowed growth in agricultural production through the use of fertilizers and, later, pesticides. Further innovation in science, engineering and economics resulted in growth of the mining, forestry, construction, medicine, energy and technology sectors, and innovations continue to appear today. All of these processes have extensively consumed the planet's finite resources and have led to exponential population growth, placing even more demand on the use of natural resources.

Increased mass exploitation of resources has caused severe stress on the planet's natural systems, such that no ecosystem on earth is left untouched by humans.[4] Technological progress outpaces our ability to understand Earth's biogeochemical processes. The great changes that have driven human development, including land use changes and the combustion of fossil fuels for energy, have led to significant emissions of greenhouse gases such as carbon dioxide and methane. The accumulation of these gases in the atmosphere is now thought to have disrupted the Earth's climate system, with long-term and potentially serious implications.

Growing concerns about the effect of human activity on the Earth have recently led to attempts to address environmental problems at both the local and global level. Tackling the problem of climate change is particularly difficult for several reasons, however. First, although scientific knowledge has produced deep insights into the functioning of the Earth's climate, uncertainties remain in scientists' understanding of the climate system and especially in the projection of future trends due to the complexity of the climate system. Policymakers must therefore make decisions that are important for the long term without the luxury of complete certainty to guide them. Second, because greenhouse gas emissions have been closely linked to human development major shifts in economic patterns will be required to decouple development and greenhouse gas emissions. Third, human development has seen social and economic benefits for many; but, a large proportion of the human race is still excluded from the benefits of health, clean water, regular food supply, and energy; this has caused complicated questions of equity to dominate international negotiations. Fourth, climate change is a global problem that requires international cooperation, which is very difficult to achieve. This report looks at the Kyoto Protocol and particularly the use of forestry projects under the Kyoto Protocol's Clean Development Mechanism as a way of addressing climate change in the context of these and other issues.

2. The Science of Climate Change

Climate change is an uncertain science because the Earth's climate is a highly complex system. The science must account for the interplays between the oceans, clouds, forests, particulate matter, seasonal temperature variations, and many other factors in addition to the increasing impact of human activities. Although there is near-consensus on the theory that human activity is having an impact on the Earth's climate, some scientists disagree on the nature and extent of this impact. It is even more problematic to predict how the climate will respond and change in the future. This poses a problem to policymakers, who are forced to make decisions that have far-reaching implications for human development on the basis of a problem that is not fully understood and whose consequences may not manifest for many years. Nevertheless, scientific understanding of the climate system has deepened over the past three decades. One of the most important forums for advancing scientific understanding has been the Intergovernmental Panel on Climate Change (IPCC).

2.1. The Intergovernmental Panel on Climate Change

From the 1970s a growing number of scientists began to hypothesize that increasing concentrations of CO_2 and other gases could lead to increased global temperatures. In 1979 the World Meteorological Organization (WMO) held the first "World Climate Conference", which discussed concerns among scientists that rising concentrations of carbon dioxide (CO_2) and other greenhouse gases could cause the Earth's temperature to rise. Subsequent conferences in 1985 and 1987 led to calls for an objective, balanced and internationally coordinated scientific assessment of the understanding of the effects of increasing concentrations of greenhouse gases on the Earth's climate as well as the potential damage to society that climate change could cause.[5]

In 1988 the WMO and the United Nations Environment Program decided to establish the Intergovernmental Panel on Climate Change (IPCC). The IPCC is an international multidisciplinary collaborative effort to advance understanding of climate change and to explain the issue to policymakers and the general public. To this end the IPCC is mandated to provide independent scientific advice on climate change and its likely impacts and to formulate realistic response strategies. The IPCC divides its work among three working groups. The first group deals mainly with the dynamics of the Earth's climate system. The second examines the potential impacts of climate change. The third focuses on possible responses to the threat of climate change, including adaptation. The IPCC publishes regular Assessment Reports about every six years as well as Special Reports on specific topics.

The IPCC's First Assessment Report (1990) was the basis for the negotiation of the United Nations Framework Convention on Climate Change (see section 3 below). Although the First Assessment Report predicted temperature increases, it mainly highlighted the uncertainties that existed in the theory of climate change. The Second Assessment Report (1995) stated in its Synthesis Report that "the balance of evidence suggests a discernible human influence on global climate", that temperatures would rise to between 1.4°C and 5.8°C above 1990 levels by 2100, and that sea levels would rise between 15 and 90 centimeters by 2100, unless emissions were reduced by 50 percent below the then-current levels.[6] The Third Assessment Report, published in 2001, stated that "There is new and stronger evidence that most of the warming over the last 50 years is attributable to human activities" and that the "Global average temperature and sea level are expected to rise under all IPCC … scenarios".[7] These reports have conditioned the international negotiations and raised public awareness on the problem of climate change. The Fourth Assessment Report is currently under preparation and is due to be published in 2007.

2.2. Scientific understanding of the climate system

Through the work of the IPCC and other forums scientists have deepened their understanding of the climate system and the potential impact that human activity could have on that system. This section describes some of the main principles that govern the climate system.

2.2.1. Solar Radiation and the Earth's Energy Balance

The primary influx of energy into the Earth comes from the Sun, some 186,000 miles away, in the form of shortwave radiation, predominately visible light and ultraviolet radiation.[8] The sun provides an average of approximately 345 watts per square meter of energy to the Earth.[9] As this solar energy enters the atmosphere, its fate is varied. Some 30% is reflected back into space by clouds, which effectively removes it from the energy balance of the Earth. Another 25% is absorbed by atmospheric gases. The remaining 45% is absorbed by the Earth's surface.[10] The Earth eventually re-radiates this energy back out to space in the form of long-wave, infrared radiation. The result of the absorption of the incoming solar short-wave radiation and the re-radiation of the long-wave radiation is an overall global energy balance that serves to maintain a relatively steady temperature from year to year.[11]

2.2.2. The Greenhouse Effect: A Natural Process

The laws of thermodynamics predict that, based on the size of the Earth and its distance from the sun, the temperature of the Earth should be an average of -18ºC. In fact, the Earth's average temperature is 15ºC.[12] The reason for this difference is the effect of several gases such as water vapor, carbon dioxide (CO_2), and methane (CH_4) that trap enough heat to warm the Earth's surface. These gases are called "greenhouse gases" because, like a greenhouse, they allow the heat of the sun to enter but prevent some of that heat from exiting. Greenhouse gas molecules are typically at least three atoms in size (e.g. CO_2, CH_4) and are transparent to visible light.[13] They have the ability to absorb infrared radiation, causing the bonds of the molecule to shift. The shifted bonds cannot retain this "excited" position indefinitely and as they return to their normal position the energy absorbed is then released as infrared radiation back into the atmosphere.[14] The absorption and release of infrared radiation back into the atmosphere prevents the complete escape of infrared radiation from the Earth's surface into space.

The greenhouse effect is a natural process that is essential for maintaining a habitable temperature on Earth, but there is increasing evidence that human activities are accelerating this process and interfering with the Earth's climate. While evidence from ancient ice and deep-ocean sediments illustrates natural variability within the climate system over geological time, the majority of the scientific community thinks that the current acceleration of a warming trend has been driven by the anthropogenic addition of carbon dioxide and other greenhouse gases into the atmosphere since the Industrial Revolution.[15]. Temperature readings reveal that the global mean surface temperature has increased by 0.6°C during the 20th Century.[16] Even a single degree change in temperature could have severe impacts on the Earth and its ecosystems. The sea level has risen by between 10cm to 20cm in the 20th Century due the melting of glacier and polar ice, as well as the thermal expansion of ocean water. Due the inverse nature of sea-ice and temperature, sea-ice thickness can be used as an indicator of warming. The IPCC reported that the thickness of sea-ice in the Arctic has declined by 42% since it was observed in 1950s.[17] Melting Arctic sea ice may also eventually lead to global changes in the ocean's thermohaline circulation, which is driven by differences in temperature and salinity.[18]

