REPORT

Implementation of avoided deforestation in a post-2012 climate regime

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Foreword

This report is based on my master thesis, which concluded my education on the Master of Science program in Environmental and Aquatic Engineering at the Uppsala University. It covered 30 Swedish academic credits (30 ECTS credits). My supervisor at IVL was Erik Särnholm, Master of Science in Engineering, and my subject reviewer was Mats Olsson, Professor at the Department of Forest Soils, Swedish University of Agricultural Sciences in Uppsala.

Stockholm, January 2009

Johan Söderblom

Table of content

Foreword I
Summary III
Sammanfattning IV
Acronyms V
1 Introduction 1
1.1 Deforestation 1
1.2 Reducing emissions from deforestation in developing countries 2
1.3 Implementing Redd in a post-2012 Climate Regime 2
1.4 Purpose 3
1.5 Sequence of Work 3
2 Background of Deforestation 4
2.1 The Carbon Cycle 4
2.2 Deforestation, Afforestation and Reforestation 6
2.3 Causes of Deforestation 7
2.3.1 Latin America 8
2.3.2 Southeast Asia 8
2.3.3 Africa 9
2.4 Scenarios of Deforestation 9
2.4.1 Carbon below ground and carbon balance for land use 10
2.4.2 Carbon above ground 14
2.5 Chapter summary 16
3 Costs and Volumes of REDD 17
3.1 Volume of Emission Reductions from avoided deforestation 17
3.2 Estimated Costs for implementing REDD 18
3.3 Implementing REDD in Brazil 19
3.4 Trends in the Estimated Costs of REDD 22
3.4.1 Marginal Abatement Cost 22
3.4.2 Interpretations of the MAC curve 24
3.5 Sensitivity Analysis of Costs for implementing REDD 25
3.5.1 Sensitivity parameters 25
3.5.2 Results of Sensitivity Analysis 27
3.6 Chapter summary 29
4 Financial Solutions to REDD 29
4.1 Proposed Solutions 29
4.1.1 Integrate REDD into the global carbon market 30
4.1.2 Alternative market solutions 31
4.1.3 Fund solution 32
4.1.4 Official Development Assistance 32
4.1.5 Combination of different alternatives 33
4.1.6 Country specific solution 33
4.2 Criteria for comparison 33
4.3 Comparison of alternative financial solutions 35
4.4 Chapter summary 42
5 Discussion and Conclusions 46
6 References 49
6.1 Printed sources 49
6.2 Internet sources 51
6.3 Personal communication 52

APPENDIX..53
Appendix a – transformation table from wood to co_2 53
Appendix b – opportunity costs for different land uses 54
Appendix c – Area of deforestation in eight countries..55

Summary

The awareness of the global warming has increased the last few years and a majority of the world's scientists believes that anthropogenic emissions of carbon dioxide are the strongest contributing cause. Greenhouse gas emissions due to clearing of tropical rainforest has so far been given little attention, even though deforestation is responsible for 20-25 percent of the anthropogenic emissions of greenhouse gases and is the second largest sector of emissions after energy production. Forest ecosystems contain large amounts of carbon, and in total there is more carbon stored in forests on earth than what is held in form of carbon dioxide in earth's atmosphere. During the latest years the rate of deforestation has been about 13 million hectares annually, which is calculated to release almost 6 gigaton of carbon dioxide each year.

The underlying causes of deforestation are normally depending on present as well as historical circumstances and the drivers of deforestation can vary substantially between different countries. This study describes the proceedings of deforestation and discusses the carbon balance for possible scenarios when a forest has been cleared. The amount of emissions can vary substantially depending on the land use after deforestation and the usage of the harvested biomass. The carbon balance in soil is also of importance for the carbon emissions. Uncertainties regarding carbon emissions from soil are however large and is therefore often neglected in estimations of carbon emissions due to deforestation, the figures mentioned above included.

Reducing the emissions of carbon dioxide through REDD (Reducing Emissions from Deforestation in Developing countries) is considered to be cost effective. In this study a Marginal abatement cost (MAC) curve is created to illustrate how the cost of REDD will increase with time. A selection of reports that estimate the total cost of REDD is also reviewed. These estimates are all more or less uncertain and in this study it is shown that small changes in the initial assumptions might increase the estimated cost severalfold.

At the moment there are no incentives for avoided deforestation under the Kyoto Protocol. However, REDD is frequently discussed in the negotiations for a post-2012 climate regime. A central question in these negotiations is how REDD would be financed. This study reviews a selection of the alternatives that are discussed. Some sort of market solution will likely be needed to generate enough funding, though for this to be possible the measurability of the emission reductions must be improved. Extensive capacity building is needed in the host countries of REDD and the easiest way to finance this would be through a voluntary fund or Official Development Assistance.

Sammanfattning

Medvetenheten om att en global uppvärmning pågår har ökat markant de senaste åren och en majoritet av världens forskare anser att antropogena utsläpp av koldioxid är den starkast bidragande orsaken. Växthusgasutsläpp orsakade av avskogning i tropiska länder har fått liten uppmärksamhet hittills, detta trots att avskogning står för 20-25 procent av de antropogena växthusgasutsläppen och är den näst största sektorn för utsläpp efter energiproduktion. Skogsekosystem innehåller stora mängder kol, och totalt sett så finns det mer kol bundet i skogar på jorden än vad som finns i form av koldioxid i hela jordens atmosfär. De senaste åren har den globala avskogningen legat på omkring 13 miljoner hektar per år, vilket beräknas frigöra närmare 6 gigaton koldioxid årligen.

De bakomliggande orsakerna till avskogning utgörs av såväl nutida som historiska faktorer och vad som driver avskogningen kan skilja sig väsentligt mellan olika länder. Denna studie redogör för hur avskogning går till och diskuterar koldioxidbalansen för olika tänkbara scenarion efter att en skog har avverkats. Skillnader i utsläpp kan vara väsentlig beroende på markanvändningen efter avskogning och vad biomassan används till. Även kolbalansen i mark spelar en viktig roll för koldioxidutsläppen. Osäkerheterna kring beräkningarna av kolutsläpp från mark är dock stora och detta försummas därför vanligtvis i uppskattningar av utsläppsmängder, exempelvis i siffrorna som nämns ovan.

Att minska utsläppen av koldioxid genom REDD (Reducing Emissions from Deforestation in Developing countries) anses vara kostnadseffektivt. I denna studie skapas en marginalkostnadskurva (MAC) som visar hur kostnaden kan förväntas ändras med tiden. Vidare ges en genomgång av ett urval av uppskattningar för den totala kostnaden för REDD. Dessa innehåller stora osäkerheter och i denna studie visas att små ändringar i de ursprungliga antagandena kan flerdubbla den beräknade kostanden.

Under Kyotoprotokollet finns i nuläget inga incitament för undviken avskogning. Förhoppningen är dock att REDD ska gå att införa i en post-2012 klimatöverenskommelse. En av de mest centrala frågorna i de pågående förhandlingarna är hur REDD ska finansieras. Denna studie går igenom ett urval av de alternativ som diskuteras. En marknadslösning skulle troligen ge tillräcklig finansiering, men mätbarheten av utsläppsreduktionerna måste förbättras avsevärt för att detta ska vara genomförbart. Kapacitetsutveckling i de länder där REDD ska genomföras behövs och detta finansieras enklast via en frivillig fond eller genom utvecklingssamarbete.

Acronyms

ALOS	Advanced Land Observation Satellite
CCX	Chicago Climate Exchange
CDM	Clean Development Mechanism
CISDL	Centre for International Sustainable Development Law
COP	Conference Of the Parties
CR	Compensated Reduction
DRC	Democratic Republic of Congo
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization (of the United Nations)
GPPI	Global Public Policy Institute
GWP	Global Warming Potential
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
JI	Joint Implementation
MAC	Marginal Abatement Cost
OC	Opportunity Cost
ODA	Official Development Assistance
PNG	Papua New Guinea
REDD	Reducing Emissions from Deforestation in Developing countries
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States Dollar
VER	Verified Emission Reductions
WHRC	Woods Hole Research Center

1 Introduction

In the last few years awareness regarding global warming has increased remarkably, and the issue is no longer controversial. The fact that greenhouse gases, in particular carbon dioxide, have an impact on the earth's mean temperature is well documented. Human influence has been confirmed recently by the Intergovernmental Panel on Climate Change (IPCC) (2007) and there is a growing understanding of the need to take action, as for instance was expressed in the Stern Review (2006).

The first steps towards mitigating the emissions of greenhouse gases have been taken and are performed by a variety of actors at different scales. The United Nations Framework Convention on Climate Change (UNFCCC) is a meeting point that tries to unite the international community on a common climate policy. UNFCCC aims at stabilizing the amount of greenhouse gases in the atmosphere at a level that will not be dangerous for the climate system, and has therefore developed the Kyoto Protocol which states how the work towards this goal is to be carried out. The Kyoto Protocol entered into force in 2005 and the first commitment period started in January 2008. During the first commitment period the countries under the Kyoto Protocol, that have agreed to reduce their emissions of greenhouse gases (so called Annex 1 countries), are obligated to reduce their emissions by an average of five percent compared to the emission levels that they had by the year 1990. If an Annex 1 country would fail with achieving this, it will get a 30 percent higher obligation for the exceeding part during the second commitment period.

The first commitment period ends in December 2012, and the second commitment period is due to start immediately afterwards. Well before that, a strategy for a new agreement is needed, so that a gap in the process can be avoided. Negotiations have started, and after the UNFCCC meeting in Bali in December 2007, where a number of critical obstacles were overcome, there is at the moment an optimistic belief that there will be a post-2012 agreement with clear objectives and a broad participation.

Negotiations under the UNFCCC work in the same way as the rest of the UN system. Participation is voluntary and it is not possible to force a country to make a commitment since the decisions are taken in consensus. Because of that it is difficult for the UNFCCC to propose drastic measures and the emission reductions that are agreed upon so far are substantially lower than the reduction of 80 percent that is suggested in the Stern Review (2006).

1.1 Deforestation

The amount of carbon that is stored in the forest ecosystems on earth is larger than what is held in the whole atmosphere (FAO, 2006). When a tree grows it captures carbon dioxide from the atmosphere and binds it as carbon in the biomass. The opposite happens when a tree is burnt down or decomposes; it releases carbon dioxide into the atmosphere.

Deforestation, meaning the conversion from a forested area to a non-forested area without the establishment of new trees, is a problematic reality in many countries. With the massive deforestation that takes place, mainly in countries with tropical rainforest, the forested area on earth is currently being reduced with about 13 million hectares each year. This releases enormous amounts of carbon dioxide, and deforestation is believed to be responsible for 20-25 percent of the global emissions of greenhouse gases (Peterson et al., 2007). Deforestation is by these estimations a greater emitter than the global transport sector and the second largest emitter after energy production.

There are many problems connected to deforestation. Except for the emissions of greenhouse gases, deforestation also leads to a decreased biodiversity and erosion of the deforested land. This impoverishes the ground and thus makes it less usable for cultivation. A decreasing forest is also reducing the livelihood for those living in forested areas. There are about 800 million people that live in and are depending on the tropical forests, often living under poor circumstances (Chomitz et al., 2007).

1.2 Reducing emissions from deforestation in developing countries

The importance of avoiding deforestation has been advocated by environmental and human right groups for the last decades. The purpose has mostly been to maintain a high biodiversity and to preserve the forest resources for those who live in and are depending on the forests for their livelihood. The importance of reducing the rate of deforestation to mitigate the emissions of carbon dioxide has not been highlighted until the last few years.

REDD (Reducing Emissions from Deforestation in Developing countries) is the acronym that is used when discussing avoided deforestation in the negotiations under the UNFCCC. The acronym sometimes includes forest degradation as well, meaning a reduction of the forest resources without a complete deforestation. REDD was discussed during the negotiations for the Kyoto Protocol, but it was not included in the agreement. The Stern Review highlights the importance of implementing avoided deforestation in a post-2012 climate regime and also notes that large scale actions to prevent deforestation must be initiated immediately to facilitate the process (Griffiths, 2007). There are a few such projects existing at the moment, and during the first six months of 2008 several funds have been initiated for the purpose of financing projects of avoided deforestation.

1.3 Implementing Redd in a post-2012 Climate Regime

The countries that are members of the UNFCCC meet once each year at the Conference of the Parties (COP). The negotiations for a post-2012 climate agreement have started, and at the COP 13 meeting, in Bali in December 2007, a schedule for the coming negotiations was agreed upon, the so called Bali Road Map. Beside the annual COP meetings there are numerous workshops and conferences about the content of the post-2012 agreement, and the aim is to have an agreement for a future climate regime at the COP 15 in Copenhagen in December 2009. REDD is one of the questions being discussed for a post-2012 agreement.

There are several difficulties that need to be considered when developing a REDD program. First of all it will need substantial funding to be implemented on a large scale. Such funding can be gathered in a few different ways, all of them having side effects that will have an impact on the REDD program. Other key issues that must be solved is how to measure the progress of the avoided deforestation and how to avoid leakage, meaning that reduced deforestation in one area leads to an increased deforestation somewhere else.

A carbon market for trading carbon credits has been formed through the Kyoto Protocol to create economic incentives for reducing emissions of greenhouse gases. A possible strategy would be to implement REDD as a part of the trading system. The current trading is managed through the flexible mechanisms. With the flexible mechanisms an Annex 1 country can fulfil its commitments by purchasing carbon credits or by financing a measure in another country that leads to the desired amount of reduction. This way the emissions are reduced with the agreed amount and at a lower cost. Credits are measured as tons of carbon dioxide equivalents (CO_2eq), meaning that the emissions from other greenhouses gases than carbon dioxide are recalculated to the corresponding amount of carbon dioxide. These market solutions have been an important prerequisite for several countries to sign the Kyoto Protocol, and are likely to play an important role in the post-2012 discussions as well.

The flexible mechanisms being most important at the moment are Joint Implementation (JI) and the Clean Development Mechanism (CDM). JI enables an Annex 1 country to invest in projects that reduce emissions in other Annex 1 countries as an alternative to reducing domestic emissions. The CDM is similar and allows an Annex 1 country to reduce its emissions by financing a project in a developing country. The expected result of the CDM is that the Annex 1 country is able to fulfil its commitments at a lower cost while the developing country gets access to new technology and makes progress towards a sustainable development. Under the Kyoto Protocol it is possible to perform projects for afforestation and reforestation and receive carbon credits. Deforestation is however not included and at the moment the developing countries do not have any economical incentives under the Kyoto Protocol to reduce their deforestation.

1.4 Purpose

The purpose of this master thesis is to investigate how avoided deforestation can be implemented in a post-2012 climate regime. An overview of the different suggested financial solutions will be given, with an analysis of possible strengths and weaknesses. A literature review will be performed to see what volumes of emission reduction that are expected from avoided deforestation, as well as the costs that are associated with these measures. The results will be used to create a Marginal Abatement Cost (MAC) curve which will highlight how the costs of avoided deforestation changes over time. A sensitivity analysis will be performed to see how small changes in the initial assumptions will affect the expected costs of implementing REDD. The study will also give a background to the factors that cause deforestation and describe how different kinds of land uses influence the emissions of greenhouse gases.

1.5 Sequence of Work

The sequence of work (fig. 1) illustrates the working path that was chosen to reach the objectives of this study, and how the different parts are related to each other. The study is divided into three areas that are somewhat separated. The first part focuses on describing how deforestation actually works. The second reviews the costs of avoiding deforestation and the corresponding volumes of emission reductions. The third part analyses the different alternatives that could be chosen to finance a large scale program of avoided deforestation. Finally a concluding discussion is performed.

Except for a few interviews this study has been performed through literature studies of research reports, discussion papers and scientific journals.

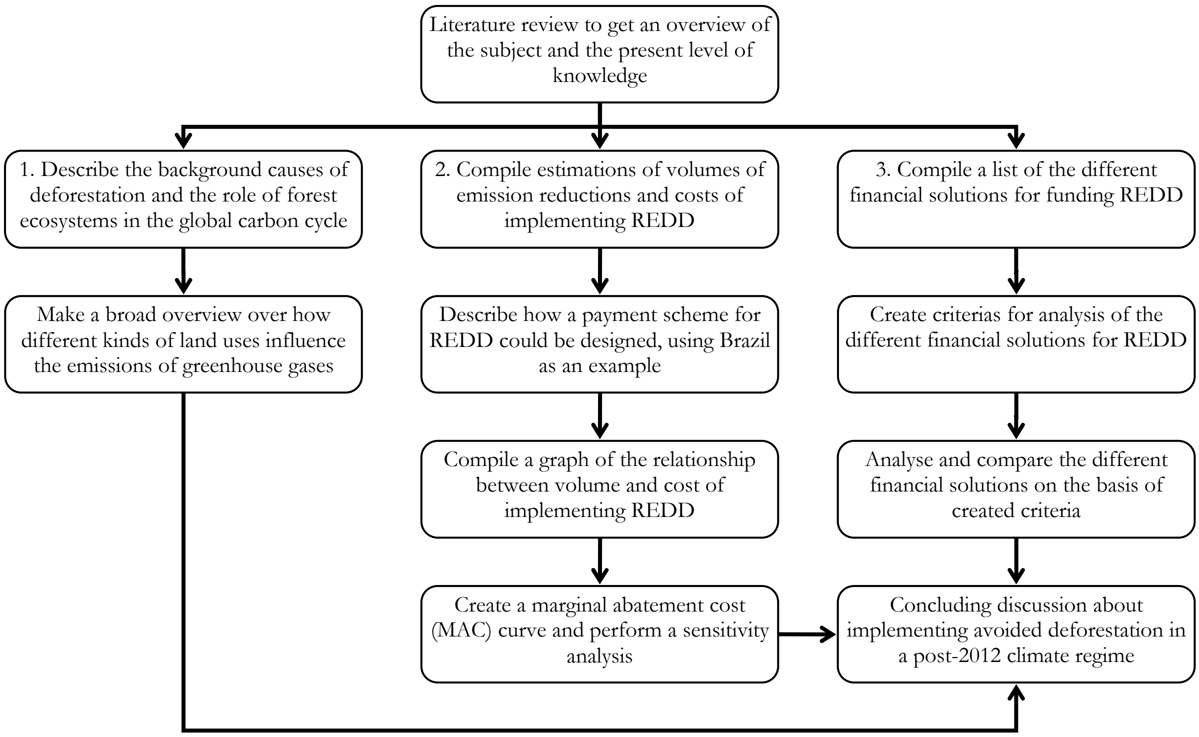

Figure 1 Sequence of work for this study.