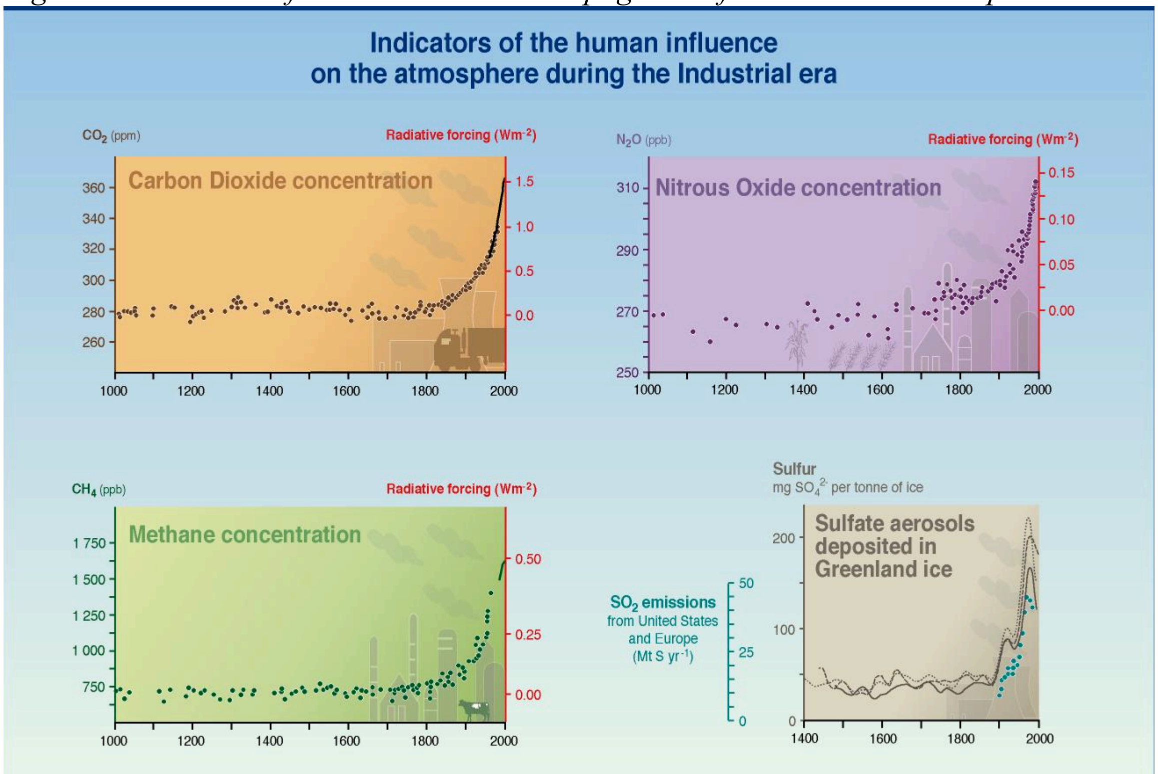
2.2.3. Anthropogenic Influences on the Climate

Energy use, especially from fossil-fuel combustion, accounts for more than two-thirds of anthropogenic greenhouse gas emissions.[19] The use of fossil fuels produces various by-products including carbon dioxide, carbon monoxide, nitrous oxides, and other hydrocarbons. The extraction, processing, transporting, distributing, and burning of fossil fuels all contribute to significant emissions of CO_2. During the period of intense industrialization from 1860 to the present, an estimated 13,000 exajoules of fossil fuel were burned, releasing 290 gigatons of carbon into the atmosphere. Along with land-use changes (e.g. deforestation), fossil fuels have caused atmospheric concentrations of CO_2 to rise by 30%.[20] The average global growth in CO_2 emissions from energy use alone between 1971-1998 was 1.9% per year, and the scenarios modeled by the IPCC foresee cumulative release ranging from approximately 1,000 to 2,100 gigatons of carbon if there are no measures in place to control greenhouse gas emissions.[21]

The key drivers of energy use include population growth, urbanization, total Gross Domestic Product, income, and the energy intensity of equipment and vehicles, among others.[22] These drivers are in turn influenced by changes in consumer preferences, energy and technology costs, settlement and infrastructure patterns, technical progress, and overall economic conditions.[23] The direct effects of land use and land-use change and the response of terrestrial ecosystems to CO_2 fertilization, nutrient deposition, climatic variation, and disturbance (e.g. fires and major droughts) may exacerbate the adverse effects of anthropogenic CO_2 emissions.[24] Due to the limited information on forest and agricultural land-management practices, global estimates of CO_2 emissions from land-use change tend to be based entirely on net deforestation-afforestation values. Moreover, these net values are generally based on average figures for carbon storage per hectare of forests.[25] Notwithstanding the limited uncertainties, anthropogenic greenhouse gases are thought to have a positive radiative forcing effect.[26]

While naturally occurring concentrations of greenhouse gases are necessary to maintain Earth's present climate, it is widely accepted that human activities have accelerated the accumulation of such gases since the pre-industrial era (Figure 1 shows the recent increase in concentration of greenhouse gases).[27] In effect, the greater concentration of these gases creates an enhanced greenhouse effect by absorbing more infrared radiation from the Earth's surface, thereby increasing the mean global surface temperatures.[28]

Figure 1: Indicators of Industrial Era Anthropogenic Influence on the Atmosphere.



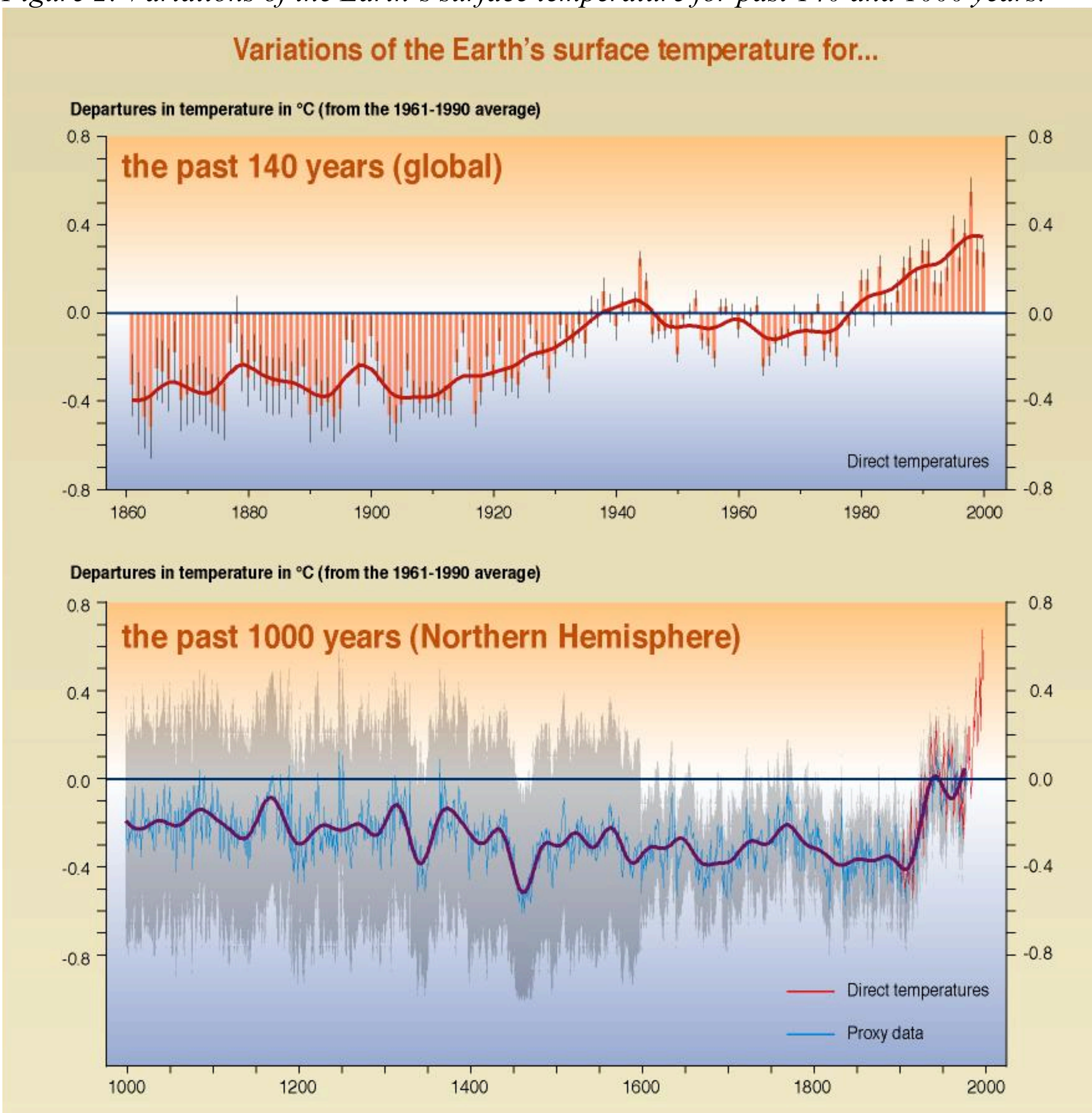
Source: http://www.ipcc.ch/present/graphics/2001syr/small/02.01.jpg

2.2.4. Uncertainty and Climate Science: Models

Although there is a great deal of consensus about the thesis of human-induced climate change, significant questions remain concerning the historic rate of warming, the extent to which the Earth will continue to warm and how best to mitigate for climate change. Scientists have relatively reliable data for global temperatures since the middle of the 19th Century (see Figure 2), but for the years prior to the establishment of regular weather observation stations scientists must rely on proxy data obtained from tree rings, marine core sediments, and pollen, which can only indirectly measure temperature and are subject to greater variability.

Climate modeling is a vital precursor to predicting how climate will behave in the future. However, modeling the climate is a difficult and complex process. One needs to consider not only a number of different extrinsic factors, such as astronomical, meteorological, geological, and biological effects on climate, but also intrinsic factors such as cloud cover, winds and air circulation patterns, volcanic activity, dust, soot, and aerosols, the oceans, sea ice, and glaciers, whose effects are extremely difficult to accurately quantify. These factors all interact with each to form a tremendously complicated system that is virtually impossible to replicate in a controlled environment. The accuracy of climate models has been improved over the past few decades but even the most sophisticated models are still limited in their ability to account for all variables. Two examples of poorly understood variables in the climate system are the roles played by aerosols and the impacts of land cover and land use change.

Figure 2: Variations of the Earth's surface temperature for past 140 and 1000 years.



Source: http://www.ipcc.ch/present/graphics/2001syr/small/05.16.jpghttp://www.ipcc.ch/present/graphics/2001syr/small/05.16.jpg

On the basis of past estimates of climatic variability, aerosols may have an overall cooling effect on climate, which could significantly impact the overall warming effects of the greenhouse effect.[29] Even though the source and distribution of aerosols are regional in scale their effects are thought to be hemispheric or even global. Three types of aerosols have important but poorly understood impacts on the Earth's climate: black carbon (a by-product of incomplete combustion of fossil fuels and biomass), carbon-bearing compounds associated with particulates (that is carbonaceous aerosols) and organic aerosols.[30] Black carbon has a global residence time of about one week which is considerably shorter than the lifetime of most greenhouse gases[31]. For this reason the spatial distribution of black carbon aerosol varies greatly and is most concentrated around its source. Black carbon aerosols absorb sunlight and for this reason they can cause local cooling of the surface but contribute to the warming of the atmosphere.[32]. Carbonaceous aerosols are caused by an increase in the burning of fossil fuels and biomass for land clearing, but lack of knowledge of the regional sources and composition of carbonaceous aerosols globally makes it difficult to project their impacts on the climate.[33] Finally, the concentrations of organic carbon aerosols and mineral dust, which are produced by both natural vegetation and fossil-fuel and biomass burning, will probably increase with human land-use activities but the extent is not clear.[34]

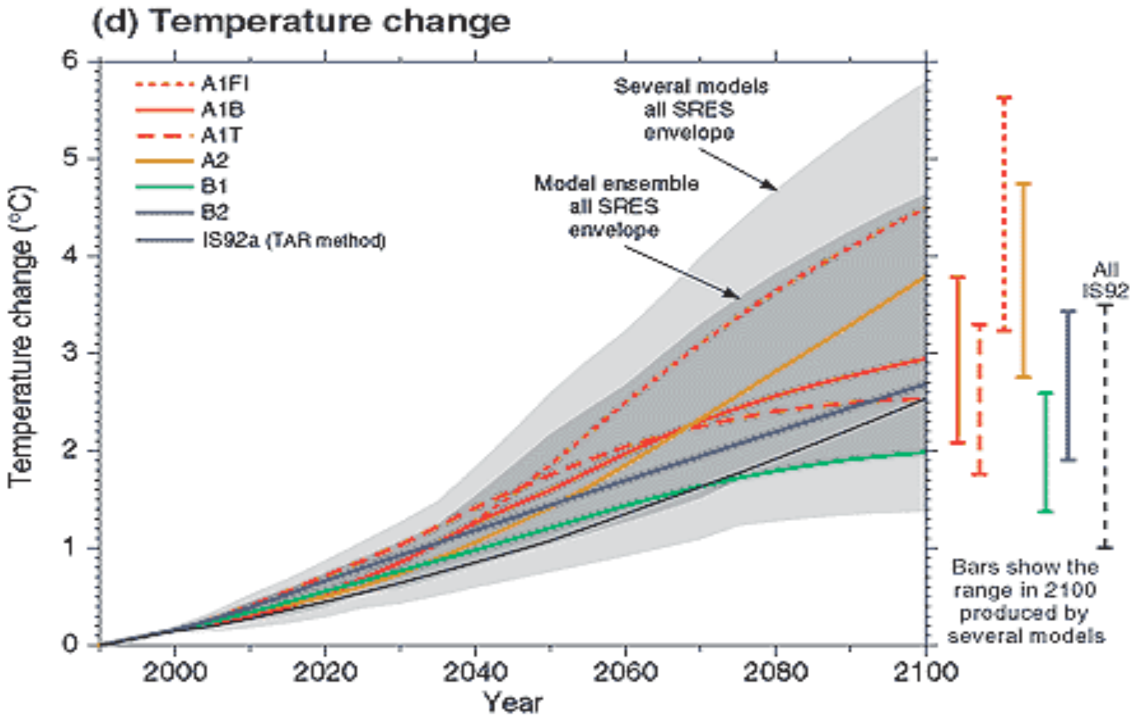
Another example of a variable whose effect is uncertain is land use and land use changes. Deforestation, for instance, can cause substantial regional climate forcing. Forests tend to conceal underlying snow, which would otherwise reflect the sun's heat back into space. Removing the forest cover could make the Earth's surface more reflective and thereby create a cooling effect.[35]. On the other hand, deforestation leads to the release of huge amounts of greenhouse gases.

Climate models attempt to deal with these levels of uncertainties in different ways, for instance by running a range of models to predict likely future trends.[36] The IPCC Special Report on Emission Scenarios is a synthesis of a range of models that predict how anthropogenic emissions of greenhouse gases could increase over the next 100 years (see Figure 3). The IPCC's Second and Third Assessment Reports contain a range of models that predict how the climate could develop in the future. These models all show a warming planet within a range of predictions from 1.4°C to 5.8°C by the end of the 21st Century.[37]

2.3. The Potential Impacts of Climate Change

Climate change models predict severe impacts on both the ecological and socio-economical spheres. The projected changes in the frequency, intensity, and duration of extreme climatic events may lead to increased risks of floods and droughts over many regions.[38] While beneficial effects can be identified for some regions as a result of moderate amounts of climate change, these are expected to diminish as the magnitude of climate change increases. For example, cereal crop yield models for some temperate regions indicate a potential increase with small increases in annual mean temperatures, and therefore, reduced frost damage. However, an increase in temperature beyond the respective threshold for varying crops can affect key development stages (e.g. spikelet sterility in rice, loss of pollen viability in maize, tubers' development in potatoes) and thus hinder the crop yields. Conversely, in most tropical and subtropical regions, potential yields are expected to decrease for most projected increases in temperature. Impacts may be especially devastating in dry land and rain-fed systems where a large decrease in rainfall is also expected. When considered by region, adverse effects are projected to be felt in much of the world.

Figure 3: Temperature change projected from the year 1990 to 2100.



Source: http://www.ipcc.ch/present/graphics/2001wg1/small/01.33.jpg

The occurrence and severity of El Nino-Southern Oscillation (ENSO) events has been a significant indicator of 20th century changes in the Earth's atmosphere, climate, and biophysical system.[39] They have become more frequent, persistent, and intense during the last 20 to 30 years compared to the previous 100 years.[40] El Nino and La Nina events have large impacts on regional weather and climate, inducing intense droughts and floods. These large climate-induced changes may have adverse impacts on the socio-economic systems. For instance, an increase in the frequency and intensity of El Nino events may lead to decrease in agricultural and rangeland productivity in drought and flood-prone regions, as well as decreased hydroelectric-power potential in drought-prone regions.[41]

2.3.1. Ecological impacts

Climate change could add to the multitude of existing anthropogenic pressures on biodiversity, including habitat loss, degradation, and fragmentation, although it is not certain to what extent climate change may enhance or inhibit these pressures.[42] Ecosystem productivity, biodiversity, and function will be threatened by the risk of abrupt and non-linear ecological changes, such as: fires, droughts, pest infestations, invasion of exotic species, storms, and coral bleaching events that are associated with climate change. As these stresses on ecosystems rise, there is an increasing threat of substantial damage to or complete loss of some unique systems as well as vulnerable species suffering from an increasing risk of extinction. There is evidence that up to a quarter of the world's coral reefs have disappeared in the last few decades as a result of rising sea-surface temperatures.

Changes in disturbance regimes and shifts in the location of suitable climatically defined habitats are also expected. It is likely that future changes in vegetation driven by climate change will profoundly alter regional ecosystems. For example, it has been shown that climate change can alter plant species composition at Toolik Lake Field Station in the Alaskan arctic.[43] One of the major effects of warming on the predominantly tussock tundra is an increase in the availability of nitrogen to plants by the acceleration of its release from decaying organic matter. The abundance of nitrogen leads to an increase in the dominance of the four plant species that were initially most abundant and a decrease in the least abundant but vital forbs and lichens. Such lichens are critical to the lactation and over-winter nutrition of the Porcupine caribou. These caribou herds are, in turn, greatly important to the lives, tradition, and culture of Alaska's native peoples, the Gwitch'in. This is just one example of how climate change could have varied and profound impacts to ecological as well as social systems.