2 Background of Deforestation

This section presents an overview of factors that contribute to cause deforestation, including the different scenarios that may take place once deforestation has been carried out. A rough sketch of the carbon cycle will be given as a background and to place the forest ecosystems in a broader context. The main purpose of this section is to illustrate how deforestation actually works, but also to describe the complexity and uncertainties concerning deforestation, and thereby also the difficulties of implementing a REDD program.

2.1 The Carbon Cycle

The fact that carbon dioxide is a greenhouse gas has been known for more than a hundred years. There are a number of other greenhouse gases that are also contributing to global warming, though carbon dioxide released due to anthropogenic activities is by far the most important one. When concerning forest ecosystems and deforestation there are for example emissions from the greenhouse gases nitrous oxide and methane, though these can be considered as small and are therefore neglected in this master thesis (Cooper & Zetterberg, 1994).

The Carbon Cycle (fig. 2) describes how carbon transfers throughout the earth and its atmosphere. Except for the enormous amounts of carbon that are stored in the bedrock, that do not substantially influence the processes on the surface, the oceans contain the largest amounts of carbon. There is a continuous interaction between the oceans and the atmosphere, and in the long run the oceans will keep the amount of carbon in the atmosphere in balance. The process is however very slow, and at the moment it does not balance the extra input of carbon that originates to a large extent from the burning of fossil fuels. (Brady & Weil, 2002)

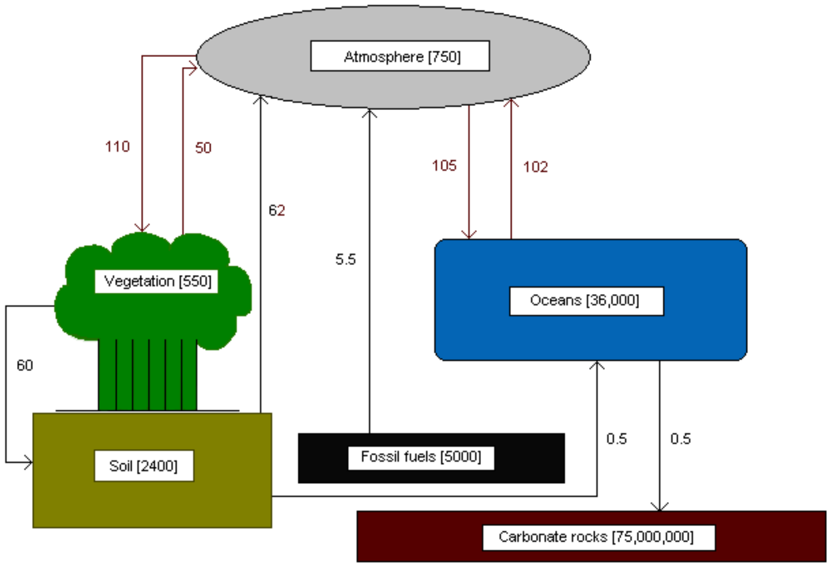

Figure 2 The carbon cycle. Numbers in boxes are in Gt carbon and numbers by arrows are in Gt carbon/year. The figure is based on information from Brady & Weil (2002).

Vegetation captures carbon through photosynthesis and binds it as carbohydrates in the plant tissue. This is however only a more or less temporary storage. Plants themselves use parts of the carbohydrates as an energy source when growing, thus releasing the carbon to the atmosphere again. When a plant dies it decomposes and some of the carbon is emitted to the atmosphere while the remaining part of the carbon is stored in the soil as plant litter or humus. As can be seen in figure 2, the soil contains much more carbon than the vegetation. Micro-organisms in the soil metabolize the plant tissue and thereby release carbon to the atmosphere, while the rest of the carbon is stored in the soil for a longer time in different types of organic compounds. (Brady & Weil, 2002)

Forests are often seen as carbon sinks, meaning that they have the ability to capture carbon from the atmosphere and store it. However, as described above, carbon is only stored in a forest temporary, until the trees are cut down or decompose. In a specific area, the forest should only be seen as a sink as long as the total amount of forest biomass in the area is increasing, thus leading to increased amounts of stored carbon. When the forest biomass reaches an equilibrium where it neither increases or decreases, in the long run it will not have a net effect on the amount of carbon in the atmosphere. The carbon balance of a forest ecosystem during its life cycle is sketched in figure 3. The soil is emitting carbon and it will take a few years until the trees will balance the emissions so that the net emissions are negative (i.e. sequestration is started). After logging most of the carbon is released again. The emissions will however depend on what the forest biomass is used for, which will be discussed further in the following sections.

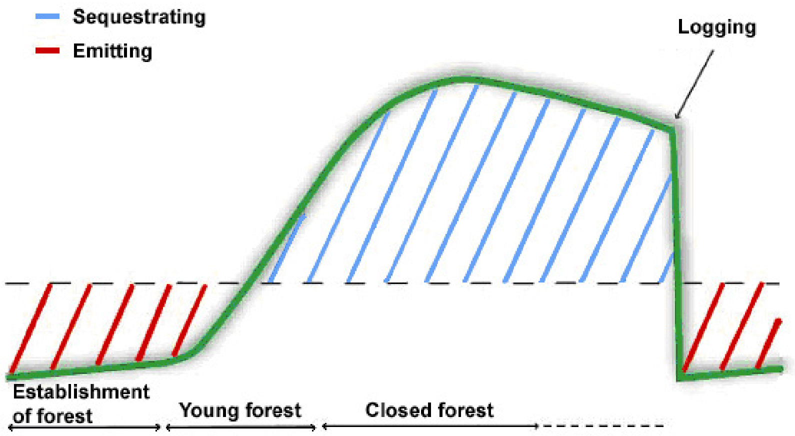

Figure 3 Carbon balance of a forest ecosystem during its life cycle. The area with blue lines indicates that the forest is sequestrating more carbon than it is emitting, and the area with red lines indicates the opposite. This figure is an adapted version of figure 1 in the LUSTRA (2008) report *Kolet, klimatet och skogen, Så kan skogsbruket påverka.*

2.2 Deforestation, Afforestation and Reforestation

Deforestation is defined in the Marrakesh Accords (2001), which is the agreement that was decided on at the COP 7, as the "direct human-induced conversion of forested land to non-forested land". It has so far been left out from the Kyoto Protocol, mainly due to uncertainties and disagreements in how to manage the compensation for avoided deforestation.

Besides deforestation it is also important to consider the impact that forest degradation has on the forest ecosystems. Forest degradation means that the values of the forest are being reduced. However, according to Hans Nilsagård who is Deputy Assistant under secretary for the Ministry of Agriculture, Food and Fisheries and who participates in the negotiations for a post-2012 climate regime, a clear definition has not yet been agreed upon under the UNFCCC. It is important that a definition can be stated since degradation will play an essential role when implementing REDD. Forest degradation can have a large impact on forest ecosystems and lead to substantial emissions of carbon dioxide even though complete deforestation is not performed.

Even though avoided deforestation is not yet accepted as projects under the Kyoto Protocol, there are at the moment two other types of forest projects that are so. These are afforestation and reforestation. Afforestation takes place when a forest is established on land that has not been forested before or at least not for a considerable time. Since a forest contains carbon that it captures from the atmosphere, afforestation is a method for binding CO_2 and can therefore be considered as a carbon sink.

At the 7th meeting of the Conference of the Parties in Marrakesh it was decided that afforestation was to be included in the Kyoto Protocol under Article 12, meaning that a non-Annex 1 country can afforest an area and obtain carbon credits for this in the CDM system. To be classified as an afforestation project under the Kyoto Protocol, a number of requirements need to be accounted for, such as the projects additionality, avoided leakage and the environmental impacts. Additionality means that the measure would not have been performed if the CDM project was not initiated. This is to make sure that carbon credits are not handed out without an effort being made. Leakage means that the project that is performed will not just move the problem to other areas. In the case of afforestation this would for example mean that a project is not accepted for the planting of a forest if it reduces the planting of trees in other areas. The Marrakesh Accords (2001) defines afforestation as

> "the direct human-induced conversion of land that has not been forested for a period of at least 50 years to forested land through planting, seeding and/or the human-induced promotion of natural seed sources"

Reforestation is the regrowth of a forest that recently has been converted to non-forest land for some reason. This can be done naturally if the area is left undisturbed, or by planed human activities. As with afforestation, a reforested area has the potential to work as a carbon sink.

Reforestation was also included in the Kyoto Protocol under Article 12 at the COP 7, together with afforestation. For the first commitment period reforestation activities were limited to areas that did not contain forest on 31 December 1989. The Marrakesh Accords (2001) defines reforestation as

> "the direct human-induced conversion of non-forested land to forested land through planting, seeding and/or the human-induced promotion of natural seed sources, on land that was forested but that has been converted to non-forested land."

So far there are few afforestation and reforestation projects that have been realized under the Kyoto Protocol. Most of those applying to initiate a project have been rejected by the Executive Board of the CDM. The methodology is however improving and more projects are expected to be accepted and initiated soon. (Haupt & Lüpke, 2007)

2.3 Causes of Deforestation

The causes of deforestation are commonly explained as the results of an expansion of a few different land uses, such as cattle ranching, cultivation and logging. These are truly the main direct contributors to the massive deforestation that takes place in many tropical countries, however the underlying causes of deforestation are better described as a combination of many factors, historical as well as present. The causes also differ greatly between different regions. (Lambin & Geist, 2003)

Lambin & Geist (2003) have summarized the results of more than 150 case studies of deforestation. They find that there are many differences between the causes of deforestation in Latin America, Southeast Asia and Africa, and that there are three sets of factors that explain these differences. The first factor is the environmental and land-use history. The history of deforestation, which in many of the tropical countries is heavily influenced by the unsustainable exploitation of natural resources during the colonial occupations, has had a major influence on the current deforestation. Either if the deforestation has followed the same pattern, or if it has developed in other directions, the historical circumstances have had an impact on the present situation. The second factor is the triggers and driving forces of deforestation. These are the specific combinations of direct and visible causes that are responsible for the actual deforestation in a certain region. The third factor is the feedback structure, meaning both the ecological and social reactions towards deforestation and the influence that these have on future deforestation.

2.3.1 Latin America

In Latin America the colonial powers started cattle ranching which today is the largest contributor to deforestation. Since 1970 the area used for cattle ranching in Brazil has doubled and it is calculated to cause 70 percent of the country's deforestation. This is influenced by the increasing demand for beef, of which the export has expanded severalfold since 1990 (Persson & Azar, 2004). Timber harvesting of exotic trees as well as rubber trade was also initiated by the colonial powers. The extraction of rubber does however not by itself have big impacts on the forests, since deforestation is not needed in the process, (Lambin & Geist, 2003). Timber harvesting constitutes a small part of the total deforestation in the Amazon, even though logging in Brazil is practiced in an area about the same size as the annual deforestation. Most part of this logging is illegal even though Brazil has a well developed environmental law system. After cattle ranching, cultivation has the second largest influence on deforestation. The annual crops, such as rice, maize and soya are likely responsible for about ten percent of the deforestation in Brazil. Soybean production is expanding due to an increasing global market and Brazil is today the second largest soya producer. (Persson & Azar, 2004)

Large scale farmers cause most of the deforestation due to cultivation and cattle ranching, however small scale farmers also contribute. A common procedure is that small scale farmers initiate a slash and burn cultivation that they manage for a few years. When the cultivation capacity of the soil decreases the land is sold to large scale farmers to be used for cattle ranching or to be used for cultivation again after a few years of fallow (Ibid.). Large scale farmers are however more likely to cultivate perennial crops which are generally managed for longer periods than annual crops and thereby leading to less deforestation. (Lambin & Geist, 2003)

2.3.2 Southeast Asia

Deforestation in Southeast Asia is mainly driven by logging and shifting cultivation. Shifting cultivation is a procedure where an area is deforested and cultivated for a few years until the amounts of soil nutrients is reduced, then the area is left and the procedure is repeated in another area. The colonial powers initiated and paved the way for deforestation by the cultivation of cash crops and by making the forest resources controlled to a large extent by international interests, later on managed by international corporations. (Ibid.)

Logging is responsible for a major part of the deforestation in Southeast Asia, and the region exports a large portion of the tropical timber that is traded on the global market (Ibid.). In Indonesia logging is also driven by the demand from the local pulp and paper industries that have expanded in the last decades. The legal logging cannot meet the demand for timber and illegal logging constitutes more than half of the timber supply to some sectors. The legal logging is performed by companies and roads are built to reach new areas that have not been accessible before. This also opens up new areas for settlers, which mainly are small farmers that practice cultivation that leads to further deforestation. (FWI/GFW, 2002)

Political failures, such as corruption and the incapacity to follow the laws and regulations, have contributed to the Southeast Asian deforestation. During the presidency of Suharto in Indonesia, members of the same party as well as Suharto's family were given control over forest resources and practiced unsustainable logging. Other political decisions, such as unsuccessful timber harvesting schemes and relocation programs of inhabitants have also had a substantial contribution to deforestation. The Indonesian government has arranged programs to reduce the dense population on the island of Java by relocating inhabitants to other parts of the country and it is assumed that these settlers have caused deforestation of about 2 million hectares since 1960. (FWI/GFW, 2002)

2.3.3 Africa

In Africa deforestation is mainly occurring in the west and central parts, which are the parts of the continent where the tropical rain forests are located. Colonial settlers started cultivating and harvesting timber in West Africa during the 16th century and shipped the products to Europe. Today deforestation in African countries is to a large extent driven by foreign companies. The governments are weak in most of these countries and in most cases incapable of controlling or reducing the deforestation made by private companies. Local small scale farmers and logging to obtain fuel wood is however also contributing to the current deforestation. (Lambin & Geist, 2003)

In Congo, which is the country that possesses the biggest part of the African tropical rain forest, colonial powers facilitated the deforestation taking place during the first half of the 20th century by constructing roads that gave access to new areas, and after the Second World War the large scale cultivations increased with a variety of cash crops. However, since oil was discovered it has been given a higher priority and agriculture has not expanded in the same extension as in neighbouring countries. In West Africa large scale agriculture has increased rapidly and at the moment the region has the world's highest deforestation rate. Cocoa production has expanded in response to the global demand. Since the soil is not suitable for growing cocoa for longer periods, the cultivations are abandoned after about fifteen years and forest is cleared to establish new cultivations. (Ibid.)

2.4 Scenarios of Deforestation

This section presents a scheme of possible scenarios that may occur once deforestation has taken place. These scenarios embody the direct causes of deforestation. However, as was discussed in the previous section, the complete picture of what causes deforestation is far more complex and consists of historical as well as present factors. The purpose of this section is to discuss the magnitude of carbon dioxide emissions that arises for the different scenarios, and to place these in a time perspective. Since there are many uncertainties involved, especially concerning the emissions of carbon dioxide from soil, the following is to be seen as an overview.

If managed in a proper way, forest ecosystems can work as carbon sinks. There are three different ways by which this can be performed. First of all, trees capture carbon dioxide and thereby remove it from the atmosphere. This is however only true for a growing forest, it sooner or later reaches an equilibrium stage where the intake and emission is equal. Another way of reducing emissions is by performing a land use that will not result in large carbon emissions from the soil. Soils generally contain substantial amounts of carbon that possibly can be emitted to the atmosphere. Thirdly, biomass that is produced in the forest can be used in different ways so that it replaces materials or fuels that cause carbon dioxide emissions. Wood can for example be used as building material instead of cement which is a highly energy consuming material. (LUSTRA, 2008)

When deforestation does occur, it will lead to emissions of carbon dioxide in some way. Figure 4 illustrates the possible scenarios of deforestation. It starts with an area of tropical rain forest, often containing carbon corresponding to more than 100 tons of carbon per hectare. As a comparison, assuming that a litre of petrol contains carbon corresponding to about 2.3 kg of carbon dioxide (Svenska Petroleum Institutet, 2008-08-20), one hectare of tropical rain forest contains carbon equivalent to more than 43,000 litres of petrol. The carbon in a forest ecosystem is for simplicity divided into two parts in the scheme presented below; the carbon above ground and the carbon below ground. The part that is above ground consists of the trees, and it is assumed to be the part that is removed or burnt when deforestation occurs. Emissions from this part of the forest ecosystem vary depending on how the wood is used. The part that is below ground is what is left at the site after an area has been cleared. This includes carbon in the soil, plant litter and the ground cover vegetation, but also the carbon balance that arises due to different land uses. The ground that is left after deforestation may be emitting large amounts of carbon dioxide, however it might also be used for activities that bind carbon dioxide from the atmosphere or that reduce the emissions in some way.