2.3.2. Social and economic impacts

The majority of scientific literature shows that human settlements will be affected by climate change in one of three major ways. Populations may be directly affected through extreme weather, changes in health status, or migration. The problems are somewhat different in the largest (over one million inhabitants) and smaller population centers. The economic sectors that support the settlement are also affected because of changes in resource productivity or changes in market demand for the goods and services produced there. Finally, some aspects of physical infrastructure (including energy transmission and distribution systems), buildings, urban services (including transportation systems), and specific industries (such as agroindustry, tourism, and construction) may be directly affected.[44]

Both indirect and direct affects to human health can be expected as a result of climate change. Direct threats include an increase in heat stress and loss of life in severe floods, storms, and landslides. An increase in the range of disease vectors (e.g. mosquitoes), water-born pathogens, water quality, air quality, food quality, and availability will indirectly affect human health. Despite a general global increase in the efficiency of water usage, the demand for water is expected to increase due to population growth and economic development.[45] Water shortages, for example, may be exacerbated in most water-scarce areas of the world by the reduced availability and degradation of water quality.[46]

These health impacts are largely determined by the local government conditions and socio-economic circumstances. The range of social, institutional, technological, and behavioral adaptations that are available in reducing the full range of threats to health due to the onset of climate change are also important aspects of the problem.[47] Wealthy countries have the financial, institutional, and technological resources to predict and adapt to such impacts. Therefore, the impacts of climate change will fall disproportionately upon developing countries and the poor persons within all countries, and thereby exacerbate inequities in health status and access to adequate food, clean water, among other resources.

Adaptation has the potential to reduce the aforementioned adverse effects of climate change and can often produce immediate ancillary benefits, but will not prevent all damages.[48] Greater and more rapid climate change would pose greater challenges for adaptation and greater risks of damages on the ecological and socio-economic sectors than would lesser and slower change.

Predicting the impact of climate change on the global ecological and socio-economic sectors may prove challenging when considering the cumulative effects of the exponentially increasing human growth and the consequential land uses changes and natural habitat loss. But, it is clear that the greater the magnitude and rate of climate change, the more severe potential adverse impacts will be.

Despite the areas of uncertainty regarding climate science and the potential impacts of climate change, the international community has largely recognized that the potential benefits of acting to mitigate climate change now greatly outweighs the possibility that the science supporting climate change is not accurate. The foremost international attempt to address climate change, the United Nations Framework Convention on Climate Change, recognizes as one it its guiding principles that climate change is a problem so potentially serious that lack of scientific certainty is no excuse for postponing action.[49] It is to the more political question of action that we now turn.

3. The International Policy Response to Climate Change

International attempts to improve governance of the Earth's environment have gathered pace since the early 1970s. 1972 was a year of great activity for the environment, with the publication of a seminal work, *The Limits to Growth*, and the convening of the UN-sponsored World Conference on the Human Environment in Stockholm, Sweden. *The Limits to Growth* was an academic study on resource use that was sponsored by the Club of Rome, an association of academics and policymakers. It was an early attempt to apply a "systems dynamics" approach to study human interaction with the natural environment, using computer models to project likely outcomes for the world economy. The study, which sold 12 million copies in 37 languages, predicted that human consumption of natural resources at 1970s rates was unsustainable and, without intervention, the Earth would simply run out of nonrenewable resources within the coming decades, leading to an abrupt economic collapse.[50] The study has been criticized for an over-simple view of resource consumption that did not take into account increased productivity through technological development.[51] However, the study's basic thesis – that exponential growth is unsustainable in a limited system – was highly influential and remains valid today.

Climate change was not on the agenda in 1972, but decision-makers were increasingly attuned to the potential problems of human's interaction with the Earth that were identified by *The Limits to Growth*. The Stockholm Conference set in motion a process of regular meetings and raised awareness about the need for international cooperation to address those problems. The United Nations Environment Program was established to coordinate international efforts to protect the environment. As a follow-up to the Stockholm Conference the World Commission on Environment and Development (known as the Brundtland Commission after its chairperson, Gro Harlem Brundtland) was established and, in 1987, presented a seminal report to the United Nations, *Our Common Future*. This report included the definition of "sustainable development" that remains the most widely used today: "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs."[52] The report recommended a global conference on development and environment. This conference took place in Rio de Janeiro, Brazil, in June 1992 and was attended by more than 100 heads of state representing 179 national governments, as well as thousands of representatives of the media and non-governmental organizations. By 1992 the issue of climate change had been steadily rising in scientific and public awareness and was one of the main subjects for discussion at the summit.

The summit adopted a number of declarations and treaties, including the Rio Declaration on Environment and Development; Agenda 21, an international plan of action to achieve a more sustainable pattern of development in the 21st Century; and the United Nations Framework Convention on Climate Change (UNFCCC). The UNFCC came into force in 1995 and has been ratified by 188 countries. The treaty did not set binding limits to the emission of greenhouse gas emissions from anthropogenic sources; rather, it established an international consensus on the problem of climate change and set up the international architecture for future decisions to help countries meet the UNFCCC's ultimate goal. This goal is to achieve "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system."[53]

3.1. The Negotiation of the Kyoto Protocol

The UNFCCC's primary achievements were to establish an international consensus on the problem of climate change and to lay down certain principles for action. One of these principles was that the problem of global climate change was so potentially serious that mankind could not afford to wait until scientific certainty to start mitigating the effect of climate change by reducing greenhouse gas emissions. Another was the principle that developed countries should take the lead in combating climate change and its negative effects, since the problem was historically caused by emissions from developed countries. A third principle states that countries should promote sustainable development.[54] In Berlin, at the first Conference of the Parties to the UNFCCC in 1995, the signatory countries agreed to work towards a Protocol to the UNFCCC that would require more assertive action to combat climate change, taking into account these and other principles.[55]

Following two years of intensive negotiations, the Third Conference of the Parties (known as COP 3) was held in Kyoto, Japan, in December 1997. The Kyoto Protocol, which was adopted at the conference, was a landmark treaty because it set the first-ever binding limits on the emission of greenhouse gases, requiring industrialized countries to reduce anthropogenic emissions of six greenhouse gases by an average of 5 percent below 1990 levels by 2010.[56] This achievement was due in part to three important decisions. First, industrialized countries agreed to take the lead in combating climate change by reducing their anthropogenic greenhouse gas emissions. Second, industrialized countries were allowed to realize these emission reductions at the lowest price, through "flexible mechanisms" that utilize the power of the market. Third, developing countries agreed that developed countries could take advantage of low-cost emission-reduction opportunities in developing countries while at the same time bringing investment and sustainable development to those countries. This third principle was realized in the Clean Development Mechanism.

3.1.1. Legally Binding Commitments to Reduce Greenhouse Gases

The Kyoto Protocol is a diverse document of 28 articles that cover issues from education to energy efficiency, fiscal policy, tradable emissions permits and carbon sinks. Several sections in particular define the quantity and methods for reducing greenhouse gases. Article 2 stated that developed countries (called Annex I countries) should take the lead in reducing greenhouse gas emissions, since historically these countries are responsible for most emissions. Article 3 set an average targets for Annex I countries to reduce their greenhouse gas emissions by an average of 5 percent below 1990 levels by 2010.[57] Additional articles defined the flexible mechanisms, which allowed Annex I countries to use market-based mechanisms to meet their targets.[58]

3.1.2. The Flexible Mechanism

During the negotiations some countries emphasized that alternatives to reducing emissions domestically were necessary for many countries to reach their respective targets. The Kyoto Protocol established three key instruments, known as "flexible mechanisms", that allow countries to meet their emission-reduction targets partly through the use of market-based mechanisms. The purpose of the flexible mechanisms is to lower the overall cost of reducing emissions, for instance by allowing countries with difficult targets to take advantage of cost-effective emission-reduction opportunities in other countries. Theoretically, the overall effect on the atmosphere should be the same if a country reduces greenhouse gases at home or in another country because greenhouse gases accumulate in the atmosphere regardless of their point of origin.[59]

The three flexible mechanisms are Emissions Trading (IET, Article 17), Joint Implementation (JI, Article 6) and the Clean Development Mechanism (CDM, Article 12).IET allows any country that is below its target to trade its surplus quota with countries that exceed their target.[60] JI allows Annex I countries to meet their targets partially by carrying out projects in other Annex I countries that lead to emission reductions there; this mechanism is particularly aimed toward the economies in transition from communism. In most cases, a developed country will fund a project in an Annex I economy in transition, such as Russia or Romania.[61] The CDM, like JI, is a project-based mechanism but activities must take place in a developing country. Box 1 outlines how these different mechanisms will interact.

Trading Units under the Kyoto Protocol

The Kyoto Protocol establishes a range of credits and units to measure carbon, including Assigned Amount Units (AAUs, the GHG amounts that Annex I Parties are allowed to emit, based on allocations determined at COP 3 in Kyoto), Emission Reduction Units (ERUs, which are generated by JI projects), and Certified Emission Reduction units (CERs, which are generated by CDM projects). These units represent alternative ways of describing allocations of greenhouse gas emission rights or reductions in greenhouse gases. The three units analyzed describe GHGs in terms of tons of CO_2 equivalent. For example, one CER is equivalent to one ton of CO_2 equivalent.

IET provides the framework in which these different units can be exchanged. Unlike the CDM and JI, IET is not a project-based instrument but rather an accounting mechanism. IET foresees the establishment of a "carbon market" where various units defined by the Kyoto Protocol will be exchanged. To this end, countries must prepare national registries of sources and sinks for greenhouse gases. The Kyoto Protocol Secretariat's own registry will verify all transactions of ERUs, CERs, AAUs and RMUs (Removal Units), including their issuance, transfer and acquisition between registries, cancellation and retirement.[62]

Countries may authorize private companies to engage in emissions trading on their behalf. Signs already point to emergence of an international market in Kyoto Protocol–based permits that resembles standard commodity markets, complete with sophisticated market devices like futures contracts and arbitrage. In fact, carbon markets have recently appeared in trading centers such as London and Amsterdam.[63] The European Union's emissions-trading system, which allows for the transfer of carbon units between EU countries, is now open to CERs from CDM projects. This provides a large potential market for credits from CDM projects and, subsequently, a large potential demand from European investors for CDM projects.

3.2. The Clean Development Mechanism

The CDM was negotiated as a compromise between the different interests of developed and developing countries.[64] For developed countries, the CDM offered the chance to reduce emissions at low cost around the world. Developing countries wanted to benefit from the investment and transfer of clean technology that could come with these projects. Developing countries also demanded some compensation for the detrimental effects of climate change. These interests can contradict each other – the cheapest project (for a developed country) might not bring the most benefits to a developing country. To address these concerns, the Kyoto Protocol set the following three criteria for the CDM:

- Projects must results in "real, measurable and long-term benefits related to the mitigation of climate change"
- Projects must result in "reductions in emissions that are additional to any that would occur in the absence of certified project activity"
- Projects must assist developing countries "in achieving sustainable development and contributing to the ultimate objective of the Convention [i.e. the reduction of atmospheric concentrations of greenhouse gases to safe levels]"[65]

Beyond setting these broad rules the Kyoto Protocol did not define how the CDM would work in practice; this was left for subsequent Conferences of the Parties, particularly at Marrakech (Morocco) in 2001. One controversial topic was determining what sort of projects should be allowed under the CDM. Many project types could theoretically reduce greenhouse gases, either by reducing emissions greenhouse gases at their sources or by enhancing the removal of greenhouse gases from the atmosphere via a sink. Not all potential projects would meet the three criteria outlined above, however.[66] For instance, the Marrakech Accords decided that nuclear power, although it produces few greenhouse gas emissions, should not be allowed under the CDM because it did not contribute to sustainable development. There was also much disagreement about the possible role that forestry projects could play. Forestry projects are controversial due to uncertainty concerning the ability of trees to absorb carbon dioxide and fears that these projects, if badly designed or poorly monitored, could cause significant social and environmental harm.[67] The Marrakech Accords allowed two kinds of forestry projects to take place under the CDM: reforestation, defined as "Replanting of forests on land that was previously forested but subsequently converted to other use", and afforestation, or "Planting of new forests on lands that historically have not contained forests".[68]

The Marrakech Accords established some other important rules for the CDM. Recognizing that the laws of economics would tend to favor large projects over smaller ones (which could be expected to bring greater relative social benefits), the Marrakech Accords established a fast-track approval process for small projects (defined as projects that reduce and emit less than 15 kilotons of CO_2 equivalent annually) to make them more competitive.[69] The Accords also set a limit on the extent to which countries can use the CDM to meet their targets, requiring that domestic emission reductions be a "significant element" of each Annex I country's compliance with the Kyoto Protocol.[70] For the first commitment period (2008-2012), CDM projects can only meet up to 5% of each country's emission-reduction targets.[71] Finally, the Marrakech Accords set up a management body for the CDM known as the CDM Executive Board. This body is responsible for the assessment and oversight of all aspects of projects approved under the CDM. To date, 30 proposed CDM projects have been submitted to the Executive Board for consideration and are currently in the validation stage (which includes a provision for public comment).[72] Proposed projects include solar energy production, landfill gas recovery, biomass-based power, and numerous agricultural efficiency initiatives.[73]

To date there have been no proposals for forestry projects, although a number of pilot projects have begun under, for instance, the World Bank's Prototype Carbon Fund. This is because negotiations are continuing on the final rules for afforestation and reforestation projects. The CDM Executive Board has commissioned a specialized working group – the Afforestation and Reforestation Working Group – to compile a set of baseline and monitoring methodologies for the assessment of forestry projects under the CDM.[74] This Working Group has proposed new methodologies that await official adoption. These proposed methodologies contain a complex array of equations and criteria that outline what variables should be accounted for in any CDM forestry project.[75] Once adopted, these methodologies will provide the Executive Board with guidelines to analyze how forestry projects may contribute to carbon mitigation strategies.

4. The CDM in Practice

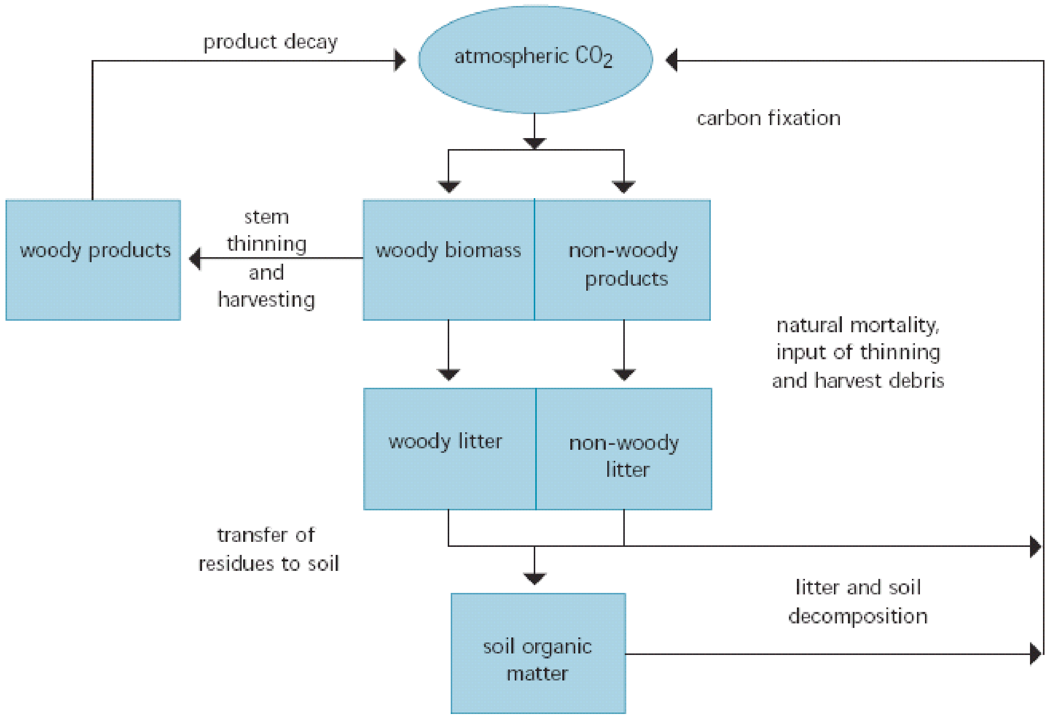
Forestry projects under the CDM would harness a natural process – the carbon cycle – to reduce the concentrations of CO_2 in the atmosphere. The carbon cycle is a major biogeochemical cycle that regulates CO_2 and other greenhouse gases (like methane). It involves exchange of carbon between the atmosphere, soils, plants, and oceans. It provides for natural cycling of carbon through various pools, or reservoirs of carbon, and drives the primary processes for life on Earth: photosynthesis and respiration. The carbon cycle has historically been in dynamic equilibrium, returning as much CO_2 to the atmosphere as is sequestered. Since the Industrial Revolution, however, humans have disturbed this natural cycle through the combustion of fossil fuels and land use changes such as deforestation for agricultural use. The effect has been both the release of additional carbon into the atmosphere and the loss of major pools of carbon – such as forests – resulting in increased concentrations of CO_2 in the atmosphere.[76] As a mitigation effort forestry projects under the CDM would capture, or sequester, CO_2 from the atmosphere into carbon pools, thereby reducing the concentrations of CO_2 in the atmosphere. This section explains the carbon cycle and the exchange of carbon in the terrestrial ecosystems.