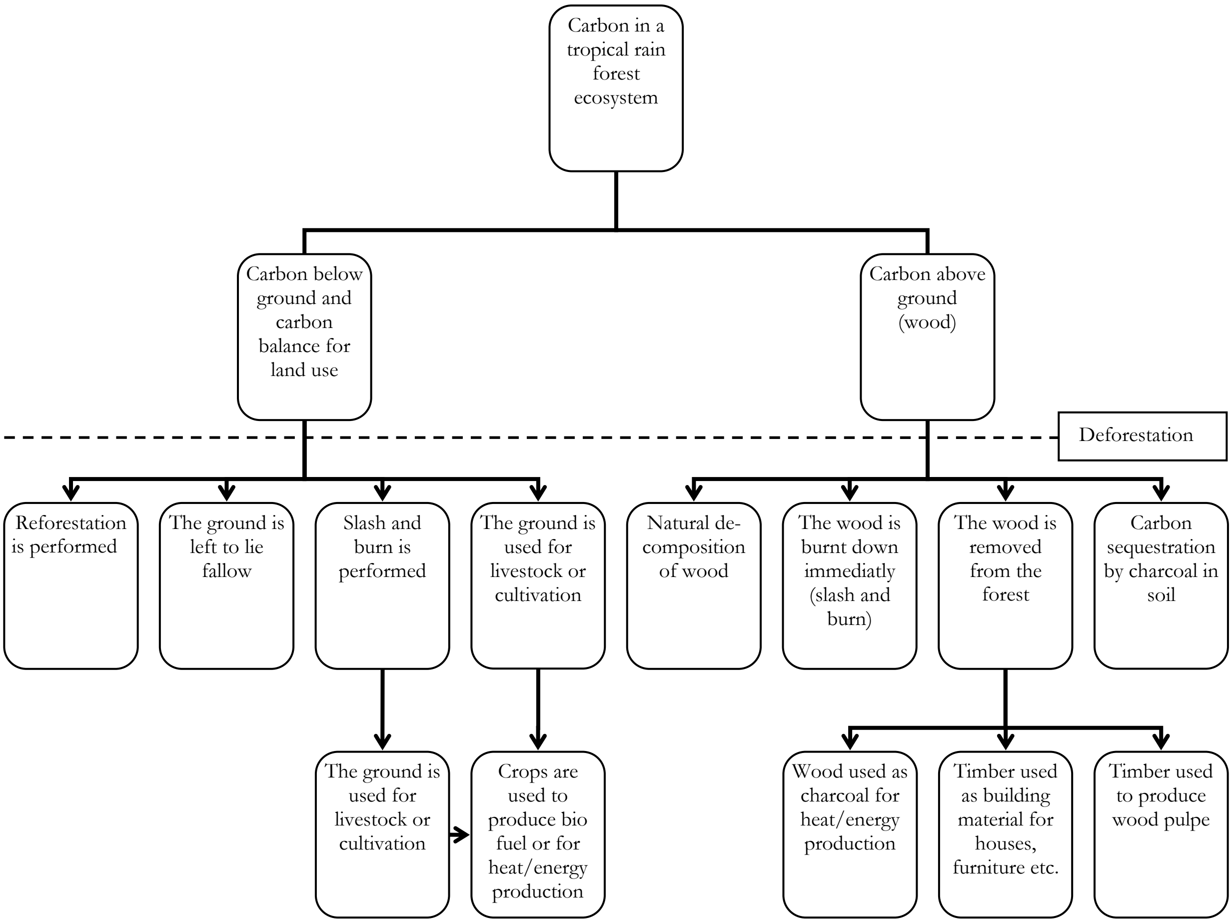

Figure 4 Possible scenarios after deforestation has taken place.

2.4.1 Carbon below ground and carbon balance for land use

The carbon below ground can be divided into carbon in soil, carbon in biomass and carbon in litter. The Food and Agriculture Organization (FAO) of the United Nations compile the available information about global forest resources and carbon stocks. According to their estimations there are about 638 Gt of carbon in the global forest ecosystems, if including soil to a depth of 30 cm. Almost half of the carbon is stored in the soil and litter. If soil to a depth of one meter is considered instead, the carbon content is about 50 percent higher. (Marklund & Schoene, 2006)

Estimations of carbon in litter and soil are however difficult to perform and there are many uncertainties. Seen at a depth of one meter the soil is larger and a more stable carbon storage than the part of the forests that is above ground and it is therefore important to monitor any changes in the carbon stock in soil (LUSTRA, 2008).

After deforestation takes place, four alternative scenarios for land use can be seen (fig. 4). The following will discuss these scenarios and what effect they will have on emissions of carbon dioxide.

Reforestation
Reforestation is, as was explained in section 2.2, the regrowth of a forest that recently has been cleared. Since deforestation is defined as the conversion of forested land to non-forested land, the case when reforestation occurs could possibly not be seen as a scenario of deforestation. When the Marrakesh Accords were decided upon, the agreement was that projects for reforestation could be allowed for areas that had been deforested at the latest in 1989, about 20 years before the first commitment period of the Kyoto Protocol that started in January 2008. 20 years is a short time seen in the aspect of a forest life cycle, and it is therefore considered as a possible scenario of deforestation in this overview. If an area is logged and then reforested after 20 years, the forest can possibly return to the stage where it was before the clearing. This would mean that the same amount of carbon that was removed is once again captured in biomass and soil. However, this is provided the soil has not been to impoverished so that there are not enough nutrients for a new forest to grow. For the complete picture of the emissions, the land use during these 20 years should also be considered. It can be seen as any of the below following scenarios, only interrupted after 20 years to perform reforestation. As seen in figure 3, a few years will pass until a reforested area becomes a sink since the emissions from the soil are initially larger than the sequestering ability of the biomass.

Even though it might appear simple to initiate reforestation and thereby restoring a forest ecosystem, it is not easy to perform projects of this kind. Reforestation can never restore a forest ecosystem with the same structure as the original and detailed planning is needed to make sure that the tree species planted are suitable in the particular area (Chazdon, 2008). An investigation in Brazil found that out of 98 publicly funded projects attempting to reforest areas only two could be considered successful. In many of the projects the trees that were planted died quickly. Diversity among the planted species was found to be an important factor for success, though due to lack of water and nutrients not even a broad diversity was enough to succeed with some reforestation projects. (Wuethrich, 2007)

Reforestation projects, especially those that have a commercial purpose, often plant trees that have a short life time and a low density. According to Chazdon (2008), forest regeneration is a long-term process that should be performed with slow growing trees that have a high density and bind high amounts of carbon. Chazdon also states that leaving a deforested area to reforest by itself often works better in a long-term perspective than projects for reforestation.

Fallow
It is common that land is left to lie fallow after deforestation has taken place. If the land is cleared only to obtain timber this could happen directly since the land is no longer of interest afterwards. Alternatively, if the land is used for cultivation it may be left to lie fallow when the soil is impoverished and no longer is suitable for cultivation. A new forest may emerge on the area, as was described above, possibly recapturing the carbon that was released on clearance. This section describes the case when no new forest is established.

Deforestation removes most of the carbon in an area, except for the carbon stored in the soil. Some carbon may however be left in the residual vegetation and in charcoal that is created during a slash and burn process. If charcoal is added to the soil it may be stored for hundreds of years (Lehmann, 2007).

Hashimotio et al. (2000) investigated the carbon balance in fallow forests in Indonesia after shifting cultivation had taken place. This was done be measuring the carbon in biomass in the vegetation that was established. The study concluded that 7.4 percent of the carbon that is released during forest clearance is reabsorbed and stored in the vegetation. This is a small portion of what is released, though since large areas are left to lie fallow globally it is not unimportant as a carbon sink and it should be considered when discussing the emissions from deforestation.

However, Hashimotio et al. do not consider the soil carbon. As illustrated in figure 3, the carbon balance is negative for a forest ecosystem until enough trees are established, since the soil is emitting carbon dioxide for a land that lies fallow. Kirchmann et al. (2004) summarize a long term experiment in Sweden where the soil organic carbon had been measured continuously for 42 years. During that period the fallow land had lost about one third of the initial content of organic carbon. With the large amounts of carbon in the soil it is important to consider this in order to be able to accurately describe the carbon balance in a fallow land.

Slash and burn

Slash and burn is a common practice to prepare a site for cultivation or cattle ranching. In the process a lot of carbon is released to the atmosphere due to burning of biomass (Brady & Weil, 2002). The soil carbon is likely not affected by slash and burn, though the carbon in the ground vegetation would however also be released when burnt. If charcoal is created and added to the soil it may become a long term carbon sink as was mentioned above. It will also improve the soil quality and the possibilities for cultivation (Lehmann, 2007), which will be discussed further in section 2.4.2.

After slash and burn is performed in an area it is often used for cultivation or cattle ranching, which will be discussed in the following section. Figure 5 illustrates how the soil carbon will be reduced for each year if the soil is used for cultivation. However, it is common that the soil is left after only a few years of cultivation since the amount of nutrients are reduced (Persson & Azar, 2004). If the ground is left to lie fallow the soil carbon will continue decreasing as was discussed above. If used for cattle ranching manure will be added to the soil and this may increase the amount of soil carbon (Kirchmann et al., 2004).

Cultivation and livestock

Carbon emissions due to land use vary significantly depending on what activity that is performed and what time perspective that is considered. Cultivation will for example lead to different outcomes if the crops are used for human food consumption or if they are used to produce fuel. Land use also has an influence on the carbon that is stored below ground.

In this section land use is divided between cultivation and livestock. This is a simplifying assumption since cultivation and livestock can be combined in different ways or performed in turns. A common practice is that cultivation is performed for a few years until the amount of nutrients in the soil is reduced. After that the land is used for livestock which is not as dependent on a nutritious soil, and may increase the amount of nutrients since manure is added to the soil. (Persson & Azar, 2004)

When initiating cultivation, it is common to first mix the upper layers of the soil as ground preparation. This increases the decomposition of organic materials and since the upper layers contain large fractions of carbon it leads to increased carbon dioxide emissions to the atmosphere (LUSTRA, 2008). A standing forest is gradually increasing the carbon in the soil as the biomass is transformed to litter (fig. 2). When an area is deforested this transfer of carbon to the soil is disrupted, and when used for cultivation the soil carbon will gradually decrease. Lemenih et al. (2004) investigated Ethiopian soils where slash and burn was performed to prepare for cultivation. The soils that were studied had been cultivated for up to 53 years and the study found that the soil carbon decreased continuously during this period, though the rate is highest during the first 25 years. The decline in soil carbon can be seen in Figure 5.

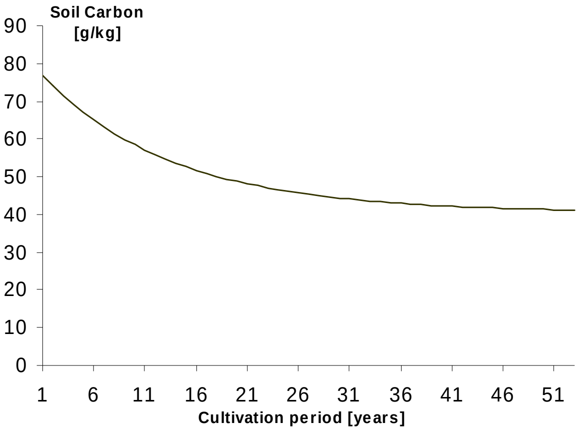

Figure 5 Carbon in soil on deforested land being used for cultivation (Lemenih, 2004).

Crops capture carbon dioxide from the atmosphere when they grow. This storage is only temporary and when the crops are harvested and consumed the same amount of carbon dioxide is released again. To influence the carbon balance and mitigate the emissions of carbon dioxide, the crops must be used in a way that has side effects resulting in reduced emissions. This can be done if the crops are used as an energy source in heat production or to produce biofuel. Energy forest can be used for heat production instead of oil or other fossil fuels. Energy crops can be used to produce biodiesel or ethanol to use as fuel for transportation. It thereby replaces fossil fuels so that the carbon dioxide that would have been emitted can be avoided.

Biofuels is a frequently discussed topic at the moment. Critics argue that the use of biofuels contributes to global deforestation and that it thereby indirectly causes emissions of carbon dioxide that cannot be motivated by the reduced emissions due to exchanging fossil fuels for biofuels. Fargione et al. (2008) calls the carbon dioxide that is released due to forest clearance for the carbon debt, and states that this carbon debt must be repaid before the biofuels can be considered to reduce the emissions of carbon dioxide to the atmosphere. According to their research this might in the worst cases take more than 300 years.

Searchinger et al. (2008) find a similar result and also note that there are studies that have found that increasing soybean prices leads to accelerating rates of rainforest clearance. Soybeans can be used as energy crops, and this would therefore indicate a direct connection between energy crops and rainforest clearance. Searchinger et al. also argue that using soybeans as energy crops could have an indirect effect on deforestation since farmers clear rainforest to make space for cultivation of soybeans to replace what will be missing on the market to use for food and feed.

The connection between cultivation of energy crops and forest clearance is however complex. As described in section 2.3 the drivers of deforestation are many and a particular component cannot always be pointed out as a single-handed cause of deforestation. The scenarios described by Fargione et al. and Searchinger et al. are therefore questioned. Sparovek et al. (2008), for example, compare the expansion of sugarcane cultivation in different Brazilian municipalities and the effect that this has on land use changes. Sugarcane can be used to produce ethanol for transportation fuel and Brazil stands for 35 percent of the global ethanol production. The study finds that no direct connection can be seen between expansion of sugarcane cultivation and deforestation. Expanding sugarcane cultivation is instead having a decreasing effect on livestock production. The authors do however not exclude the possibilities that expanding sugarcane cultivation leads to indirect deforestation in areas not included in the study.

Gibbs at al. (2008) concludes that clearing tropical forest for cultivating energy crops is likely never beneficial regarding CO_2 emissions. Though when cultivated on degraded lands that are not suitable for producing food the benefits are immediate.

Cattle ranching is a common land use after deforestation has taken place. This can either be initiated immediately, or after a few years of cultivation. Cattle ranching in Brazil is assumed to be responsible for about 70 percent of the total deforestation (Persson & Azar, 2004). Globally the livestock sector is calculated to be responsible for about nine percent of the total anthropogenic carbon dioxide emissions, though since carbon dioxide emissions from the actual ranching are small this is mainly due to the emissions from deforestation (Steinfeld et al., 2006). However, livestock emits considerable amounts of other greenhouse gases and it is calculated to produce 37 percent of the anthropogenic methane and 65 percent of the nitrous oxide emissions. The so called global warming potential (GWP) is much higher for these greenhouse gases than for carbon dioxide. GWP is a measurement that is used to relate the warming potential of different greenhouse gases to each other, using carbon dioxide as a referent with the GWP 1. Methane has a GWP of 21 and nitrous oxide has a GWP of 310 seen in a perspective of hundred years (IPCC, 2007). In total the livestock sector is assumed to be responsible for 18 percent of the total emissions of greenhouse gases to the atmosphere (Steinfeld et al., 2006). A scenario where deforestation occurs to make space for cattle ranching will thereby have a significant contribution to the emissions of greenhouse gases, even though it releases small amounts of carbon dioxide.

2.4.2 Carbon above ground

The carbon above ground is the biomass that is cut down or burnt during forest clearance. The biomass has sequestrated carbon from the atmosphere and this carbon will be released to the atmosphere at one time or another. Different usages will however lead to different scenarios regarding the time aspect of the emissions.

According to estimates by the FAO about 50 percent of the carbon in forest ecosystems is found in biomass and dead wood when considering soil to a depth of 30 cm as part of the system (Marklund & Schoene, 2006). Compared to the part below ground the above ground carbon is however easily released if disturbances in the ecosystem occur.

Natural decomposition
Decomposition of the above ground biomass is not a likely scenario after an area has been deforested. Timber is a valuable product in many aspects and is unlikely not to be made use of or sold even if the access of wood was not the primary cause of deforestation. It is however included as a possible scenario in this overview to be used as a comparison with the other alternative

scenarios. Decomposition of wood occurs when fungi attack the biomass and the moisture and temperature conditions are favourable (Institute for Research in Construction, 2008-08-05). When so, the decomposition can occur rather quickly if the wood is left in the forest to decompose and a major part of the above ground carbon would likely be released within a few years.

Instant burning
Slash and burn is a common practice to clear forest and make space for cultivation or cattle ranching. This practice directly releases large amounts of carbon dioxide to the atmosphere (Brady & Weil, 2002). Most of the above ground carbon will likely be released permanently. Slash and burn practiced by small populations in large areas may be sustainable for the environment if the ecosystems would be given the possibility to recover (Science Daily, 2008-08-05). This is however normally not the case with the massive deforestation that takes place globally today, and with the cultivation that is practiced the ground is often impoverished and the possibilities for a new forest to grow are often limited.

The wood is removed from the forest
Clearing forest to harvest timber is a significant contributor to tropical deforestation, especially in Southeast Asia that exports a large part of the timber that is traded globally (Lambin & Geist, 2003). There are many possible usages for timber and the total emissions of carbon dioxide will vary substantially over time depending on what the timber is used for. In general the timber that is harvested will be releasing its carbon at one time or the other since the material will eventually be burnt of decomposed. For a specific forested area the total balance of carbon dioxide emissions will depend on the net growth of the forest. On a regional level, if timber is being harvested but with the forest biomass increasing or being held at an unchanged level, the forest within that area will decrease the amount of carbon dioxide in the atmosphere. This is occurring in several countries today, though in the tropical countries, that are in focus for this study, the forest resources are being reduced and thus contributing to the global deforestation of about 13 million hectares annually.

Using wood as an energy source will instantly release the carbon dioxide to the atmosphere. The use of wood is however the only available fuel alternative in some regions and it is assumed to be the most important source of energy for two billion people around the world, most of them living under poor circumstances (Porrúra et al., 2007). Using wood will however lead to smaller emissions than those caused by using fossil fuels. The use of fossil fuels also returns carbon to the atmosphere that has been stored for a much longer period than the carbon stored in forest ecosystems.

Using timber as building material will store the carbon that the wood contains for as long as the product is used. This could delay the emissions of carbon dioxide substantially, though it will eventually be emitted. The material could however be reused several times and possibly also be used as fuel wood when no other use is of interest, thus being an alternative to burning fossil fuels. Using wood as building material is also advantageous since it could replace concrete or steel which are materials that use a lot of energy and thereby lead to emissions of carbon dioxide. A study by Gustavsson et al. (2006) finds that using wood as a replacement of concrete instead of using it as fuel leads to considerably lower emissions of carbon dioxide.

Timber can also be used in the pulp industry. In Indonesia the increasing demand for pulp wood has been a contributing factor to the current deforestation (FWI/GFW, 2002). As for building materials the use of woodpulp will slow down the process until the carbon dioxide is released to the atmosphere and the material is possible to recycle a few times. The pulp industry itself is however contributing to large emissions of greenhouse gases through transport and processing (Cooper & Zetterberg, 1994).

Carbon sequestration through burying charcoal
An alternative usage of wood is to produce charcoal and bury it in the ground. This is a method to create a long term carbon sink that is less exposed for disturbances than carbon stored in biomass. Mixing carbon with soil has the advantage that it will keep the nutrients in the soil and thereby improve its fertility. In this way the possibilities to cultivate for longer periods are improved at the same time as the amount of carbon dioxide in the atmosphere is reduced. It is required, however, that new biomass will grow up in order to sequestrate the amount that was emitted from burning. Studies have shown that carbon in this way can be stored in the soil for hundreds or possibly thousands of years, thus being a storage that is more long term than forest ecosystems. Charcoal is commonly produced through pyrolysis where the biomass is heated in an oxygen free environment. This process will need energy to be started, although it is possible to combine with bio energy production so that charcoal is created as a by-product when heating a thermal power station or creating biogas. (Lehmann, 2007)

2.5 Chapter summary

Deforestation may appear as a phenomenon that is easy to describe and that likely would be easy to prevent. The underlying causes of deforestation are however often consisting of many factors, historical as well as present, and the effects that a program for avoided deforestation would have are presumably hard to predict with certainty. There is also a regional variation of what drives deforestation, though generalisations can often be made on a country level. This is important to consider when planning for measures against deforestation.