4.1. Carbon Sinks and Photosynthesis

Photosynthesis is the primary activity that drives the carbon cycle and thus the carbon sequestration in ecosystems. Photosynthesis, also known as primary production, occurs when chlorophyll-containing plants in the presence of sunlight use water and CO_2 (from the atmosphere) to produce carbohydrates. It is by this process that CO_2 is captured from the atmosphere and sequestered, or incorporated into green plants. The amount of CO_2 that is fixed (i.e. converted from CO_2 to carbohydrates during photosynthesis) is called gross primary production and is estimated at 120 gigatons of carbon per year. Simultaneously, however, plants respire and release CO_2. Terrestrial ecosystems sequester CO_2 because primary production is greater than respiration and other oxidative processes like decomposition and combustion.[77] This net primary production is the balance between photosynthetic and respiratory activity by higher plants and is a measure of the annual plant growth. The total amount of CO_2 in leaf water that is absorbed by the plants is 270 gigatons of carbon per year, which is approximately a third of all the CO_2 in the atmosphere.[78] Combustion and decomposition can further release CO_2 into the atmosphere. The net carbon uptake by an ecosystem is thus the balance between the net primary productivity (photosynthetic activity minus the respiratory activity of plants) and the decomposition in an undisturbed environment. This is called net ecosystem production. Due to deforestation and other land use changes, however, terrestrial ecosystems release carbon from plants and soils and can become a net source of CO_2.[79]

Eighty percent of the carbon exchange between the land and the atmosphere occur in the forests.[80] Carbon fixed during photosynthesis is stored in leaves, roots, needles and bark.[81] Some of the carbon is transferred as dead foliage and twigs and forms the litter layer. The litter layer decomposes and the carbon is transferred as organic matter to the soil. Bacterial decomposition in the soil restores the carbon to the atmosphere. Figure 4 illustrates the exchange of carbon between the various carbon reservoirs.

Figure 4: Carbon pools and fluxes in a plantation forest ecosystem



Source: Cannell, M.G.R. 1995. *Forests and the Global Carbon Cycle in the Past, Present and Future.* Research Report 2, European Forest Institute, Joensuu.

Currently the terrestrial ecosystem acts as a global sink for carbon in spite of the large amounts of fossil fuel combustion and land use changes. About half of the dry weight of a tree is carbon.[82] Carbon uptake occurs both in vegetation and in soils. Figure 5 shows that tropical forests are the biggest carbon stocks for vegetation but the boreal forests are the biggest for soils. Also, the amount of carbon in the pools is much higher in the case of soils as compared to vegetation.[83] Soil carbon represents the largest carbon pool of terrestrial ecosystems, and has been estimated to have one of the largest potentials to sequester carbon worldwide.[84]

Figure 5: Global carbon stocks in vegetation and soil carbon pools down to a depth of 1

Biome	**Area (10^9 ha)**	**Global Carbon Stocks (Gt C)**		
		Vegetation	*Soil*	*Total*
Tropical forests	1.76	212	216	428
Temperate forests	1.04	59	100	159
Boreal forests	1.37	88	471	559
Tropical savannas	2.25	66	264	330
Temperate grasslands	1.25	9	295	304
Deserts and semideserts	4.55	8	191	199
Tundra	0.95	6	121	127
Wetlands	0.35	15	225	240
Croplands	1.60	3	128	131
Total	15.12	466	2 011	2 477

Source: IPCC (2000); Summary for Policy makers: Land Use Change Land Use and Forestry. A Special Report

4.2. Measuring the Success of Forestry Projects under the CDM

The Kyoto Protocol requires that CDM projects lead to real, additional, and long-term emission reductions and contribute to sustainable development. Measuring the success of forestry projects under the CDM necessarily involves measuring the extent to which the projects address these criteria. At the Tenth Conference of the Parties, in Buenos Aires in December 2004, agreement was reached on many definitions of land use, land-use change and forestry issues mentioned by the Kyoto Protocol. These definitions relate directly to the applicability of afforestation and reforestation projects.[85] For instance, a "forest" under the CDM was defined according to minimum size (0.1-1 hectare), minimum crown cover (10-30 percent) and minimum height of trees (2-5 meters).[86] Measuring the sequestration that occurs in CDM forestry projects will be facilitated by such definitions. Measuring the extent to which the CDM meets the requirement of sustainable development is more complex and controversial, however.

4.2.1. Carbon Stock Method

A proposed methodology for assessment and monitoring of CDM forestry projects known as the carbon stock method addresses the extent to which a project leads to additional, real and long-term greenhouse gas reductions. The carbon stock method was set forth in the IPCC Good Practice Guidelines for Land-Use, Land-Use Change and Forestry projects that was presented at the Eighth Conference of the Parties, at New Delhi, India, in 2002.[87] Under the proposed methodology, a series of criteria and equations would be utilized to determine carbon balances for both a baseline and a project scenario. The annual carbon stock changes are taken into account for the main carbon pools: above-ground biomass, below-ground biomass, litter and soil organic carbon, all of which are detailed below. This methodology allows determination of the "additionality" of a particular project by taking into account the "with" and "without" project scenarios, along with any emissions associated with project implementation.[88] The resulting net change in anthropogenic emissions is measured in carbon dioxide equivalents, representing the sum of "verifiable post project changes in carbon stocks within the reservoirs" minus the baseline minus leakage, in the form of carbon release from pools outside of the project area that result from management activities inside the project area. The carbon sequestered represents a "liquid contribution" of the CDM forestry project to the increase of carbon dioxide sequestration within project boundaries.[89]

4.2.2. Establishing the Baseline

Establishment of the baseline condition occurs at the start of the project and involves determination of the most likely land use for the project area in a "without project" or "business-as-usual" scenario. The baseline approach is defined in the "Proposed New Methodology for Afforestation and Reforestation Project Activities: Baseline" as an account of "changes on carbon stocks in the pools within the project boundary from the most likely land use at the time the project starts".[90] The determination of carbon stock changes associated with the most likely land use in the absence of the project is made by identifying and quantifying several key factors. Direct human impacts on the components of the ecosystem, such as land-use conversion, anthropogenic fires, or agricultural conversion, must be projected. Natural ecosystem dynamics of the project area, including the natural succession of species, and indirect human impacts like occurrence of invasive species or climate change, must also be predicted. These factors are incorporated into the baseline by utilizing economic modeling, policy and local practice research, available data on ecosystem variables, and on-site data collection. A model based on these variables is developed for each vegetation stratum.[91] These baseline model components are then compared against actual carbon sequestration under the "with-project" scenario, determined by carbon monitoring within the project area.

4.2.3. Project Monitoring

Monitoring the carbon sequestered in a CDM forestry project area involves both modeling and data collection via remote sensing and on-site sampling and measurement. Remote sensing describes different methods that involve measuring from a distance, including aerial photography, in order to develop maps for afforested and reforested areas. This spatial data can be analyzed using Geographic Information Systems to monitor changes in forest growth and cover.[92] On-site data collection involves techniques used for forest inventories, soil sampling, and ecological surveys. Only those carbon pools measured and monitored may be claimed for carbon credits.[93] Vegetation is divided into strata in order to ensure that carbon pools are being measured for geographically and ecologically homogeneous areas. Experimental plots are established within these stratified areas in which the actual sampling of various carbon pools will occur. The number of experimental plots designated is based on statistical analysis and must take into account both the typology of the vegetation and the different types of soil. These plots must be determined by the fifth year of the project. Random plots of four by twenty-five meters are delineated, but lots are expanded to five by one hundred meters if trees are found within the plot with diameters exceeding 30 centimeters.[94]

Carbon pools include above-ground biomass (trees and herbaceous growth), below-ground biomass, litter and soil. Biomass measurement procedures include diameter at breast height for trees and dry weight for herbaceous growth. The diameter at breast height measurement, taken at 1.3 meters from the ground, is converted to biomass and then to a carbon estimate (carbon = 50% of biomass) using standard biomass regression equations.[95] In order to sample herbaceous biomass, two sub-plots measuring one meter by one meter are delineated at random within the larger experimental plots. Within these smaller quadrants, all biomass at soil level is cut, and fresh weight per square meter is measured. Litter – leaves, branches, twigs and other accumulating dead or decaying material on the forest floor – is sampled in still smaller sub-plots (0.5 meters by 0.5 meters) within the one square meter quadrants. Samples are also brought back to the lab to obtain a dry-weight measurement. Standing and fallen dead trees are measured in the same way as live trees, though the biomass of fallen dead trees also takes into account the length of the tree within the experimental plot.[96] Below-ground biomass is estimated based on an accepted ratio of above-ground biomass to below-ground biomass. This is done because methods for below-ground measurement are complicated and have not yet been standardized.[97] The standard below-ground to above-ground biomass ratio, which exhibits little variation across latitudes and soil types, is listed in the IPCC guidelines as 0.26[98]. Soil cores are also to be taken within the experimental plots and analyzed using laboratory procedures such as loss on ignition, in order to determine carbon content. Most measurements are taken annually, though soil stock changes occur even slower than biomass changes, so soil samples are to be taken every 2 years. These are recommended to be soil cores taken to a depth of 30 cm. Project verification occurs on a 5 year cycle with results presented to the Executive Board at this time.[99]

The overall purpose of this carbon monitoring process is to convert carbon-stock changes into carbon credits to be sold on the market, using the Certified Emission Reduction (CER) unit. In order to carry out this conversion, the carbon stock is calculated as the mean carbon sequestered for all sample plots in the project area.[100] One ton of biomass carbon is equivalent to 3.67 ton of atmospheric CO_2, or 3.67 CER units.[101]

4.2.4. Measuring the Sustainability of CDM Forestry Project

Article 12 of the Kyoto Protocol states that CDM projects must help developing nations to realize sustainable development. To ensure this, the CDM project approval process includes an assessment of the ecological and socioeconomic impacts of each project. Several sets of criteria and indicators to assess these impacts have been developed, though no single set has yet been agreed upon to serve as the standard.[102] One example of a series of criteria and indicators to assess environmental integrity and social equity was developed in 2003 as part of a study conducted by the International Institute for Environment and Development.[103] Criteria for environmental integrity include a net increase in the amount of carbon sequestered; improvement in air, water, and soil quality; and maintenance of or increase in biodiversity. Assessing social equity takes into account a number of criteria, examples of which include net employment gain, quality of employment, financial commitment to social goals, and local participation. This degree of social inclusion of residents in the generation of carbon credits is a key issue in assessing the contribution of CDM forestry projects to local sustainable development.[104] More formalized options for the assessment of sustainable development at the project level include detailed environmental and socioeconomic assessments that could be adapted to CDM forestry projects.[105]

5. CDM Forestry Projects and the Problem of Uncertainty

The objective of forestry projects under the CDM is the reduction of carbon dioxide concentrations in the atmosphere through the cultivation of trees that sequester carbon in a way that promotes sustainable development. The IPCC's Special Report on Climate Change and Land Use, Land-Use Change, and Forestry states that successful forestry projects should be transparent, consistent, comparable, complete, accurate, verifiable, and efficient in recording and reporting methods in measuring the amount of change in carbon stocks.[106] Much of the controversy around forestry projects under the CDM center around whether such projects meet these requirements. Critics claim that trees are not permanent repositories of carbon, that it is difficult to measure how much carbon trees sequester, and that such projects do not reduce greenhouse gas concentrations because they lead to additional greenhouse gas emissions elsewhere. Many of the negotiations around the use of forestry projects under the Kyoto Protocol were attempts to reach consensus on how to account for such areas of uncertainties.

5.1. Uncertainties Relating to Carbon Sequestration

Forestry projects are included under the CDM because of the ability of green plants to sequester carbon from the atmosphere and incorporate it within their chemical composition. There are many variables that determine the capacity of trees to sequester carbon, giving rise to uncertainty about the effectiveness of forestry projects as mitigation efforts.

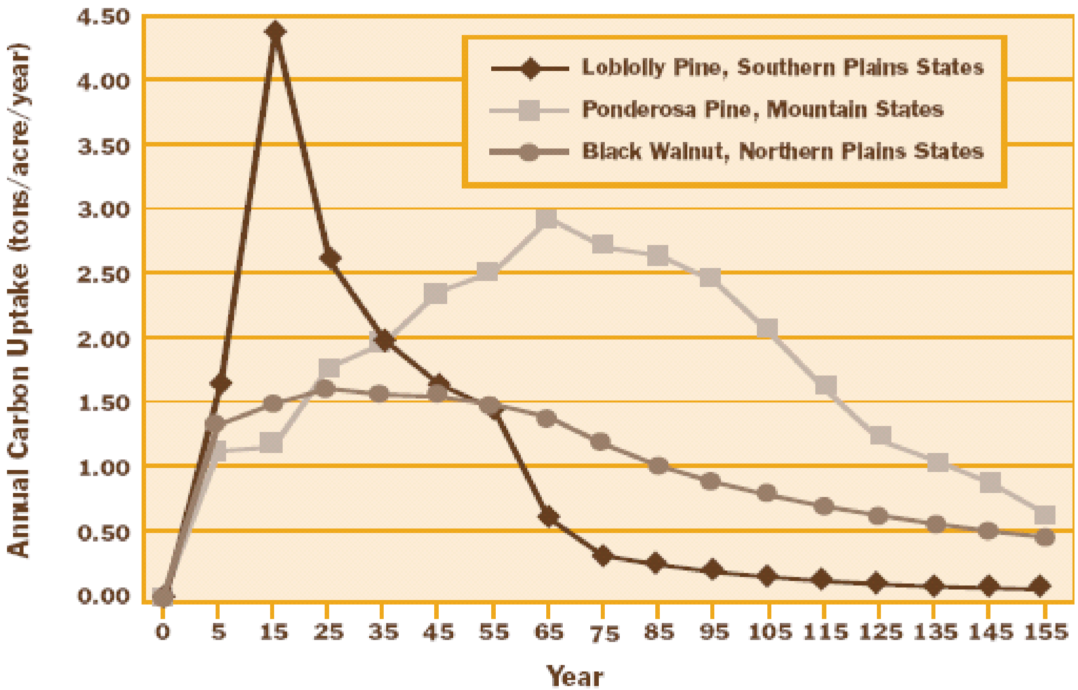
5.1.1. Tree Age

Growing plants have a higher rate of carbon sequestration than mature plants. This is because younger trees require additional carbon (created through photosynthesis) to grow and synthesize various parts of their structure. Younger, growing forests thus sequester large amounts of additional carbon proportional to the forest's growth in biomass. However, mature trees are a larger carbon pool and are able to store larger amounts of carbon than younger trees. Additionally, carbon sequestration capacity has been found to be higher in longer lived trees with high density wood as compared to short-lived, low density, fast-growing trees.[107] The old growth forest acts as a carbon reservoir even though it is not experiencing net growth.[108] Planting new forests trees is beneficial because growing forests have the highest rates of carbon sequestration whereas mature forests hold the largest carbon pools and as such should also be protected.

5.1.2. Tree Species

To make matters more complicated, the carbon sequestration rates also differ according to the species. As illustrated in Figure 6, loblolly pine has a high rate of sequestration within the first two decades which rapidly declines and becomes insignificant after 70 years. In contrast, ponderosa pine shows a steady uptake of carbon with a peak at 70 years. Thus the total carbon uptake might be higher in the case of ponderosa pine as compared to loblolly pine but the sequestration peaks much later than in the loblolly pine.[109] Another study examined the carbon sequestration rates in plantations under CDM forestry projects (figure 7).[110] While teak had the highest sequestration, palm oil was found to be a net source of carbon. This highlights the importance of the species planted in an afforestation or reforestation project.

F*igure 6: Carbon Sequestration Rates for three regions / species combination*



Source: Richards, Moulton and Birdsey (1993).

Figure 7: Carbon sequestration for four species in Brazil

Tree Species	Total Certified Emission Reduction (t C)
Rubber Plantation	220,622
Palm Oil Plantation	-117,057
Teak Plantation	399,382
Eucalyptus	36,514

Source: Adapted from Van Vliet et al. 2003

5.1.3. The Potential Effect of Climate Change

Another factor that controls sequestration of carbon in the ecosystems is the observed and predicted changes in the Earth's climate. As the temperature rises, the photosynthetic activity of the plants increases. CO_2 fertilization – the process by which increased CO_2 concentrations will enhance plant growth – could increase the carbon uptake from the atmosphere. The combined effect of increased temperatures and increased CO_2 concentrations means that carbon sequestration should increase proportionally, suggesting that climate change might be a self-regulating problem. However, it is more complicated than this. Along with photosynthesis, respiration within plants increases with rising temperatures. Moreover, the rate of photosynthesis levels off and may decrease after a certain temperature, which means that plants may begin to release more carbon into the atmosphere rather than capturing it if temperatures continue to increase. A study created three scenarios to assess the effect of climate change on the carbon sequestration capacity of terrestrial ecosystems.[111] The study found that an increase both in CO_2 concentrations and temperature would cause an increase in carbon sequestration in the higher latitudes and the tropics. However, this feedback system is uncertain and there is ambiguity around the point at which the carbon uptake due to CO_2 fertilization will level off or diminish.[112] Eventually these sinks could become sources due to limited nutrient availability, ecosystem degradation, and increased decomposition due to higher temperatures.[113]

5.1.4. Nutrients and Water

When adequate nutrients (especially nitrogen and phosphorous) are available in the soil and atmosphere, organic carbon is converted to new plant biomass. If these nutrients are limited, photosynthetic activity is reduced and as a result the carbon uptake decreases. Nutrient-rich soils are therefore essential for the growth of plants and for carbon uptake. Northern mid-latitude forests are large carbon sinks but shortages of nitrogen can limit carbon sequestration.[114] Another factor that could affect sequestration relates to the availability of water, an essential component of photosynthesis. Slow water infiltration, low water holding capacity and high salinity could limit plant growth and therefore sequestration.