Forests and forest management have the potential to lower the amount of carbon dioxide in the atmosphere. This is provided that there is a net growth of biomass, or that carbon is being accumulated in the soil. When there is a net growth of biomass it is for example possible to harvest timber to use as building material or fuel without reducing the forest stand in the long term. This will sequestrate carbon dioxide and reduce the emissions. This is however not the trend in the countries with tropical rainforest at the moment and there is therefore a global deforestation of about 13 million hectares each year.

When deforestation does occur, the total emissions that arise will depend on a number of factors. It is important to consider both the carbon in biomass and the carbon in soil. It is also important to consider the time perspective of the emissions.

Shifting cultivation, such as slash and burn, will release most of the carbon stored in biomass directly. About 300 million people are depending on shifting cultivation for their livelihood, thus having an enormous impact on the forest ecosystems (Brady & Weil, 2002). Clearing forests by harvesting timber will eventually lead to more or less the same emissions, though it might be delayed substantially if used as building material and such. This would also be advantageous since it may substitute more energy consuming materials such as cement or steel.

The carbon below ground, as well as the carbon balance of the activity that is performed after deforestation has taken place, should also be considered to get the complete picture of emissions due to deforestation. The soil carbon may be leaking for many years if the ground is left to lie fallow or even when used for cultivation. In the case of fallow some of the carbon that is released might however be sequestrated once again in ground vegetation, though often only constituting a small portion of what was released through the forest clearance. Cultivation can result in reduced CO_2 emissions if energy crops for production of biofuel are cultivated. The benefit of biofuels is heavily debated since there are studies indicating that the cultivation of energy crops will increase the deforestation rate. Others however find that this is not the case and more studies will be needed so that this can be determined.

3 Costs and Volumes of REDD

The previous chapter illustrated the difficulties regarding estimates of carbon emissions from forest ecosystems. There are many uncertainties regarding how to measure carbon emissions from soil and land use. In the following it is only the carbon above ground that is included in the calculations and no consideration is taken of the carbon balance due to the land use after deforestation has taken place. If nothing else is stated all of the carbon is assumed to be released to the atmosphere immediately after clearance.

3.1 Volume of Emission Reductions from avoided deforestation

As discussed above, forests are large storages of carbon. In total there are approximately 638 Gt of carbon stored in forest ecosystems around the globe, more than what the entire atmosphere contains (FAO, 2006). Forests capture carbon dioxide from the atmosphere and bind it in the biomass, and because of this a growing forest is a potential carbon dioxide sink. With the large amounts of carbon bound in forests on the planet, the cutting of forests can conversely be a considerable source of carbon dioxide to the atmosphere. This is the situation at the present, with an annual deforestation of about 13 million hectare.

Blaser & Robledo (2007) state that 5.8 Gt of carbon dioxide is released from the forest sector each year and the Stern Review (2006) finds that 4.9 Gt CO_2 is released from the countries that contribute with 70 percent of all emissions caused by deforestation. Most of this deforestation takes place in tropical countries with high amounts of carbon per hectare. The global average of carbon in biomass is about 71 tons per hectare of forest (FAO, 2006). However, Brazil which is the country with the highest amount of carbon in its forest has an average of 142 tons per hectare (Nepstad, 2007). Calculations of total emissions can be made by making a rough estimate that the average carbon content per hectare in the total tropic area is in between these numbers, thus 107 tons of carbon per hectare of forest. According to Grieg-Gran (2006) about 90 percent of this carbon can be assumed to be released into the atmosphere, which would mean that the annual deforestation of 13 million hectares sets more than 1.2 Gt of sequestrated carbon free each year. The relation between carbon and carbon dioxide is a factor of 3.67 (Appendix A), giving that about 4.6 Gt of carbon dioxide is released to the atmosphere through deforestation each year. As can be seen above there are several studies that find higher amounts than this, likely because more carbon per hectare forest is assumed, or that all of the carbon stored in biomass is assumed to be released in the clearing.

3.2 Estimated Costs for implementing REDD

There are several difficulties with calculating the costs of reducing emissions from deforestation in developing countries (REDD). The basic principle is that the cost of REDD is about the same as the opportunity cost (OC) for the land-use plus some additional costs such as administration and monitoring systems (Tollefson, 2008). The opportunity cost for the land-use is basically the income that would have been generated through the activities that lead to deforestation.

An example of opportunity cost could be a forested area that is cleared to sell timber or make space for cultivation of a crop that generates an income. In this case the opportunity cost for not clearing the forest is the same as the missed income. With the variety of causes that lead to deforestation, there is a wide span in the opportunity costs in developing countries. This is not only depending on the income generating activity, but also on the prices on the local market where trade with crops, timber and livestock is to take place. However, studies have found that today's market prices for carbon offsets often may exceed the opportunity costs by 50 times (Chomitz et al., 2007).

Monitoring systems are needed to make sure that actual progress is being made, which is of great importance for the credibility of any REDD program. According to Klas Österberg at the Swedish EPA (Environmental Protection Agency), who takes part in the negotiations for a post-2012 climate regime, Brazil has made progress in monitoring their forest by satellite. Satellite surveillance is however still under development, and the most recent developed technique is a type of remote sensing satellite named ALOS (Advanced Land Observation Satellite). ALOS has the possibility to get pictures of a forest even in cloudy areas, which has been a problem with monitoring forests in the Amazon region. (Mongabay.com, 2008-03-27)

There will be large variations in cost for REDD between different regions and types of forests (IPCC, 2007). Marginal costs, meaning the total cost for every additional unit, are likely to increase over time (see section 3.4.1). The areas with the lowest opportunity cost will probably become involved in a REDD program at an early stage, leaving the areas with higher opportunity cost to be compensated for at a later stage (WHRC, 2007).

There are so far few studies that attempt to calculate the cost for implementing REDD, and due to the difficulties mentioned above the results differ significantly. Costs for reduction are usually measured in United States Dollar (USD) per ton CO_2. According to Doug Boucher from the Union of Concerned Scientists, who has made a compilation from different studies trying to calculate the costs of reducing deforestation, estimations differ from a few US dollars to USD 30 per ton. (Tollefson, 2008)

In the Stern Review (2006) it is stated that reducing emissions by avoided deforestation is a cost effective approach to mitigate global warming. The estimations of the costs of implementing REDD that are found in the Stern Review are based on a report performed by Maryanne Grieg-Gran (2006). This report states that reducing global deforestation can be achieved for under USD 5 per ton CO_2 or possibly as little as USD 1 per ton CO_2. The main conclusion is that reducing deforestation to zero in eight countries that together are responsible for 70 percent of the emissions would have an opportunity cost of about USD 5-10 billion each year. This would however only be true initially, since the marginal costs would rise over time. There are also considerable administrative costs involved. The costs of administrating REDD in these eight countries would start between USD 25 and USD 93 million per year, though with an increasing area to protect these administrative costs might rise to almost USD 1000 million by year ten.

In a paper prepared for the UNFCCC Secretariat it is estimated that USD 12.2 billion per year would be needed to reduce emissions from deforestation and forest degradation to zero by 2030. An average cost of USD 2.8 per ton CO_2 is calculated for 8.2 million hectare out of the total 13 million hectare that is cleared annually (Blaser & Robledo, 2007). The authors emphasize that the results of their research cannot be seen as the full cost of REDD, since future decisions by the UNFCCC will have a big influence on the actual cost. Before a post-2012 climate regime is agreed upon by the UNFCCC it will not be possible to make a realistic estimation of the cost of implementing REDD, according to Blaser & Robledo (2007).

Other reports estimate that larger amounts are needed to fully compensate for avoided deforestation. Obersteiner et al. (2006) finds that USD 33.5 billion per year is needed over 20 years to reduce deforestation by 50 percent, giving an average cost of USD 21 per ton CO_2. Griffiths (2007) extrapolates the cost of reducing deforestation to zero to a price of USD 20-100 billion annually, based on estimates from the World Bank saying that a reduction of 20 % could cost between USD 2 and 20 billion per year. Table 1 summarizes the results of a selection of studies that estimate the cost of performing a REDD program.

Table 1 Summary of studies that estimate opportunity costs and volumes for integrating REDD. Extensive comparison is not advised without detailed study of the sources, since these estimations are based on assumptions that differ considerably.

Opportunity cost [USD]	Opportunity cost [USD per ton CO_2]	Reduced volume [CO_2] (Gt)	Preserved area [ha] (million)	Measure	Source
5-10 billion per year	1-2	4.9 per year	6.2 per year	Reduce emissions by deforestation to zero in 8 countries that are responsible for 70 % of emissions	Grieg-Gran (2006)
12.2 billion per year	2.8 (for 8.2 million ha)	5.8 per year	12.9 per year	Reduce global emissions from deforestation to zero	Blaser & Robledo (2007)
33.5 billion per year	21	32 in 20 years	5.3 per year	Reduce emissions from deforestation with 50 % in the next 20 years	Obersteiner et al. (2006)
20-100 billion per year	N/A	N/A	N/A	Reduce deforestation to zero	Griffiths (2007)
18 billion in 30 years	2.8 (for 94 % of Brazilian Amazon)	25.5 in 30 years	2 per year	Reduce deforestation in Brazil to zero within ten years	Nepstad (2007)

3.3 Implementing REDD in Brazil

Brazil, with a population close to 200 millions, is the world's 4th largest emitter of carbon dioxide. The Brazilian Amazon contains more carbon per area than any other tropical forest and the deforestation and degradation of these forests are responsible for about 70 percent of Brazil's CO_2 emissions. In total the Brazilian Amazon constitutes 330 million hectares of forest, storing about 47 billion tons of carbon. Average deforestation rates between 1997 and 2006 were 1.92 million hectares each year. (Nepstad, 2007)

The Woods Hole Research Center (WHRC) (Ibid.) calculates the possible costs of implementing REDD in Brazil. The assumed scenario is that deforestation is to decrease by 10 percent each year from the present 2 million hectares, resulting in zero deforestation after ten years. Figure 6 illustrates this avoided deforestation over thirty years, with the corresponding costs.

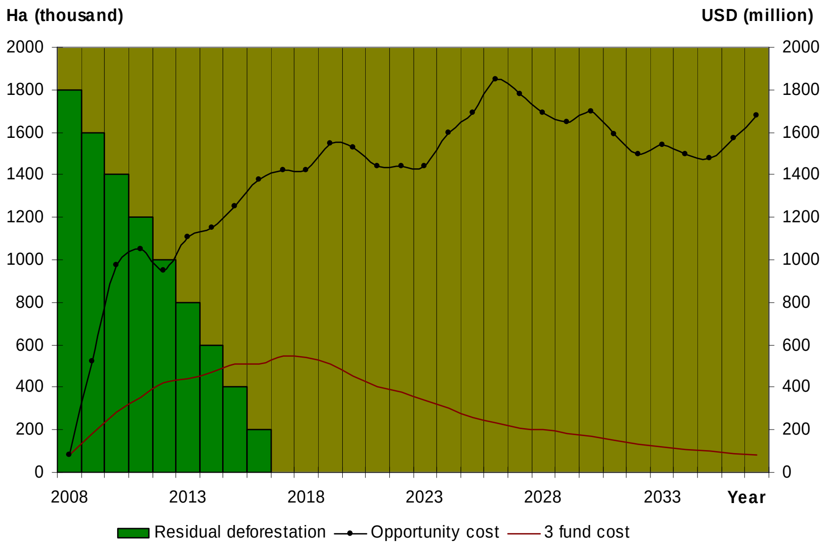

Figure 6 Scenario of residual deforestation with corresponding cost. This graph is an adapted version of figure 9 in the WHRC report *The costs and benefits of reducing carbon emissions from deforestation and forest degradation in the Brazilian Amazon* (Nepstad, 2007).

Opportunity costs in Figure 6 are calculated for all forested areas in Brazil. At current deforestation rate it would take more than 100 years until all of the Brazilian Amazon is gone, so the payment that will compensate for the forgone opportunity costs are to be handed out at the same pace. A spatial model is used that estimates the OC at different parts of the country, taking into account the type of forest and the present land use. The model uses a five percent discount rate and results in a summarized OC for Brazil over a period of thirty years. Marginal opportunity costs are expected to increase substantially for the most expensive six percents of the forest (fig. 7). This land is mainly used for soya production and cattle ranching. In the model calculations (fig. 6) one fourth of this forest is to be included in the forest that is still expected to be cleared during the first ten years.

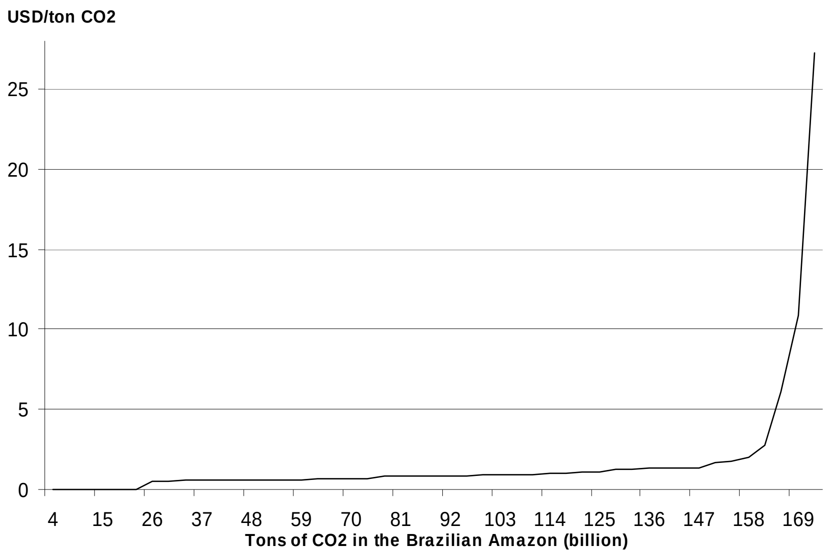

Figure 7 Marginal opportunity costs. This graph is an adapted version of figure 8 in the WHRC report *The costs and benefits of reducing carbon emissions from deforestation and forest degradation in the Brazilian Amazon* (Nepstad, 2007).

WHRC proposes that the payment for REDD is to be managed by three different funds. The calculated opportunity cost is seen as the upper limit for the costs of implementing REDD, and these funds are expected to be the actual cost of implementation. The first fund is called the Public Forest Stewardship Fund. The purpose of this fund is to compensate indigenous groups and other groups that live in and take care of the public forests. By compensating these groups their role as forest stewards is expected to be strengthened. The cost of this fund will increase initially and reach a maximum of USD 250 million per year by year ten. This is assumed to be sufficient to give half of a minimum salary to all forest steward families that live in reserves. Some additional costs are added to the fund, though after year ten it is expected to decline when forest stewards find other sources of income based on sustainable forest management.

The second fund is the Private Forest Stewardship Fund that is intended to compensate private landholders for avoided deforestation. The current law obligates private landholders to maintain 80 percent of their forest intact. Compensation would be 20 percent of the OC for these 80 percent while full compensation is given for the remaining forest that would have been legal to clear. The cost of this fund is expected to start at USD 9 million the first year and reach its peak at USD 90 million by year ten. After that, the cost is assumed to diminish when the major part of the private land has been compensated for.

The third fund is the Government Fund that compensates the government for administrative costs of monitoring and protecting the forest. The total cost of this fund is expected to reach its maximum of USD 190 million by year ten and after that it is presumed to decline when the administrative and monitoring systems are fully developed and made effective. The biggest part of this fund goes to improving the conditions for the forest stewards that work for the government, so that they will have access to public health and education.

As mentioned above, there is about 47 billion tons of carbon in the Brazilian Amazon which stretches over 330 million hectares. Using the transformation table in Appendix A this gives a total forest volume of about 240 billion cubic meters of wood. Figure 8 illustrates how the Brazilian

Amazon would be reduced if deforestation was to continue at the current rate, a so called Business as usual scenario. Figure 8 also shows the scenario calculated by WHRC where deforestation is reduced to zero in ten years. The difference between the two scenarios after 30 years is about 35.5 billion cubic meters of forest, corresponding to 25.5 Gt of CO_2 emissions. Summing up the costs of the three funds over 30 years leads to a total cost of about USD 8 billion (about USD 0.3 per ton CO_2). As can be seen in Figure 6 the cost for the three funds is lower than the total opportunity cost. This means that there is a margin to increase the costs for the funds since the opportunity cost is seen as the upper limit. According to the authors the compensation should however be lower than the full opportunity cost. This is because large forest areas are already made into reserves, placing them outside the market for agricultural and livestock land, and beside economical compensation there are also many other benefits for the Brazilian society to implement REDD, such as decreased risk for forest fires and soil erosion.

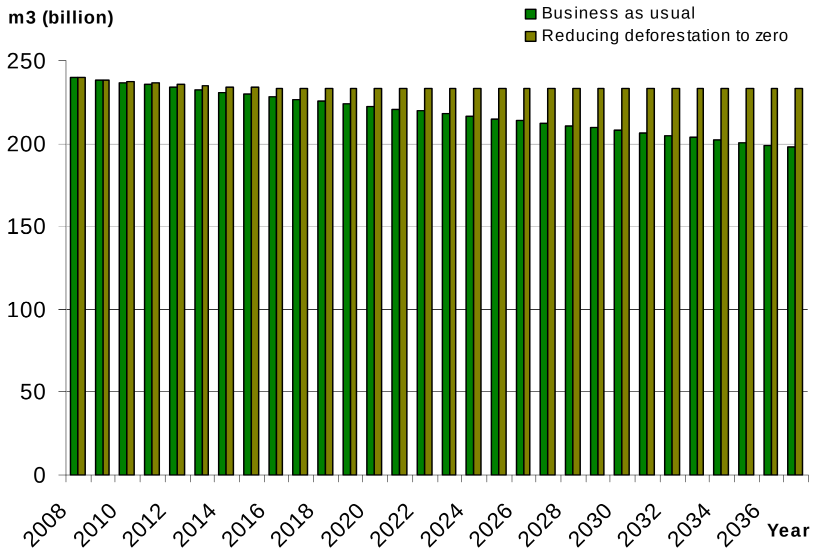

Figure 8 Scenarios for standing volume in Brazil over a period of 30 years.

3.4 Trends in the Estimated Costs of REDD

3.4.1 Marginal Abatement Cost

A Marginal Abatement Cost (MAC) curve generally shows how the marginal cost increases for every additional unit that is added to a payment scheme. An example of this is seen in figure 7, which shows how the opportunity costs of mitigating a ton of carbon dioxide through avoided deforestation increases. The graph in figure 7 represents all of the forest resources in Brazil, and it can be seen that the costs remain low until the last few percents of the forest are compensated for. This is however assuming that the cheapest measures to avoid deforestation will be performed first. In this section a similar graph is created for a number of countries that are assumed to be representative for the global deforestation. This graph gives indications on how the costs of avoiding deforestation will change depending on the volume of carbon dioxide emissions that is mitigated by implementing REDD. It can also be used to see trends among the different types of land uses that lead to deforestation.

The cost estimation by Grieg-Gran (2006) includes data from deforestation in eight countries where 46 % of the global deforestation occurs, which adds up to 6.2 out of the 13 million hectares that are deforested each year. Since these countries have high amounts of carbon in their forests they contribute to 70 % of the global carbon dioxide emissions due to deforestation. There are however many uncertainties in this data. For example Brazil has the largest annual deforestation according to this data, while other sources state that the largest deforestation occurs in Indonesia.

Grieg-Gran lines up the different kinds of land uses that cause deforestation in each country together with the corresponding area that is assumed to be cleared each year. Opportunity costs for avoiding deforestation for a period of 30 years are estimated for each type of land use in the different countries. A summary of this can be seen in Appendix B. Grieg-Gran makes the simplifying assumption that the governments of these countries are able to implement a national REDD scheme that works ideally. Three different scenarios are calculated depending on the income that is generated from timber harvesting on the land that is cleared, which results in different opportunity costs. The first scenario assumes that no compensation for timber harvesting is needed, a second scenario is calculated for a complete compensation for all of the deforested area, and an intermediate scenario tries to estimate the timber harvesting that is practically feasible in each country. In the following calculations the intermediate scenario is used. The total area being cleared in each of the eight countries is presented in Appendix C.

The data in Appendix B is used to create a MAC curve for the cost of deforestation in these eight countries. The information about the areas that are deforested is converted to tons of carbon dioxide. This is done by assuming that an average content of carbon in tropical forest is in between the world average and the average in the Brazilian forests, as was done in section 3.1. This assumption gives an average carbon content in tropical forest of 107 tons of carbon per hectare, and this is converted to carbon dioxide per hectare by a factor of 3.67. The cost per hectare is converted to the cost per ton of carbon dioxide in the same way. Figure 9 is then created as the cost in USD per ton carbon dioxide as a function of the accumulated volume of carbon dioxide that would be released if deforestation occurs. The different forms of land use are sorted ascending, starting with the land use that has the lowest opportunity cost.

There is no information available about how the cost changes within the different land uses. This is illustrated by setting two values for each point that builds up the graph; one for the cost that is estimated in the report and one for the cost of the land use that is next in the sorted table (see Appendix B). This gives the graph an angular form instead of assuming a linear relation from one point to the next. Each corner of the graph can be seen as the opportunity cost that has to be exceeded to make sure that all of the forest that is threatened to be cut down for the sake of a certain land use is compensated for.

Regardless of how it is implemented, a REDD program will need to be administrated. This would for example include monitoring the forest and measuring the carbon stock. The costs for this will vary between the different countries and as noted by Grieg-Gran (2006) the estimations are more or less speculative until it is decided how a REDD program will be designed. Grieg-Gran reviews a number of pilot projects that are initiated for REDD and find that the administrative costs for these ranges between USD 1.5 and 19 per hectare. A central estimate of USD 10 per hectare has been used as an administrative cost in Figure 9. Since deforestation of 6.2 million hectares is to be avoided each year, and be compensated for a period of 30 years, an administrative cost of USD 300 is added to each hectare, which corresponds to USD 0.76 for each ton of carbon dioxide.

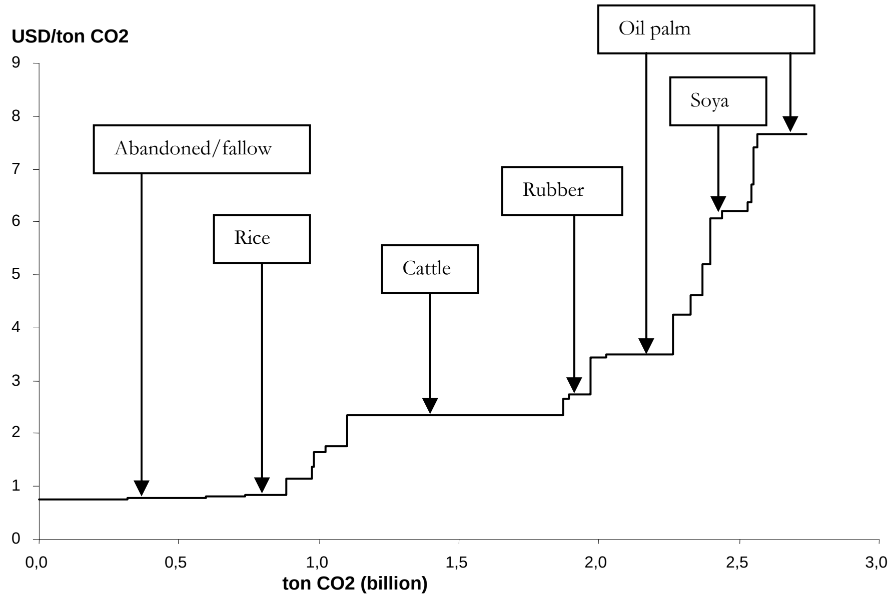

Figure 9 MAC curve for opportunity costs of avoiding deforestation in eight countries that are responsible for 70 % of greenhouse gas emissions due to deforestation. Examples of foregone land uses are indicated.

3.4.2 Interpretations of the MAC curve

There are many uncertainties in the graph created above and it should be seen as a rough sketch. Grieg-Gran (2006) has compiled the information based on a variety of different reports and notes that these differ in the approach towards some of the factors that influence the result when calculating the opportunity cost. As mentioned above, these estimates assume that a program for avoided deforestation will work ideally. At the moment there are however few of the concerned countries that have the capacity for monitoring and administrating a REDD program. Zero leakage is also assumed. Whether such assumptions are realistic or not will depend on how REDD will be implemented. This will be discussed further in chapter 4.

Figure 9 differs significantly from the MAC curve presented in figure 7, which is partly because they describe different scenarios. Figure 7 represents the Brazilian Amazon, whereas figure 9 represents eight countries where Brazil is one of them. Further, figure 7 represents all of the forest in the Brazilian Amazon and the opportunity cost that is corresponding to every part of it. Figure 9 only describes the part of the forests that would be deforested in a business as usual scenario. This explains why the price starts increasing at a later stage for figure 7, since large parts of the Brazilian Amazon are not threatened by deforestation and will therefore have low opportunity costs. However, the most expensive land in the Brazilian Amazon reaches costs that the graph in figure 9 never gets close to. There is no obvious reason to why the two studies make such different estimations of the highest opportunity costs.

As can be seen in Appendix B, the land use in figure 9 that has the lowest opportunity cost is land that would not be used after the deforestation. The opportunity cost of this land is assumed to be zero. This is probably because the land is logged illegally and no economical compensation is needed. Land used for growing rice or other crops with a low yield is among the land uses with lowest opportunity cost. This is followed by cattle to produce beef or dairy. Rubber production is in the centre of the graph, and the part of the graph that has an opportunity cost above USD 3 per ton CO_2 is mainly oil palm and soya production. In general, as can be seen in Appendix B, the land use that is in small scale or performed by smallholder has a lower opportunity cost than the corresponding activities performed on a larger scale.

This MAC curve assumes that the land with the smallest opportunity cost will be compensated for first. However, this is provided that carbon credits would be given for a REDD program within a trading scheme. As will be discussed in section 4, there is a variety of suggestions on how to finance REDD, and it is not certain that it will be based on a market system.

3.5 Sensitivity Analysis of Costs for implementing REDD

Sensitivity analyses can be used to see how changes in the input variables will affect the output results. In this section a sensitivity analysis is performed to see how the costs for implementing REDD, as well as the expected volumes of emission reductions, can vary depending on changes in the initial assumptions. The MAC curve that was derived in the previous section is used to illustrate these changes.

Input variables for the graph in figure 9 are for example administrative costs of implementing REDD and opportunity costs of different land uses. Output is given by the MAC curve and the total annual cost of implementing REDD which can be derived by calculating the integral of the graph. By changing the input parameters one at a time the effect that each parameter has on the result can be seen. This will also give an indication on which input parameters that are the most important sources of uncertainty. (Pascual et al., 2003)

The costs and volumes that are used to create the graph in figure 9 are based on Grieg-Gran (2006) and presented in Appendix B. As noted by Grieg-Gran these figures contain many uncertainties and should be seen as a rough approximation of the actual cost of REDD. Thus, this sensitivity analysis is not performed merely to conclude that there are high degrees of uncertainty in the figures that are available concerning the cost of implementing a REDD program. The main objective is to highlight some of the factors that have an impact on the cost of a REDD program and to see how the total annual cost as well as the marginal abatement cost will change.

3.5.1 Sensitivity parameters

A number of parameters are defined below. These will be used to perform the sensitivity analysis. The changes made on each parameter are motivated by the brief discussions below. However, this study does not aim at estimating the probability that a parameter will deviate from the initial assumption.

Changes in the input parameters can either be affecting the volume, represented on the horizontal axis, or the costs that are represented on the vertical axis. These changes will modify the graph and thereby changing the integral value that represents the total annual cost.

For cultivation the change in opportunity cost is mainly due to changes of the global market price for a certain crop. If the price increases the opportunity cost for avoided deforestation will increase as well, since it will be possible to make a larger profit on the same area and this profit is what is needed to be compensated for to avoid deforestation. It is important to note that the increase in opportunity cost will not be the same as the increase of the global market price, since the opportunity cost is equal to the profit that is made on the land use and not on the income. When the global market price increases the farmer that makes an income, for example from selling a crop, will have a larger income compared to the spending than earlier. A decrease in the market price of that crop will have the opposite effect. However, there will be a limit where the income is not high enough to motivate the spending that is needed for cultivation. When this limit is reached the incentives for clearing forest to make space for cultivation will be reduced substantially.

- Opportunity cost of soya

As can be seen in figure 9, the opportunity cost for the forgone land use of cultivating soya beans is relatively high. The global market prices of soya can fluctuate greatly and during the last few years there have been a large increase. Since the beginning of 2006 the market price has risen with more than 100 percent (Global Research, 2008-06-26). Soya is however only assumed to be contributing to the deforestation in two of the eight countries that are investigated by Grieg-Gran.

- Opportunity cost of oil palm

Palm oil has a high opportunity cost and is represented in several of the eight countries investigated by Grieg-Gran. The cultivation of oil palm is commonly mentioned as an important cause of deforestation. The market price for palm oil has risen with more than 100 percent since 2006 (International Plant Nutrition Institute, 2008-06-26). The prices are however expected to fall in the future when more oil palm is cultivated (PalmOilHQ, 2008-06-26).

- Opportunity cost of cattle ranching

As can be seen in figure 9, the opportunity cost of cattle ranching is low and the global market price for meat has been relatively stable the last twenty years (FAO, 2008-06-27). However, the areas that are deforested due to cattle ranching are large and small changes in the opportunity cost could therefore have a substantial impact on the total cost.

- Administrative costs

The cost of administrating a REDD program will depend to a large extent on how such a program is implemented (Blaser & Robledo, 2007). It is difficult to estimate the administrative costs of performing REDD on a national scale and the estimate used in the initial scenario is very uncertain.

- Increased deforestation

The global rate of deforestation has been stable for the last few years with about 13 million hectares being cleared annually. There are however many factors that may influence the rate to change from one year to the other. Natural reasons such as forest fires and drought can have an impact, as well as a change in practice of forest management in a country with large forest resources. The Democratic Republic of Congo (DRC) is used as an example, since it is likely to increase its rate of deforestation in the next few years due to large investments that have been made to expand the oil palm cultivation (Laporte, 2007).

- Limited participation or unsuccessful implementation

Grieg-Gran (2006) makes the simplifying assumption that all eight countries will be able to implement a successful REDD program. With all the difficulties that are associated with a REDD program this is highly unlikely to occur. If any of the eight countries fail to implement REDD it will lead to a smaller volume of emission reductions. It is also possible that an agreement on how to implement REDD cannot be made. Brazil has stated that they will not agree on a market solution to finance REDD and if Brazil is not included the volume of emission reductions will be reduced severely (Point Carbon 1, 2008-04-16).

- Logging

Grieg-Gran has sketched three different scenarios for compensation of the forgone income from logging. In the first scenario it is assumed that no compensation is needed, in the second a full compensation will be given for all logging and the third scenario is an intermediate where the practical limitation of timber harvesting has been estimated. The opportunity costs of these different scenarios vary substantially.

3.5.2 Results of Sensitivity Analysis

With the initial assumptions that are used for figure 9 the total annual cost for implementing REDD in these eight countries is USD 7.13 billion. This is given by calculating the integral of the graph. The results of the sensitivity analysis are given in table 2. As can be seen there is a linear relation between the change of each parameter and the total cost. A few examples are given for each parameter to illustrate what the total cost would be within a range that is considered possible in this study.

As can be seen in table 2 many of the scenarios that are used for the sensitivity analysis will change the annual cost of implementing REDD with a billion US dollar or more. The largest effect is given by an increase in administrative cost by 300 percent, resulting in a cost for REDD that is more than six billion US dollar larger than given by the initial calculations. The smallest changes are given by the scenarios where the opportunity cost for soya is decreased with 50 percent and if a REDD program would not include Bolivia or Cameroon, each changing the total cost with less than five percent of the initial assumption.

Changing the opportunity cost of soya will add about half a billion to the total cost for every hundred percent that it is increased. Cultivation of soya beans is only performed in two of these eight countries and the areas that are cultivated are rather small. The opportunity cost is however high and the effect that these changes would have on the total cost might therefore be substantial.

Table 2 Results of sensitivity analysis. Total cost in initial scenario was USD 7.13 billion. It is important to note that an increase in the opportunity cost is not the same as an increase in price. The change in the price on the global market will be much smaller.

Parameter being Changed	Scenario	Change of cost for REDD [USD]	Total cost for REDD [USD]
Opportunity cost (OC) of soya	Increased OC with 100 %	+ 0.50 billion (7.1 %)	7.63 billion
	Increased OC with 200 %	+ 1.01 billion (14.1 %)	8.13 billion
	Increased OC with 300 %	+ 1.51 billion (21.2 %)	8.64 billion
	Decreased OC with 50 %	- 0.25 billion (3.5 %)	6.87 billion
Opportunity cost of oil palm	Increased OC with 100 %	+ 1.71 billion (24.1 %)	8.84 billion
	Increased OC with 200 %	+ 3.43 billion (48.1 %)	10.55 billion
	Increased OC with 300 %	+ 5.14 billion (72.1 %)	12.27 billion
	Decreased OC with 50 %	- 0.86 billion (12.0 %)	6.27 billion
Opportunity cost of cattle ranching	Increased OC with 100 %	+ 1.30 billion (18.2 %)	8.42 billion
	Increased OC with 200 %	+ 2.60 billion (36.4 %)	9.72 billion
	Increased OC with 300 %	+ 3.89 billion (54.6 %)	11.02 billion
	Decreased OC with 50 %	- 0.65 billion (9.1 %)	6.48 billion
Administrative cost (AC)	Increased AC with 100 %	+ 2.09 billion (29.4 %)	9.22 billion
	Increased AC with 200 %	+ 4.19 billion (58.8 %)	11.31 billion
	Increased AC with 300 %	+ 6.28 billion (88.1 %)	13.41 billion
	Decreased AC with 50 %	- 1.05 billion (14.7 %)	6.08 billion
Increased deforestation in DRC	Increased with 100 %	+ 0.37 billion (5.2 %)	7.50 billion
	Increased with 200 %	+ 0.75 billion (10.5 %)	7.87 billion
	Increased with 500 %	+ 1.86 billion (26.1 %)	8.99 billion
Limited participation or unsuccessful Implementation	Without Brazil	- 2.85 billion (40.0 %)	4.28 billion
	Without Bolivia	- 0.33 billion (4.6 %)	6.80 billion
	Without Cameroon	- 0.26 billion (3.6 %)	6.87 billion
Logging	No compensation	- 2.09 billion (29.3 %)	5.04 billion
	Full compensation	+ 1.49 billion (20.9 %)	8.62 billion

A change in the opportunity cost of oil palm would have a large impact on the total cost of REDD. An increase in the opportunity cost with hundred percent would increase the total cost with almost 25 percent. This is because the opportunity cost is high and cultivation is practiced on large areas in five out of the eight countries that are investigated. Cattle ranching is performed on large areas, mainly in Brazil, and even though the opportunity cost is low an increase might have a large impact. An increase with one hundred percent would increase the total cost with almost 20 percent.

In the initial scenario the administrative cost is USD 0.76 per ton of carbon dioxide. This gives a total administrative cost of 2.1 billion. If the administrative cost would increase with one hundred percent it would consequently be 4.2 billion, giving a total cost for REDD that is 2 billion larger than in the initial scenario.

The effect of increased deforestation in the Democratic Republic of Congo DRC would not be that large unless the increase is severalfold. The initial area that is cleared in DRC is relatively small and the opportunity costs are low, thus not affecting much on the total cost of REDD. The initial scenario assumes a total avoided deforestation of 6.9 million hectares, and an increase in the deforestation in DRC with 100 percent gives a total avoided deforestation of 7.3 million hectares. If Brazil was not included in a REDD program, the total avoided deforestation would be reduced to 3.1 million hectares. This would reduce the total cost of REDD with about 40 percent, though resulting in a much lower amount of emission reductions. Whether forgone income from logging is included in the calculations or not will have an impact on the total cost. A full compensation would increase the total cost calculated in the initial scenario with about 20 percent.