5.2. Uncertainties Relating to Measuring Sequestration

There are many uncertainties in accounting for the actual carbon stock in the carbon pool. The amount of carbon stock in a forest is calculated by measuring the carbon sequestered, the carbon stored in biomass above and below the ground and the carbon found in the soil. The amount of carbon released is accounted for by measuring the carbon lost during the process of respiration, decomposition of dead decay matter and litter by bacteria in the soil, and carbon also lost by the leakage activities. Several uncertainties affect the accounting of carbon stock in the carbon pools when forestry projects are implemented. These include: *definitional errors* due to bias or inconsistencies resulting from the interpretation of the rules; *classification errors* causing the mis-classification of land; *estimation errors* due for instance to events such as the omission of errors in remote sensing; *identification errors*, which arise while defining the geographical boundaries of forest projects; and *sampling errors*, when samples obtained for a forestry project do not sufficiently represent the whole project.[115] One example is posed by satellite imagery, which is used to provide information on the total area, percentages of land-cover, and geographical boundaries of a forestry project. Remote sensing is used to identify lands and units of land of forestry projects. Uncertainty can arise if the satellite images are of inadequate resolution.[116] Errors can also occur if images are incorrectly dated and are incorrectly attributed to the wrong plot of land.[117]

In addition to uncertainties in default carbon emission and removal factors, missing activity data gives rise to further uncertainties. Determining retrospectively the inventory for the base year (usually 1990) may be difficult for cropland management, grazing land management and revegetation.[118] Where the net carbon emission and removals for the base year cannot be established using the default carbon emission and removal factors, they may be estimated by extrapolating a consistent time series. This requires accurate data keeping and logs on the land management history for twenty years.[119]

5.3. Uncertainties Relating to Measuring the Impact of Forestry Projects

Even if the amount of carbon sequestered by a forest can be accurately measured, there are significant uncertainties surrounding the effect on greenhouse gas emissions of CDM forestry projects outside the project boundaries and into the future. The CDM Working Group has proposed methodologies for accounting for these uncertainties.

5.3.1. Permanence

The use of forest projects depends on the assumption that trees sequester carbon dioxide and keep it for a significant period. The life spans of forests (except those planted for wood products) are measured in centuries: Research has demonstrated that tropical forests continue to sequester carbon dioxide throughout their life[120]. In contrast, the first commitment period for Annex I countries is 2010 (measured as an average over 2008-2012). It is difficult to predict with certainty that a forest's projected sequestrations will actually occur over the lifetime of the trees. Stored carbon could be released back to the atmosphere through natural forces like fire, disease, and hurricanes, or through human activities such as the non-enforcement of contracts, non-compliance with guarantees, expropriation, revocation of property rights, changes in policy, and market risks.[121]

5.3.2. Additionality

The Kyoto Protocol states under Article 12 that CDM projects must be additional compared to a business-as-usual scenario. This means that projects must lead to more greenhouse gas reductions than would have occurred without the project. One possible objection is that a forestry project would have happened anyway either without the CDM due to commercial or political reasons.[122]. Although there are methodologies to account for additionality, different forestry projects will pose different accounting factors. Some forestry projects would probably go ahead whether or not the CDM existed, such as industrial-scale exotic-tree plantations for pulpwood or saw-timber.[123].

5.3.3. Leakage

Leakage is the unanticipated increase in greenhouse-gas emissions that occur outside the boundaries of a project as a result of the activities conducted within the project boundary.[124] Experience with leakage to date has been restricted to a few projects due to a lack of data and limited time since project inception.[125] One controversial example is a pilot reforestation project taking place in Minas Gerais, Brazil, where reforestation may cause energy-intensive pig-iron industries to move to states with less environmental control. In addition, there is the possibility that landowners will be displaced, causing them to establish new pastures on presently forested land.[126] Quantifying leakage may be difficult in some cases.

6. Conclusion

Faced with the threat of climate change, humans must create policies that are adaptive and innovative. There is no set solution to the problem of climate change, but as the science evolves, hopefully so too will the policies to support science's findings. The Clean Development Mechanism's inclusion of forestry projects is innovative because it utilizes a natural process to address climate change. Forests provide an array of benefits, including ecological benefits as well as essential services to humans as the lungs of the Earth. In theory, the CDM provides a win-win situation for both industrialized countries and developing countries. Industrialized countries can exploit lower-cost emission-reduction opportunities abroad. Developing countries, many of which do not have the means today to join the global economy, could attract investment in the guise of CDM projects and in the process contribute to the global effort to reduce atmospheric GHG concentrations. Forestry projects are controversial, however, due to uncertainties about te expected rates of carbon sequestration and the difficult-to-determine social and environmental impacts. Resolution of the controversies around the CDM forestry projects will depend upon the adoption of acceptable baseline methodologies to measure their effects and broad impacts.

The CDM aims to allow developing countries to participate in activities that could potentially bring down the cost of meeting the Kyoto Protocol's targets and simultaneously facilitate sustainable development in the host country. In spite of some unresolved issues, many developing countries have already shown an interest in hosting CDM forestry projects. CDM projects also hold appeal towards the private sector, as numerous private companies from Annex I countries have begun to investigate possible projects. A global carbon-trading system is beginning to emerge and emission reductions generated under CDM forestry projects could soon be traded like any commodity. The United Nations Environment Program has launched a project, "Capacity Development for the CDM", to help developing countries to participate.[127]

Such initiatives will be necessary to ensure that the correct focus is placed on one of the main criteria of the mechanism, that it lead to development that benefits not just the economy but also society and the wider environment. The CDM Executive Board will also have to ensure that the correct balance is maintained and that projects are not guided solely by the interests of private companies. In this regard, the success of forestry projects under the CDM depends on the development of adequate baseline methodologies to account for the various uncertainty factors outlined in this report. The CDM's Afforestation/Reforestation Working Group has outlined a set of methodologies that will assess the different extent to which projects actually lead to reduced CO_2 concentrations in the atmosphere, are long-term, and benefit society and the environment more broadly. It will be necessary to observe the effects of individual projects before the success of the CDM can be evaluated.

Appendix: Glossary of Terms[128]

Afforestation	Defined by IPCC as the establishment of forest on land that has been without forest for a period of time (e.g., 20–50 years or more) and was previously under a different land use
Assigned amount unit (AAU)	Units of greenhouse gas emission permits. AAUs can be exchanged through emissions trading)
Certified emission reductions (CER)	A unit equal to one metric ton of carbon dioxide equivalent, which may be used by Annex I countries towards meeting their binding emission reduction and limitation commitments under the Kyoto Protocol.
Clean Development Mechanism (CDM)	A procedure under the Kyoto Protocol under which developed countries may finance greenhouse-gas emissions-avoiding projects in developing countries, and receive credits for doing so which they may apply towards meeting mandatory limits on their own emissions.
Emission reduction unit (ERU)	A unit equal to one metric ton of carbon dioxide equivalent, applicable to binding emissions-reductions targets under the Kyoto Protocol, and generated through joint implementation projects.
Emissions trading or International Emissions Trading	Mechanism under the Kyoto Protocol through which Parties with emissions commitments may trade units of their emissions allowances with other Parties. The aim is to improve the overall flexibility and economic efficiency of making emissions cuts.
Flexible Mechanisms	Three procedures established under the Kyoto Protocol to increase the flexibility and reduce the costs of making greenhouse-gas emissions cuts; they are the Clean Development Mechanism, emissions trading, and joint implementation.
Joint implementation (JI)	A mechanism under the Kyoto Protocol through which a developed country can receive “emissions reduction units” when it helps to finance projects that reduce net greenhouse-gas emissions in another developed country (in practice, the recipient state is likely to be a country with an “economy in transition”)

Marrakech Accords	Agreements reached at COP-7, which set various rules for "operating" the more complex provisions of the Kyoto Protocol. Among other things, the accords include details for establishing a greenhouse-gas emissions trading system; implementing and monitoring the Protocol's Clean Development Mechanism; and setting up and operating three funds to support efforts to adapt to climate change.
Quantified Emissions Limitation and Reduction Commitments	Legally binding targets and timetables under the Kyoto Protocol for the limitation or reduction of greenhouse-gas emissions by developed countries.
Reforestation	Defined by IPCC as the establishment of a forest on land that has been without forest within the aforementioned period of time and was previously under different land use
Removal Unit (RMU)	Removal unit (generated in Annex I Parties by activities that absorb carbon dioxide)
Sources	Fossil Fuel (coal, oil, natural gas, gasoline) burning by industry, power plants, and automobiles; Biologic Respiration; CO2 exchange between ocean and atmosphere; Changing Land Use;
Sinks	UNFCCC defines "sink" as any process, activity, or mechanism which removes a greenhouse gas, an aerosol, or a precursor of greenhouse gas from the atmosphere.
Sequestration	Refers to the provision of long-term storage of carbon in the terrestrial biosphere, underground, or the oceans so that the build-up of [CO2] in the atmosphere will reduce or slow

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