3.6 Chapter summary

There is more carbon stored in the forest ecosystems on earth than in the whole atmosphere. Due to this there is a potential for large emissions of carbon dioxide, as well as there is a potential to sequestrate. The current rate of deforestation is 13 million hectares per year, releasing about 6 Gt of carbon dioxide to the atmosphere and thus constituting 20-25 percent of the total anthropogenic emissions and being the second largest source of emissions after energy production.

Reducing deforestation is considered a cost effective measure to mitigate the emissions of carbon dioxide to the atmosphere. The most frequently used method to estimate the costs of implementing a program for avoided deforestation is to calculate the opportunity cost. Except for the opportunity cost there will also be administrative costs and these may make up a significant part of the total cost. So far there are many uncertainties regarding how a REDD program would be implemented and it is therefore difficult to approximate the true costs. Studies trying to do so differ within a few US dollars to 30 US dollars per ton of carbon dioxide mitigated. Estimations for the total costs of performing a program for reducing emissions from deforestation find that the annual cost could be USD 12.2 billion for a reduction to zero deforestation (Blaser & Robledo, 2007), 5-10 billion for mitigating 70 percent of the emissions (Grieg-Gran, 2006) or even 33.5 billion just to reduce the emissions with 50 percent (Obersteiner et al., 2006).

Regardless of the differences between the estimations that have been made, the cost of reducing emissions through avoided deforestation is likely to be low compared to other measures that are performed on an international basis to mitigate CO_2 emissions. This is especially true initially. Marginal costs are however expected to rise when the forest resources with lower opportunity cost have been compensated for, which is illustrated in the MAC curve in figure 9. This graph also illustrates how trends can be seen among the land uses that have different opportunity costs. Oil palm and soya production cultivated in large scale have the highest cost whereas the opportunity cost for land that is left to lie fallow is next to zero.

The sensitivity analysis that was performed illustrates how small changes in the initial assumptions may have a large impact on the total cost of implementing a REDD program. An increase in the administrative cost with 300 percent would almost double the cost that was calculated in the initial scenario based on Grieg-Gran (2006). Changes in the market price for a product can change the opportunity cost severalfold. Since the prices for soya, palm oil and meat have increased remarkably the last few years it is not unrealistic that the opportunity cost for these land uses would change with a few hundred percent, thus having a large impact on the total cost of REDD.

4 Financial Solutions to REDD

The previous chapter illustrated how to calculate the costs of a REDD program and the magnitude of funding that will be needed for performing REDD on a large scale. This chapter discusses the different alternatives for generating this funding.

4.1 Proposed Solutions

Reducing the rate of deforestation is considered a cost effective method to decrease emissions of carbon dioxide (Stern, 2006). Developing countries have so far not agreed on any binding commitments to reduce their emissions of greenhouse gases, and most of them are also unlikely to do so in a post-2012 climate regime. Deforestation is mainly occurring in developing countries in the tropical region, and incentives will be needed in form of financial compensation for the forgone income due to avoided deforestation. (Daviet et al., 2007)

Capacity building is also needed before a country can manage a program for avoided deforestation, and this must also be funded. There are several studies that estimate the expected costs for compensating developing countries for the implementation of REDD. Uncertainties in these studies are many but most of them find that USD 5 billion or more is needed annually to reduce deforestation to zero (see section 3.2). This is a considerable amount of money, but not unattainable in the context. Norway has recently decided to raise USD 500 million a year for the next five years to support measures for avoided deforestation, and the World Bank has created a fund that at the moment has gathered USD 150 million for the same cause. A strong wish to combat deforestation is evidently emerging. However, there is so far no agreement on how to integrate REDD in future climate regimes, and the discussions are currently in process.

There are several possible alternatives on how to gather funding for REDD, and all of them have both advantages and disadvantages. This section will describe the main outlines of the proposed solutions that are most frequent in the discussion. A strict categorisation is difficult since many proposals overlap each other and some proposals are not yet fully developed. Hence the following is to be seen as a rough sketch. A central question is whether a market with tradable carbon credits is to be applied or not and there are a few different approaches towards how such a market solution could be shaped. Other solutions involve creating a fund to gather money for REDD, or that the funding would be managed through official development assistance (ODA). Combinations of these alternatives are also possible, as well as a country specific approach where REDD has different shapes in different countries (Klas Österberg, pers. comm.).

4.1.1 Integrate REDD into the global carbon market

The most frequently suggested financial solutions for REDD are market solutions. The structure for such a solution already exists due to the flexible mechanisms, and REDD could be implemented in the trading system in a similar manner. Avoided deforestation would then be rewarded with credits that are tradable on the global carbon market. Annex 1 countries would be able to buy these credits as a way of achieving their commitments under a future climate regime.

Compensated Reduction (CR) is based on a proposal that the Coalition of Rainforest Nations presented at COP 11 in 2006. Through this system developing countries could voluntarily join the trading system and receive credits for reducing their deforestation rate. A historical baseline for the total deforestation in each of the joining nations would be developed and credits are to be handed out after the reduction can be proven. (Environmental Defense, 2007)

A market solution does not exclude the possibility that a fund is created to facilitate the system. As mentioned above a few funds have already been created for capacity building. The fund that the World Bank has created is called the Forest Carbon Partnership Facility (FCPF), and it works towards getting a more sustainable forest management while decreasing the emissions of greenhouse gases that arises due to deforestation (The World Bank, 2008-04-15). This partnership can at the moment be seen as a fund solution, since it will select a few countries to function as pilot projects for compensation for decreased deforestation through the fund. But according to Peterson et al. (2007) the FCPF was created with the hope that certified credits from the carbon market would be received if REDD is implemented in future climate regimes.

The Carbon Stock Approach is a market based approach that is developed by the Centre for International Sustainable Development Law (CISDL) and the Global Public Policy Institute (GPPI). It differs from CR in some aspects, mostly regarding the attitude towards baselines. The main objective of this approach is to involve the private sector, assuming that it is the best way of generating the amounts necessary for implementing REDD. The volume of carbon that is stored in each of the participating countries forest in a base year is calculated, without considering the historical circumstances. The part of this forest that is not threatened by deforestation is considered a reserve that is to be protected without compensation. The rest of the forest is influenced by the global carbon market and will be eligible for carbon credits if it is stored. In that way both private and public interests can get direct access to these carbon credits if they arrange so that the forest is protected. (Prior et al., 2007)

A similar approach is suggested by the European Commission Joint Research Centre. They propose that historical averages are to be developed for the period 1990 to 2005, and from that all tropical countries are divided into two groups, those who have a large and those who have a small deforestation rate. The income from REDD would then be divided between the countries that reduce their large deforestation and the countries that maintain a low deforestation. Carbon credits are then given to be traded on the global carbon market, based on each ton of carbon dioxide equivalent that is reduced. (Mollicone et al., 2007)

4.1.2 Alternative market solutions

The expected volume of emission reduction through avoided deforestation is large. Several studies indicate that releasing credits from REDD on the global carbon market might overflow the market and create volatility (Leach, 2008). A proposed solution to this is called the Dual Market approach, which suggests that REDD is managed on a market that will not be fungible with the existing carbon market. The proposal is developed by the Center for Clean Air Policy (CCAP), which is an independent, non-profit organisation that is considered one of the leaders in developing climate and air quality policies. A separate market for forest projects is to be created, where investments can be made for the sake of reducing deforestation in developing countries. Different REDD-programs will be developed and Annex 1 countries will be able to choose from these as a way to fulfil parts of their commitments under the Kyoto Protocol. However, the UN will set a maximum of percentage of a commitment that a country can fulfil through REDD, so that the impact on domestic reductions will not be too large. By 2020, the COP will decide whether the REDD-market is sufficiently stable to be directly linked to the global carbon market. (Ogonowski et al., 2007)

The first compensations for avoided deforestation with the intention to decrease carbon dioxide emissions came through the voluntary carbon market. The voluntary market offers a possibility for companies and private persons to compensate for some emission generating activity that they perform. The credits that are sold on the voluntary market are called Verified Emission Reductions (VER), and are not tradable as credits on the global carbon market. VER credits can therefore not be used to fulfil commitments under the Kyoto Protocol. Forest projects of different kinds are common on the voluntary market and the aim of reducing emissions is often combined with other aspects such as protecting the biodiversity. The voluntary market has increased the last few years and is likely to continue to do so. REDD is assumed to be an important part of the voluntary market and grow in proportion to it. So far, most of the activities on the voluntary market have been performed by a few non-profit organisations, but the present development goes towards involvement of many different actors with a clear objective to gain profit. However, REDD projects might not follow the same development since these projects to a higher degree resemble official development assistance. (Peterson et al., 2007)

Since 1997 a project for avoided deforestation has been taking place in Noel Kempff Mercado National Park in Bolivia, which serves as an example of a REDD project on the voluntary carbon market. The project is called the Noel Kempff Mercado Climate Action Project and the purpose of the project is to protect 800,000 hectares of tropical forest that was threatened by deforestation from timber harvesting and agricultural use. Over the next 30 years the project is expected to mitigate 5.8 Mt of CO_2 emissions (The Nature Conservancy, 2008-04-14). Since 2005 the project has generated carbon credits for the Chicago Climate Exchange (CCX) which is a North American voluntary market for carbon offsets. Until 2007 it had generated about 1 million carbon credits for a market price of USD 4 per CO_2eq. (Peterson et al., 2007)

4.1.3 Fund solution

Market solutions for REDD, as well as all kinds of market solutions to mitigate global warming, are not uncontroversial. Some critics question the moral aspects of trading with carbon emissions instead of making domestic emission reductions, especially with the modest reduction of 5 percent compared to the levels in 1990 that is what the Annex 1 countries are bound to during the first commitment period of the Kyoto Protocol (Lohmann, 2006). Others are critical to the stability in a market solution, and a solution through a fund is frequently mentioned as an alternative, either as a complete solution or as a part of the solution. Such a fund could be based on mandatory contributions from Annex 1 countries under a post-2012 agreement, though the funds that are discussed in this section are based on voluntary contributions.

Brazil, which is one of the countries with the highest rate of deforestation in the world, opposes the idea of gathering finances to REDD through trading with carbon credits. Instead they have proposed a solution where the market is replaced by a voluntary fund where developed countries can contribute without the possibility to get carbon credits. A baseline for the previous deforestation would be set, taking into account the difference in carbon stored in forest in different areas so that compensation for avoided deforestation would be proportional to the actual mitigation of released carbon dioxide emissions. (Stern, 2006)

Pilot projects for a fund solution have already started through several separate initiatives. As mention above, the World Bank has introduced the Forest Carbon Partnership Facility, which is a fund that will work towards compensating developing countries for avoided deforestation, with the aim of contributing to a more sustainable forest management while decreasing the emissions of greenhouse gases. The FCPF is divided into two separate mechanisms. At first about twenty developing countries will be involved in The Readiness Mechanism that will prepare these countries for a future participation in REDD. The second part, The Carbon Finance Mechanism, will select a few of these twenty original countries to function as pilot projects for compensation for decreased deforestation. At this moment, nine developed countries and one non-governmental organization have contributed with USD 150 million to FCPF (The World Bank, 2008-04-15). As noted above the FCPF is possibly not a pure fund solution, since it was developed with a hope of receiving future carbon credits. However, at its current shape, it serves as an example of a fund solution for implementing REDD.

4.1.4 Official Development Assistance

A financial solution that is very similar to a fund solution is to finance REDD through Official Development Assistance (ODA). This could be done by an increase in the ODA where a certain part is earmarked to go to REDD programs. No carbon credits would be given so countries that give money to REDD through ODA would not be able to fulfil their commitments under the Kyoto Protocol in this way.

As mentioned above, Norway has recently decided to support measures for avoided deforestation by USD 500 million a year for the next five years, and this money will come from ODA. The Norwegian ODA has increased this year and it is the surplus that goes to REDD projects. The amount that goes to other forms of ODA is therefore unchanged in comparison with last year. (Hans Nilsagård, pers. comm.)

A financial solution to REDD through ODA could be combined with other sources of funding. ODA could for example work as a complement to a market based solution, by providing funding for capacity building. A solution where ODA is combined with a voluntary fund is also possible. At the moment a lot of capacity development is needed since most developing countries are not yet ready to manage a REDD program with high credibility. ODA can play an important role to prepare these countries to manage REDD projects in future climate regimes (Ibid.).

4.1.5 Combination of different alternatives

Combinations of all of the mentioned alternatives are possible. This could be done in several different ways, and a few have been mentioned above. World Resources Institute (WRI) presents a review of proposed financial solutions from different countries and organizations in their report *REDD Flags: What We Need to Know about the Options*, and most of these suggest combinations of some sort (Daviet et al., 2007). Combining market and non-market solutions dominate, mostly where a fund or ODA is used together with CDM projects where REDD is included. The non-market part would work as support to the market solutions and provide funding for capacity building. Other combinations are to use different kinds of funds together with ODA. There are so far few detailed descriptions on how a combined financial solution would work in practice, and the proposals that can be found are only comprehensive. However, according to Klas Österberg at the Swedish EPA, a combined financial solution to REDD is what seems most probable at the moment (pers. comm.).

4.1.6 Country specific solution

Implementing REDD in a way that is tailor-made for all involved countries could be a possible solution. This would probably be performed by developing a few different alternative strategies and letting the countries where these projects are to be performed choose the solution that they find most suiting. The proposal has been presented by a few developing countries but so far it is not clear how the details in such a solution would be formed. (Hans Nilsagård, pers. comm.)

4.2 Criteria for comparison

To be able to make comparisons between the different alternatives, a list of criteria has been made. These criteria consist of important areas that a financial solution to REDD preferably should take into consideration. On the basis of these criteria an analyzing discussion of the different alternative solutions will be performed. The criteria are to be seen as the areas that are found most important in this study and not as a complete description of all aspects of a complete REDD program. They are also likely to overlap each other.

The wealth of detail that is available about the different financial solutions differs greatly. Some suggestions are prepared and described in detail while other suggestions are merely mentioned briefly in research papers covering the field. Because of this it is difficult to make a complete comparison of the alternative solutions. The criteria for comparison that are used in this study are:

- **The source of funding**

The key difference between the different alternatives is the question of where the money will come from. It is important that the solution is durable and not just a temporary source of funding. Possible effects that the solution will have on other areas that are in need of funding should also be considered.

- **The amount of money that can be generated**

Even though REDD is expected to be a cost effective method of emission reduction, there are large amounts needed to perform a program that will have a substantial effect. The costs are also likely to increase with time. Thus, a financial solution to REDD will have to generate sufficient amounts of money.

- **The definition of activities**

The definition of deforestation is well defined in the Marrakesh Accords (2001). The definition of degradation however is at the moment less definitive and can be interpreted in different ways. The ideas about what should be included in REDD differ and this will have an effect on the impact of a REDD program as well as the viability.

- **The support**

To evaluate the viability of a proposed solution for REDD it is important to consider the attitude that different actors have towards the proposals. A proposal that is disliked by many decision makers is unlikely to be included in a future climate regime. The attitude of countries with a high deforestation rate, such as Brazil and Indonesia, is also crucial.

- **The baseline area of the program**

There are several possible approaches towards the scale of the baseline where REDD is to be implemented. A program could for example be performed on a project basis or on a regional basis of some scale. The chosen alternative is likely to have a great effect on the viability and measurability of the program.

- **The approach towards baseline for comparison**

To be able to estimate whether the rate of deforestation is changing or not, some sort of baseline must be determined for comparison. This could for example be done by calculating historical averages.

- **The measurability of achieved results**

It is of great importance for the credibility of any REDD program that the results can be measured. The risk of leakage should also be considered to make sure that the program is actually making progress.

- **The effect on the global carbon market**

With the large volumes of emission reductions as well as large sums of money that are expected from REDD, a financial solution is likely to influence the global carbon market. It is therefore important to consider what effects this might have on the mitigation of greenhouse gases in general.

- **Additional benefits**

A REDD program that is well implemented is likely to bring many positive synergies. Avoided deforestation will help to preserve biodiversity and avoid erosion. The income that can be generated through REDD can also contribute to a sustainable development and to eradicate poverty if it is distributed to poor landowners and indigenous groups. A REDD program could also provide developing countries with new technologies and knowledge in sustainable forest management.

4.3 Comparison of alternative financial solutions

In this section the criteria that were described in the previous section will be used as a basis for an analyzing discussion of the different financial solutions that were described in section 4.1. Advantages and disadvantages of the different proposals will be pointed out and comparisons will be made. As can be seen, the suggested proposals that are grouped together in section 4.1 do not necessarily relate to the criteria in a similar way. A summary of the analysis is presented in table 3.

The source of funding

With the large amounts of money that are expected to be needed for a REDD program, it is likely that it will have an impact on other adjacent areas that are in need of funding. An example that can be seen already is the Norwegian fund for avoided deforestation that was mentioned above. The fund is created through Norwegian ODA. The amount that Norway invests in ODA is in proportion to their Gross National Product (GNP) and with last year's increase in GNP a proportional increase in ODA would have been natural, but by creating the fund for avoided deforestation the amount that goes to other development projects is about the same as last year. In that way this fund has an indirect negative effect on the amount invested in development projects. This problem does not only account for a scenario where REDD would be financed fully by ODA, but also if ODA is a part of a combined financial solution. However, the benefits from a successful REDD program could fulfil similar objectives as ODA since it can contribute to a sustainable development in the host country.

A fund solution to REDD is similar to a solution through ODA. Since a fund solution would most likely be based on voluntary contribution and not give any carbon credits, it is possible that Annex 1 countries will look at such a fund as ODA and that donations would be taken from money that otherwise would have gone to ODA. Because of the absence of incentives for the private sector to donate to a REDD fund it would be depending on the donations from governments. It is likely that this would result in a stable income to the countries where the REDD programs are implemented, and this would not be affected by the fluctuations on the carbon market (Daviet et al., 2007). A disadvantage with a fund solution is that incentives for developing countries to continually further advance their REDD program, to compete with other developing countries to get funding for REDD, would probably not be as strong as with a market solution (Ogonowski et al., 2007).

A financial solution to REDD through the carbon market enables funding to come from both the public and the private sector. This will not be as stable as a strict fund solution, since the market price can fluctuate, but gives good possibilities for large amount of funding. A market solution would also be easy to get started since the market is already working for CDM projects, where afforestation and reforestation projects are included, and REDD could be included in a similar way.

Since the credits from a REDD program are likely to be relatively cheap there is a risk that there will be less domestic reductions in Annex 1 countries and that other types of CDM projects will be less competitive in comparison. There are however many uncertainties with REDD projects and it might be necessary to rescale the credits to make up for these uncertainties. For example a reduction of 1.2 tCO_2 could be sold as 1 tCO_2 to make up for the uncertainties (Klas Österberg, pers. comm.). Credits from REDD would however still be likely to have a large impact on the global carbon market, as will be discussed further below.

If a separate market is created for REDD, as proposed by CCAP in the Dual Market approach, the funding would come from both public and private sectors. A cap would be set as to how many percent of their emission reductions that an Annex 1 country can buy from REDD credits. In that way it should not have a negative effect on the domestic emission reductions in Annex 1 countries.

The voluntary market would not give any carbon credits that count as emission reductions under a post-2012 agreement. The credits are therefore likely to be bought mainly by companies and private persons. The voluntary market is trend sensitive, and since there would be no commitments there is a huge risk that the funding for a REDD program through the voluntary market would not be sustainable (Hans Nilsagård, pers. comm.).

A country specific approach to finance REDD would lead to the development of a few different alternative sources of funding that could be chosen from by the host country of a REDD program. How the composition of these alternatives would be formed is at the moment unclear.

The amount of money that can be generated
Large amounts of money are needed to implement a REDD program that has a substantial effect on the global emissions of greenhouse gases. A market solution has clear advantages over the non-market solutions in this aspect since a market solution is expected to be able to generate considerably more money. This is mainly because there would be incentives for both public and private sector to buy these credits, as with the credits that are tradable through CDM projects at the moment (Ogonowski et al., 2007). A REDD program that is financed through a fund that is not connected to the carbon market will probably not generate enough money to perform a long term reduction of the global deforestation (Environmental Defense, 2007). An advantage with a fund solution however, as well as a solution through ODA, is that it could finance capacity building directly through the fund. How capacity building would be handled within a strict market solution is not that obvious.

The Dual Market approach is, according to CCAP, that has developed the proposal, likely to generate more money than any non-market solution would (Ogonowski et al., 2007). Since the private sector would get involved this is probably a reasonable assumption. In 2008 about 80 percent of the buyers of CDM and JI credits came from private companies (Capoor & Ambrosi, 2008). The Dual Market approach also proposes an agreement where developed countries commit to finance capacity building to prepare developing countries for the implementation of a REDD program, something that will be needed if a market solution for REDD is implemented in a post-2012 climate regime. However, a limiting factor for the funding available through the Dual Market approach is that the amount of credits that an Annex 1 country can buy will be restricted by a percentage of the total committed emission reduction. As a consequence of this the incentives for developing countries to perform REDD activities might also be limited.

A voluntary market, as noted above, is trend sensitive. Even if there would be a possibility to generate a sufficient amount of money to REDD, which is doubtful since a voluntary market does not include any binding commitments for developed countries, there is no guarantee that this would lead to a long term funding. The voluntary market would not be regulated and negative publicity from only a few credit suppliers could lower the reliability of the system quickly.

The definition of activities

The acronym REDD most commonly stands for Reducing Emissions from Deforestation in Developing countries, though in some cases it stands for Reducing Emissions from Deforestation and forest Degradation. The acronym RED, as in Reducing Emissions from Deforestation, is also used occasionally. This demonstrates the ambivalence towards the term degradation, which at the moment does not have a clear definition under the climate negotiations. However, a debate is going on about the definition and what should be included in this. An alternative definition could for example be to include degradation of biodiversity (Hans Nilsagård, pers. comm.).

Compared to deforestation, forest degradation is much more difficult to measure and quantify with certainty. Though without including degradation in a REDD program there is a substantial risk to fail with reducing emissions just by halting deforestation, since degradation could go on as before or possibly increase.

Most articles that discuss the different approaches towards financing REDD do not specify in detail what should be included in such a program. The acronym REDD is used as though there was a definition agreed upon. However, in some proposals the definition of the proposed activity is stated. Compensated Reduction, the proposal that is developed by the Coalition of Rainforest Nations, proposes that the focus would be on the reduction of deforestation (Myers, 2007). The Norwegian ODA fund will partly be used in a five year project in Tanzania that will be "invested in research and capacity-building, developing pilot areas for reduced deforestation, technology development and methods to measure and verify changes of the carbon level in forests" (Point Carbon 2, 2008-04-22). The aim of measuring the change in carbon level in the forest indicates that both deforestation and forest degradation is to be included. This goes for most proposals, and is stated explicitly in the Carbon Stock Approach (Prior et al., 2007), the Forest Carbon Partnership Facility (The World Bank, 2008-04-15), the Dual Market approach (Ogonowski et al., 2007) and the Joint Research Centre proposal (Mollicone et al., 2007).

The support

For a financial solution for REDD to be included in a post-2012 climate regime it will need to have massive support. Besides that, it is also important that countries with large forest resources and a high deforestation rate will agree to join so that the REDD program can make a substantial difference.

A market solution in combination with a fund for capacity building is supported by most governments (Ogonowski et al., 2007), and this combination is also frequently mention in the review presented by WRI that was discussed in section 4.1.5 (Daviet et al., 2007). A strict fund or ODA solution does not have a strong support, and the main argument against it seems to be that it is not expected to generate enough funding.

The Dual Market approach was presented at the COP 13 in Bali, December 2007. It is so far hard to find information about what different actors think of the proposal. However, CCAP is a recognized developer of climate policies and the Dual Market approach fulfils many important criteria, being a market solution without any negative effects on the existing carbon market, and also solving the issue of financing capacity building.

A country specific solution, as well as a financial solution through the voluntary carbon market, is seldom mentioned in the papers and articles concerning REDD, so the support for such solutions must be considered small.

Brazil and Indonesia are the countries that emit the largest volumes of CO_2 from deforestation. Brazil is at the moment not supporting a market solution even though it might be the country that has the most to gain from it economically, since it has relatively good control over its forest resources and are already well on the way to develop a system for monitoring its forest (Klas Österberg, pers. comm.). Brazil is in general unwilling to accept an agreement where it gets a reduced control over its forest, and this is likely the most important reason why it is not in favour of a market solution. Instead Brazil has suggested that REDD is to be financed through a voluntary fund. In April 2008 Brazil launched a fund at a value of USD 200 million that will be used to avoid deforestation in the Amazon. The director general of Brazil's forestry service stated that they don't want to see credits from REDD being traded on the global carbon market now, but a discussion was held about the possibilities of the voluntary market (Point Carbon 1, 2008-04-16). Indonesia is positive to a market solution and has developed an own proposal where tradable credits are to be given as an incentive to reduce deforestation.

If a market solution is chosen, it is important that there is a demand for the credits that would be generated. With a post-2012 agreement that has a high ambition it is likely that there will be a large demand for credits, however it is not certain that there is a demand for credits from a REDD program. The European Commission has proposed that credits from forest projects should be banned from the European carbon market EU-ETS until 2020 and that reducing deforestation should be handled through government programmes (Tollefson, 2008).

The baseline area of the program

A key issue that most suggested financial solutions have a clear opinion about is regarding the baseline of the REDD program.

Activities under the CDM are performed on a project basis. When an Annex 1 country funds a project in a developing country it is able to redraw the emission reductions that this project leads to from their commitment under the Kyoto Protocol. A REDD program could be implemented in a similar way, where specific areas are chosen to perform projects to avoid deforestation. This is the case with the REDD projects that exist on the voluntary market. Another option is to implement REDD on a larger scale and look at the total change in carbon stock in an area. This could either be done on a national or a regional scale.

A REDD program that is performed at a project level has to deal with the problem of leakage. This is assumed to be avoided if REDD is performed at a national level since leakage over the national borders is not expected to occur, though the area that is to be monitored will be large and it will require advanced satellite technique. Charlotte Strech, director of Climate Focus, is critical to the capability of most developing countries to manage such programs and points out that deforestation is largest in countries that do not have a strong governmental system. Strech also writes that the tropical countries have missed an income of about USD 15 billion annually during recent years since they have not managed to collect fees and taxes from deforesting activities. Because of that it might be naive to believe that economical compensation alone will solve the problem of deforestation. (Ecosystem Marketplace, 2008-04-28)

Most proposals favour a national baseline of some sort. The EU has even stated that it will not consider a solution that does not use a national baseline (Ibid.). Compensated Reduction, the proposal from the Coalition of Rainforest Nations, states that credits should be given to the countries that reduce their deforestation rate for the whole nation (Environmental Defense, 2007). The Joint Research Centre proposal is similar, though with credits given also to those who maintain an already low national deforestation rate (Mollicone et al., 2007). The Dual Market approach also advocates a national baseline, but emphasises that it might be more practical to use sub-national baselines for countries that have their forest resources concentrated in a few areas (Ogonowski et al., 2007). The director general of Brazil's forestry service said on a press conference in Sao Paulo in April that "it's impossible to prove that one project avoids deforestation". Because of that the fund that they launched will be distributed to the state governments that will perform REDD activities in their region. (Point Carbon 1, 2008-04-16)

The Carbon stock approach combines a national baseline with a project approach. The part of the forest, in a participating country, that is not threatened by deforestation is considered a reserve and the government will be responsible for monitoring it so that it is maintained. The part of the forest that is threatened to be deforested is subject to REDD activities performed as projects by public as well as private entities. This sort of baseline would likely be easier to monitor than a baseline for all of the forest resources in a country. (Prior et al., 2007)

The approach towards baseline for comparison
A credible REDD program must be able to measure the progress that it is making. For this to be possible a baseline for comparison of some kind must be developed. This could for example be done by estimating the current or historical amount of forest resources, or the current or expected future rate of deforestation. If REDD is implemented on a national scale it is important to have a baseline of this sort so that any leakage within the country can be detected. On a project level, as with the REDD projects that exist on the voluntary market, national baselines would not serve the same purpose since there would not be an agreement to decrease deforestation on a national scale. Instead baselines are specific for each existing project.

The Dual Market approach suggests that a historical baseline is calculated from the previous deforestation rates in the participating countries. The progress will then be measured as the deforestation rate compared to this baseline, and tradable credits will be given for the reduced emissions. The proposal that Brazil has developed, with a REDD program that is financed through a fund, includes the development of historical baselines for comparison in the same way (Ogonowski et al., 2007). Compensated Reduction would be similar, and satellite techniques are suggested to be used to measure if a country reduces its emission rate from deforestation in comparison to a historical average. The ideal case is said to be a historical base period for 5-10 years, so that annual variations are accounted for (Environmental Defense, 2007). The Joint Research Centre proposal also suggests a baseline, but based on an average for the period 1990 to 2005 (Mollicone et al., 2007).

The Carbon Stock approach has a different way of dealing with baselines. The approach does not consider the historical circumstances, but instead it starts with the present forest resources that are available and uses it as the baseline. All of the forest in a participating country is taken in consideration though the part of it that is not likely to be deforested is seen as a reserve where there is no need to take action. Projects will then be performed at the remaining part of the forest to make sure that it will not be cut down. Since the historical data that is available in some of the concerned countries is of low quality it is advantageous with an approach that is not depending on this. (Prior et al., 2007)

The measurability of achieved results
It is very important that the progress in mitigating carbon dioxide emissions that a REDD program makes can be measured with accuracy. This is irrespective of the source of the funding, though the

need of precision varies between the different alternatives. The effects of forest projects are in general much more difficult to measure than from most other sources of emissions, for example from factories or energy plants. The techniques of measurements are still in need of further development and the countries where REDD programs would be implemented need to be able to handle these techniques. So far most of these countries are not able to do so (Klas Österberg, pers. comm.).

If carbon credits are to be traded on a carbon market, either the global market or a separate one, the amount of mitigated carbon dioxide emissions must be possible to measure with high precision. If an Annex 1 country funds a project as a part of their commitment in a post-2012 agreement it must be possible to know that this project actually leads to that volume of mitigated emissions that is funded for. At the moment the precision is not good enough for credits from REDD to be traded on the carbon market and further capacity building is necessary (Hans Nilsagård, pers. comm.). Credits on a voluntary market would probably not need the same precision since those funding it are not obliged to report their emission reductions. Though it is still important that projects that are funded through the voluntary market are somewhat accurate so that the credibility of the voluntary market can be high. Funding through a fund or ODA will probably not be in the same need of precision of measurement as a market solution though to be credible it will need to be able to demonstrate its progress.

REDD programs that are performed with a national baseline will be harder to measure than those that are performed on a project scale. Projects however, as those performed under the voluntary market, do not handle the risk of leakage. The Carbon Stock approach is advantageous in this respect since it reduces the area that needs a more frequent monitoring without increasing the risk of leakage. The approach also includes the formation of a fund for capacity building, which will increase the possibilities to perform a REDD program that can be measured.

A combined financial solution that includes trading credits on the global carbon market will also need to have a high precision. It will however have the possibility to provide funding to capacity building by a fund or ODA, something that a strict market solution does not include. The Dual Market approach also suggests capacity building through a separate fund and would therefore also have advantages over a strict market solution in this aspect.

A country specific solution could give a possibility for a market solution in those countries where this is feasible, while those countries that do not have a sufficiently developed monitoring system, or for some other reason prefer a non-market solution, could be compensated for their avoided deforestation through a fund or ODA.

The effect on the global carbon market

The global carbon market has been created through the carbon credits that are traded under the Kyoto Protocol. Through this market developing countries are given economical incentives to reduce their emissions of greenhouse gases in cases where this otherwise would not have occurred. The market has increased in size steadily during the last years (Capoor & Ambrosi, 2008). According to calculations by the UNFCCC the trading system has a potential to supply a maximum of 5.7 billion credits by 2030. With the large emissions from the forest sector each year due to deforestation the potential amount of credits from REDD alone by 2030 is 7.2 billion. If this occurred a commitment by Annex 1 countries to reduce their emissions by 71 percent would be needed to create a sufficient demand for carbon credits. This is to be compared with today's commitment of reducing emissions by 5 percent. (Leach, 2008)

In general, when there is a large difference between the supply and the demand in a market, there is a risk that the price becomes volatile. This will likely occur if REDD generates anywhere close to the amount of credits that it is capable of and those credits are released on the global carbon market. If the price is pressed down far enough it might not exceed the opportunity cost for the land use and there would no longer be an incentive for land owners in developing countries to involve in a REDD program. China at the moment has an informal policy not to carry out CDM projects that do not generate an income of above USD 11.5 per ton CO_2eq. Since credits from projects in China constitute about half of all credits on the carbon market it would have a big impact if the price went below this level and China would stick to its policy. (Leach, 2008)

The main objective of the Dual Market approach is to get around the problem of volatility by creating a separate market for REDD credits. A post-2012 commitment would include that a limited part of a country's emission reduction can be allowed to be fulfilled by purchasing REDD credits. These credits would however not be fungible with the global carbon market, thus not leading to price volatility. A drawback with this proposal is that it limits the amount of credits that can be traded through REDD, thus limiting the incentives to avoid deforestation.

Financial solutions through a fund or ODA are not expected to have a negative effect on the global carbon market (Center for Clean Air Policy, 2008-06-28). The effect of a combined solution where REDD is implemented by a market solution in combination with a fund or ODA would depend on the proportion that the market make up. If it provides large amounts of credits to the global carbon market the effect would be the same as with a strict market solution. The voluntary market is already in place with projects for avoided deforestation running. It is so far not influencing the global carbon market and will not do so after 2012 either since the different markets are not fungible.

Additional benefits

Except for the main purpose of mitigating global warming, REDD can result in a number of positive side effects. Deforestation reduces the available resources for the hundreds of million people that are depending on the tropical forests for their livelihood. Governments and NGOs have been working with these issues for many years and there is no doubt that the tropical countries are much better equipped against future challenges, including an increased global warming, with an intact rainforest. Deforestation leads to a degradation of the biodiversity and increased erosion of the soil, problems that could also be mitigated by implementing a REDD program. The benefits of maintaining a high biodiversity is mentioned in most proposed financial solutions to REDD.

When an Annex 1 country funds a CDM project that reduces emissions by utilizing a type of technology that so far has not been available in the host country, it is considered as technology transfer. Technology transfer has become an important part of CDM projects and can contribute to the development in the host countries. REDD programs can lead to technology transfer by developing and installing monitoring equipment, such as computer based GIS (Geographic Information System) programs and satellite techniques. The benefits of technology transfer are mutual for all financial proposals that contribute to capacity building, however it is seldom mentioned in the context of REDD and could be considered small in comparison to the full effects of a REDD program.

A large portion of the 800 million people who are depending on the tropical forests for their livelihood are poor, in the meaning that they live on less than USD 2 a day. About ten percent of these are indigenous groups (Chomitz et al., 2007). REDD programs can contribute with money to combat poverty as well as working towards a sustainable development in general. A financial solution through ODA or a fund is likely to have this in focus. The market solutions Compensated Reduction and the Joint Research Centre proposal, as well as the Dual Market approach, also mention the benefits of bringing resources to indigenous groups and the local communities. The REDD activities under the voluntary market are normally performed as ODA projects, where sustainable development is taken into consideration (Peterson et al., 2007).

There is a risk that including too much of these additional benefits in a REDD program will make it difficult to implement. It will also be hard to reach an agreement that has a large support in the climate negotiations. Working towards a sustainable development and supporting poor and indigenous groups is important, but this work can be carried out in other ways without being included in REDD. (Hans Nilsagård, pers. comm.)

4.4 Chapter summary

Even though REDD is considered to be a cost effective measure to reduce the anthropogenic emissions of greenhouse gases, large amounts of funding are still needed to perform extensive reductions. Several developing countries have made efforts to reduce their deforestation rates, though evidently without much progress so far. Furthermore there are no incentives for the developing countries to reduce their deforestation under the Kyoto Protocol, since they have not made any commitments and are unlikely to do so for the second commitment period as well. Funding will thus be needed from developed countries. There is a noticeable interest to contribute and several funds for avoided deforestation projects have been initiated during the first six months of 2008. REDD has been frequently discussed in the negotiations for the post-2012 climate regime and the aim is to agree on a way to implement REDD at the COP 15 in December 2009.

Integrating REDD into the global carbon market would generate carbon credits and this is assumed to give sufficient funding for REDD, though there is a concern that releasing to many credits from REDD would overflow the carbon market and make other measures less attractive for buyers. A market solution does not automatically solve the important issue of financing capacity building, which is needed for the host countries to be able to perform REDD. The support for a market solution is relatively strong and this is important if it is to be agreed upon in the negotiations for a post-2012 agreement. However, Brazil is not in favour of a market solution, and performing REDD without Brazil being involved would mean much smaller emission reductions. Another problem with a market solution is that it must be possible to measure the progress that it is making if credits are to be traded on the carbon market. At the moment the reliability in these measurements are low in the concerned countries.

Two alternative market solutions were discussed, the Dual Market approach and the Voluntary market. The Dual Market approach suggests that a separate market is created for REDD and that it would not be fungible with the global carbon market in the initial stage. In that way it would not overflow the market. The Voluntary market is already managing projects for avoiding deforestation. These do not generate credits that are tradable on the global carbon market. Leaving REDD to be handled on the voluntary market would not guarantee that there is a long term demand for credits since there would not be any commitments.

A fund solution and a financial solution through ODA resemble each other in many ways. The positive aspects of these are that they would generate stable and reliable incomes to the host countries and that they are not that dependent on exact measurements since carbon credits would probably not be generated as within a market solution. These solutions are however not expected to generate as much money as a market solution and the support for a strict fund or ODA solution does not seem to be that wide. A Combination of different solutions, likely a market with support from a fund or ODA, is also a possibility that is frequently mentioned. Little information about how this, or a country specific solution, would work was however found for this study.

Table 3 Summary of the main outlines among proposed financial solutions for REDD.

Solution / Criteria	Integrate REDD into the global carbon market	Alternative market solutions	Fund solution	Official Development Assistance (ODA)	Combination of different alternatives	Country specific solution
The source of funding	Carbon credits that can be bought by both public and private sector.	Dual Market approach: Carbon credits that can be bought by both private and public sector. Voluntary market: Voluntary credits outside the UNFCCC system, no commitments to future reduction.	No incentives for private sector to contribute, funding depending on governments. Stable flow of income to host countries.	Funding collected through ODA, might drain money from other development projects.	A combination of different sources of funding, likely a market solution with support from a fund or ODA.	Different alternatives would be given for developing countries to choose from.
The amount of money that can be generated	Expected to generate sufficient amounts of money for REDD, does not solve funding for capacity building.	Dual Market approach: Likely to generate sufficient amounts. Voluntary market: Uncertain in a long term.	Not expected to raise a sufficient amounts of money for REDD.	Not expected to raise a sufficient amount of money for REDD.	A market solution with support from fund/ODA is expected to generate sufficient amounts and fund capacity building.	N/A.
The definition of activities	Carbon Stock Approach: Reduce deforestation and degradation. Compensated Reduction: Focus on reducing deforestation. Joint Research Centre: Reduce deforestation and degradation.	Dual Market approach: Reduce deforestation and degradation.	Forest Carbon Partnership Facility: Reduce deforestation and degradation.	Norwegian ODA fund: Reduce deforestation and degradation.	N/A.	N/A.
The support	Relatively strong support for a market solution. Brazil and European commission are negative.	Voluntary market: Do not have a strong support.	Do not have a strong support. However supported by Brazil.	Do not have a strong support.	Market with support from a fund has a strong support.	Do not have a strong support.
The baseline area of the program	Compensated Reduction: National baseline. Joint Research Centre: National baseline. Carbon Stock Approach: Combined national and project baseline.	Dual Market approach: Combination of national and project baseline. Voluntary market: likely performed through projects.	Brazilian fund: Sub-national baseline.	N/A.	N/A.	N/A.
The approach towards baseline for comparison	Compensated Reduction: Historical deforestation rate, ideally for a period of 5-10 years. Joint Research Centre: Historical deforestation rate based on the period 1990-2005. Carbon Stock Approach: Avoids the need of historical baseline, uses present forest resources for comparison.	Dual Market approach: Historical deforestation rate. Voluntary market: Baselines on project level.	Brazilian fund: Historical deforestation rate.	N/A.	N/A.	N/A.

Solution / Criteria	**Integrate REDD into the global carbon market**	**Alternative market solutions**	**Fund solution**	**Official Development Assistance (ODA)**	**Combination of different alternatives**	**Country specific solution**
The measurability of achieved results	Compensated Reduction: Exact measurability important, so far not sufficiently precise. Joint Research Centre: Exact measurability important, so far not sufficiently precise. Carbon Stock Approach: Exact measurability important, possibly easier to measure since baseline area is smaller.	Dual Market approach: Provides funding for capacity building which will improve possibility of measurements. Voluntary market: Relatively easy to measure since based on projects, however do not account for leakage.	Exact measurability less important than market solution and provides funding for capacity building which improves possibilities for measurement.	Exact measurability less important than market solution and provides funding for capacity building which improves possibilities for measurement.	A market solution with support from fund/ODA provides funding for capacity building which will improve quality of measurements.	Provides possibility to use a market solution where measurability is working and other solutions where measurability is not fully developed.
The effect on the global carbon market	Likely to overflow carbon market if no limits are set.	Dual Market approach: Will not be fungible with existing market, thus will not affect carbon market. Voluntary market: Will not affect the carbon market.	Will probably not affect the carbon market.	Will probably not affect the global carbon market.	The effect of a market solution in combination with a fund/ODA will depend on the amount of credits that are generated.	N/A.
Additional benefits	Compensated Reduction: Preserving biodiversity and supporting indigenous groups. Joint Research Centre: Preserving biodiversity and supporting indigenous groups. Carbon Stock approach: Preserving biodiversity.	Dual market approach: Supporting indigenous groups.	Likely to include a variety of additional benefits, such as technology transfer, preserving biodiversity and supporting indigenous groups.	Likely to include a variety of additional benefits, such as technology transfer, preserving biodiversity and supporting indigenous groups.	N/A.	N/A.

5 Discussion and Conclusions

The estimations of emission reductions that are expected from implementing REDD are normally not considering carbon below ground, and the carbon balance of land use after deforestation is generally neglected as well. The carbon in biomass is in most cases contributing more directly to the emissions of CO_2, but the carbon in soil as well as the carbon balance depending on changed land use after deforestation might have a substantial influence on the volume of CO_2 emissions seen in a longer time perspective.

Including CO_2 emissions from soil in the estimations of emission reductions due to avoided deforestation would lead to larger emission reductions than an estimated scenario where soil carbon is neglected. Including the carbon balance depending on changed land use as well as the usage of harvested biomass can increase as well as reduce the estimated volume of greenhouse gas emissions obtained by REDD. If the biomass that is harvested is used in ways that substitute energy consuming materials, such as concrete and steel, the total amount of emissions will be lower than in a scenario where effects of substitution is not included. Changing land use to cultivation of energy crops would also lower the total emissions since these can substitute fossil fuels. Other land uses leads to larger emissions of greenhouse gases. For example rice cultivations and cattle ranching lead to large amounts of methane emissions.

By using a more realistic estimate of the emissions that different scenarios of deforestation leads to, it would be possible to get a better understanding of the complexity of emissions due to deforestation. This would describe what scenarios of deforestation that leads to the largest greenhouse gas emissions and are therefore most important to address. Since there are many uncertainties concerning carbon emissions from soil and due to changed land use these type of emissions are currently unlikely to be included in REDD. A REDD program implemented in a post-2012 climate regime will most likely focus on the carbon that is stored in the biomass above ground.

With an increasing world population the demand for food crops will surely increase as well. This might be conflicting with reducing deforestation. REDD would limit the possibilities to convert forest land to farmland, since a deforested area often is used for cultivation. This will likely influence the price on land and thereby also the market price for food crops. An overall successful REDD program would need to consider how deforestation can be avoided without limiting the access to farmland.

An increasing global demand for biofuels could have the same effect as a REDD program, since it can limit the area that can be used to cultivate food crops and thereby increase the price on land. The connections between cultivation of biofuel crops and deforestation are debated and more studies are needed to determine this.

There are large differences in the estimations of the total costs of implementing REDD. The reasons for these differences are due to a number of factors. As illustrated by the sensitivity analysis, the estimated opportunity cost for different land uses is of great importance for the total cost. The prices of crops often fluctuate and the opportunity cost is therefore also likely to do so. Estimated costs might also vary due to differences in the scenario of the payment schemes for REDD. Grieg-Gran (2006) estimates that compensations for forgone land use are to be made for a period of 30 years, and most studies use a similar approach if the time aspect is considered at all.

However it is uncertain what is expected to happen after this period of 30 years. If the land is to be compensated for again it will increase the total cost of REDD, and if not there is a risk that the forest will be cleared and the avoided deforestation would only have resulted in slowing down the process temporarily. Hopefully the countries with large deforestation will develop a sustainable forest management and a system for controlling the forest ecosystems during the time that REDD is performed.

The sensitivity analysis is based on information from eight countries that together causes 70 percent of the total emissions due to deforestation. In the initial scenario the total cost for mitigating these emissions is USD 7.13 billion per year. Extrapolating this to reducing 100 percent of the emissions, presuming that the distribution of the opportunity costs is similar for the additional 30 percent, gives USD 10 billion. Increasing the administrative cost threefold would then lead to a total cost of almost USD 20 billion. If some of the other parameters that are listed under section 3.5.1 would change as well the total cost would exceed the initial scenario of USD 7.13 billion severalfold. This hypothetical example illustrates the magnitude of the uncertainties involved when estimating the total cost of implementing REDD.

A REDD program will likely need a few years to get started before large emission reductions can be made, and it is probably not realistic that all deforestation could be avoided at an early stage. Prioritizing what regions where avoided deforestation should be performed can be made in different ways. As mentioned above it would be possible to get a better understanding of the true emissions from deforestation if carbon emissions from soil as well as changed land use were included. This could be used to avoid the deforestation that leads to the largest emissions of greenhouse gases. Including other benefits of avoided deforestation, such as maintaining biodiversity and supporting indigenous groups, are another possible factors for prioritizing. With a market based solution the cost will be the main focus. The MAC curve can easily be used to sketch different estimations for the total cost of performing a limited REDD program where cost is the main priority.

The total cost of performing a REDD program will depend on how such a solution will be implemented. The MAC curve provides information about how the costs will change depending on the volume of carbon dioxide emissions that is mitigated by implementing REDD. It is however not certain that the area with the lowest opportunity cost will be compensated for first. If a market solution is chosen to finance REDD it is probably more likely to happen since those providing carbon credits to the market will be interested in keeping the cost down so that the credits can be competitive. Though if financed through a fund or ODA without generating carbon credits the cost would probably not have the same focus.

In most cost estimations for REDD, different compensation is to be given for different forgone land uses, as illustrated in the MAC curve. This can be problematic since a land owner who is to be compensated might not be willing to except that other land owners get a higher compensation per area. However, as noted above, it is not likely that all deforestation will be avoided immediately. Seen in a longer time perspective REDD could be performed by first avoiding deforestation in the areas with low opportunity cost, and thereafter moving on to compensate for the areas with a higher opportunity cost. Except for a possible time difference regarding the compensations there is regional difference. As described in section 2.3 it is possible to make a rough generalization of the direct causes of deforestation in different countries. A land owner in a certain country will likely not have all the information about the compensation for avoided deforestation that occurs in other countries. Another difficulty is that land owners that were not planning to clear forest could claim that they are about to do so when informed about possible compensations. This would lead to larger areas that need to be compensated for and thus a higher cost for performing REDD.

The baseline of a REDD program, meaning the scale of the area where REDD will be performed, will affect the cost. The MAC curve in figure 9 is based on the simplifying assumption that no leakage will occur. If performed on a project basis this will be difficult to guarantee. On a larger scale the monitoring will be difficult, though leakage will probably not be that severe. If leakage does occur it will counteract the avoided deforestation and the effort would be in vain. However, no connection could be seen between the type of financial solution and the approach towards baseline area for REDD. No conclusion can therefore be drawn regarding what financial solution that would be best in this perspective.

A market solution is the only alternative that is expected to generate enough funding for a large scale REDD program, and it is therefore a likely alternative. It has a relatively strong support, but not from Brazil. If a market solution is chosen it might therefore be difficult to involve Brazil in the process, which would limit the progress substantially. To enable a market solution the measurability of the emission reductions must probably be improved. Extensive capacity building would therefore be needed in the host countries of REDD and the easiest way to finance this would be through a voluntary fund or Official Development Assistance. However, as pointed out by Persson & Azar (2007) there are other sources of greenhouse gas emissions that are involved in the trading system under the Kyoto Protocol where the uncertainties are larger than for deforestation. These greenhouse gases do not contribute with as large volumes of greenhouse gas emissions as deforestation and the comparison might therefore not be adequate. Avoided deforestation was discussed for the Kyoto Protocol though not included since it was considered to involve too many uncertainties. It is therefore likely that to large uncertainties will not be accepted in a post-2012 climate agreement.

Financing REDD through a fund or ODA creates direct possibilities to finance capacity building. It is uncertain how capacity building would be handled within a strict market solution, though it would possibly need to be supported by a fund or ODA. A strict fund or ODA solution would also be likely to focus more on additional benefits besides mitigating CO_2 emissions, such as preserving biodiversity and supporting indigenous groups. These kinds of additional benefits are desirable and since avoiding deforestation is connected to development issues in many ways there could be many positive synergisms with working with these questions simultaneously. However, if there are too many requirements about what is to be included in REDD the feasibility might be limited.

Including avoided deforestation in a post-2012 climate regime has the potential to lead to large emission reductions and this is a question that most certainly will get a lot of attention the next few years. The uncertainties on how to implement REDD are however many and the time is short if an agreement is to be made in December 2009.

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APPENDIX

Appendix a – transformation table from wood to co_2

Transformation table for the relations between wood, dry matter, sequestered carbon and Carbon dioxide.

Wood	**Dry matter**	
1 m^3	0.4 ton*	(Nilsson, 2004)
Dry matter	**Carbon**	
1 ton	0.5 ton	(United States Department of Agriculture, 2008-07-17)
Carbon	**Carbon dioxide**	
1 ton	3.67 ton	(Naturvårdsverket, 2008-07-17)

* This is an approximation of the average dry matter for wood in Swedish forests. It is assumed to be valid also for the tropical rain forests.

Appendix b – opportunity costs for different land uses

Table based on information from Grieg-Gran (2006).

Area [Hectare] (thousand)	**CO_2 emissions [ton] (million)**	**CO_2 accum. [kg] (billion)**	**OC [USD per hectare]**	**OC [USD per ton CO_2]**	**OC including admin. cost [USD per ton CO_2]**	**Country**	**Land use**
496	195	0.19	0	0.00	0.76	Brazil	Fallow
310	122	0.32	0	0.00	0.76	Brazil	Abandoned/degraded land
217	85	0.40	2	0.01	0.77	Brazil	Beef cattle small scale
496	195	0.60	2	0.01	0.77	Brazil	Manioc/rice
355	139	0.74	18	0.05	0.81	Indonesia	Cassava monoculture
355	139	0.88	26	0.07	0.83	Indonesia	Rice fallow
28	11	0.89	26	0.07	0.83	Malaysia	Rice fallow
217	85	0.97	154	0.39	1.16	Brazil	Dairy
31	12	0.98	239	0.61	1.37	Brazil	Perennials (bananas etc.)
44	17	1.00	346	0.88	1.65	Cameroon	Annual food crops long fallow
64	25	1.03	346	0.88	1.65	DRC	Annual food crops long fallow
189	74	1.10	390	0.99	1.76	Bolivia	Beef cattle
1955	768	1.87	626	1.59	2.36	Brazil	Beef cattle medium/large scale
22	9	1.88	740	1.88	2.65	Cameroon	Cocoa without marketed fruit
32	13	1.89	740	1.88	2.65	DRC	Cocoa without marketed fruit
85	33	1.92	774	1.97	2.73	Cameroon	Annual food crops short fallow
124	49	1.97	774	1.97	2.73	DRC	Annual food crops short fallow
115	45	2.02	1052	2.68	3.44	Ghana	Small-scale maize and cassava
28	11	2.03	1053	2.68	3.45	Malaysia	Cassava monoculture
561	220	2.25	1071	2.73	3.49	Indonesia	Smallholder rubber
42	16	2.26	1071	2.73	3.49	Malaysia	Smallholder rubber
2	1	2.27	1180	3.00	3.77	Cameroon	Oil palm and rubber
3	1	2.27	1180	3.00	3.77	DRC	Oil palm and rubber
66	26	2.29	1365	3.48	4.24	Cameroon	Cocoa with marketed fruit
96	38	2.33	1365	3.48	4.24	DRC	Cocoa with marketed fruit
79	31	2.36	1515	3.86	4.62	Indonesia	Low yield independent (oil palm)
23	9	2.37	1515	3.86	4.62	PNG	Smallholder oil palm
70	27	2.40	1737	4.42	5.19	PNG	Smallholder subsistence crops
109	43	2.44	2085	5.31	6.07	Indonesia	Supported growers (oil palm)
155	61	2.50	2135	5.44	6.20	Brazil	Soybeans
81	32	2.53	2135	5.44	6.20	Bolivia	Soya
30	12	2.54	2205	5.62	6.38	Indonesia	High yield independent (oil palm)
13	5	2.55	2330	5.93	6.70	Malaysia	Oil palm supported growers
4	2	2.55	2363	6.02	6.78	Malaysia	Oil palm independent growers
31	12	2.56	2614	6.66	7.42	Brazil	Tree plantations
380	149	2.71	2705	6.89	7.65	Indonesia	Large scale oil palm
25	10	2.72	2705	6.89	7.65	Malaysia	Oil palm Large scale/government
46	18	2.74	2705	6.89	7.65	PNG	Oil palm estates

Appendix c – Area of deforestation in eight countries

Table based on information from Grieg-Gran (2006).

Country	**Area [Thousand hectares]**	**Share of total [%]**
Brazil *	3908	26
Indonesia	1869	12
DRC	319	2
Bolivia	270	2
Cameroon	219	1
Malaysia	140	1
PNG	139	1
Ghana	115	1
Rest of the world	8193	54
Total **	15172	100

* There are many uncertainties regarding the estimated area thatis cleared each year. Other studies find that Indonesia has a larger annual deforestation than Brazil.

** The total annual deforestation is given by summing up thearea for the eight countries where 46 percent of the deforestationoccurs and calculating the deforested area of the rest of the world.