THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

LAND USE IN CLIMATE POLICY – FOREST BASED OPTIONS AT LOCAL LEVEL WITH CASES FOR INDIA

By

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ABSTRACT

With India's large population, an increased pressure on forest and agricultural land indicate a growing demand for environmental services that is sustainable for the future. Fertile agricultural land is limited and with an increased demand for energy production the development expands to degraded lands, the wasteland. About one fifth of India's total area is classified as wasteland with estimated biomass productivity of less than 20% of their overall potential. Re-vegetation of wasteland can be one way to reclaim the productivity and restore the carbon storage in the soils

This thesis combines five separate papers and results in an improved understanding of the local, regional and global implications of different initiatives on land use change. It also analyses the environmental and socioeconomic effects of different efforts, both theoretical and practical. The research presented in this thesis was motivated by a perceived lack of local case studies exploring the contexts of climate policy.

The results in this thesis confirm that the performance of individual forest-based project activities will depend on local conditions, for example land availability and local acceptance. In other words, successful implementation of forest-based project activities will require local participation and is likely to involve multiple forest products and environmental services that are prioritised by the local community. Further the results illustrate the environmental and socioeconomic benefits from a large-scale establishment of multi-functional biomass production systems on wasteland could be substantial, for example decreased erosion, increased infiltration and income generation. However, in many cases, the establishment of afforestation and reforestation activities is hindered by low land productivity, water scarcity and a lack of financial resources for investments. Compensatory systems may help to overcome the financial barrier; however, the price of carbon needs to be significantly increased if these measures are to have any large-scale impact. The land suitability analysis uses environmental thresholds in GIS analyses to create data layers showing the amount of wasteland available for plantations. Using tree different options for land use management the result shows that over 70% of the wasteland in the district of Tumkur can be planted with suggested six species.. The literature review shows that policymakers set the research agenda by declaration, which states the focus, while researchers feed the decision-making process until a decision is made.

Keywords: Carbon sequestration, sustainable development, bioenergy, afforestation, CDM, rural development

Preface

This thesis includes five papers:

I. Palm M., Ostwald M., Berndes G. and Ravindranath NH. (2009) Application of Clean Development Mechanism to forest plantation projects and rural development in India. Applied Geography 2:2-11.

II. Palm M., Ostwald M. and Reilly J. (2008) Land use and forestry based CDM in scientific peer-reviewed literature pre-and post-COP 9 in Milan. International Environmental Agreements: Politics, Law and Economics 8:249-274.

III. Berndes G., Börjesson P., Ostwald M. and Palm M. (2008) Multifunctional biomass production systems – an overview with presentation of specific applications in India and Sweden. Biofuels, Bioproducts & Biorefining 2:16-25.

IV. Palm M., Ostwald M., Murthy I., Chaturvedi R. and Ravindranath NH. (2009) Barriers for afforestation and reforestation activities in different agro-ecological zones of Southern India. Submitted to Regional Environmental Change.

V. Palm M. (2009) Land suitability analysis and the establishment of land use options on wasteland in Tumkur district, India. Working paper.

All of the above papers were written in close collaboration with colleagues. The fieldwork for Papers I and IV was conducted by Palm (the author of this thesis) in the state of Karnataka in collaboration with the Centre for Ecological Science and the Centre for Sustainable Technologies at the Indian Institution of Science under the supervision of Ravindranath. The literature review in Paper II was conducted in collaboration with Ostwald. Palm has actively contributed to the analysis in all the papers, has had major responsibility for the writing of all papers except Paper III, where the sections related to Sweden were prepared by Berndes and Börjesson. Chaturvedi was responsible for the GCOMAP modeling in Paper IV. Data for Paper V was partly provided by the research group at the Centre for Sustainable Technologies and collected by Palm. Finally, GIS modelling was carried out by Karlsson and analysed by Palm.

Peer-reviewed scientific papers not included in the thesis

- Mattsson E., Oswald M., Nissanka SP., Holmer B. and Palm M. (2009) Recovery of coastal ecosystems after tsunami event and potential for participatory forestry CDM – examples from Sri Lanka. Ocean and Coastal Management 52:1 1-9.

- Balkmar L., Hjerpe M., Ostwald M., Ravindranath NH. and Palm M. (2009) Diverse views of how Clean Development Mechanism projects assist in achieving sustainable development. Submitted to Climate Change and Development.

Reports

- Palm M. (2005) Beyond Kyoto - India in a climate perspective. Report 5386 for *Naturvårdsverket* (The Swedish Environmental Protection Agency).

- Ostwald M., Palm M., Mattsson E. and Ravindranath NH. (2008) Land use and forest issues at COP13 on Bali Dec 2007, Report. CSPR Briefing No. 1. Centre for Climate Science and Policy Research, Norrköping 2008.

Conference proceedings

- Ostwald M., Palm M., Berndes G. and Ravindranath NH. (2004) Clean Development Mechanism and local sustainable development – Illustrations from Karnataka, India. 2nd World Conference and Technology Exhibition on Biomass for Energy, Industry and Climate Protection May, Rome, Italy.

Submissions to the UNFCCC

- Ostwald M., Palm M., Berndes G., Azar C. and Persson M. (2006) View on issues relating to reducing emission from deforestation in developing countries – approaches to stimulate action.

- Ostwald M., Palm M., Mattsson E., Persson M., Berndes G. and Amatayakul W. (2007) Views on the implication of possibly changing the limit established for small-scale afforestation and reforestation clean development mechanism project activities.

- Palm M., Ostwald M., Mattsson E., Persson M., Berndes G. and Amatayakul W. (2007) Response to the call for public inputs on new procedures to demonstrate the eligibility of lands for afforestation and reforestation projects activities under the CDM.

All papers are reprinted with permission from the respective journals.

Abbreviations and Acronyms

AEZ	Agro-ecological Zone
A/R	Afforestation and Reforestation
AWC	Available Water holding Capacity
C	Carbon
CCX	Chicago Climate Exchange
CDM	Clean Development Mechanism
CEC	Cation Exchange Capacity
CERs (lCER & tCER)	Certified Emission Reduction (long-term CER & temporary CER)
CO_2	Carbon dioxide
COP	Conference of Parties
FAO	United Nations Food and Agricultural Organization
GCOMAP	Generalized Comprehensive Mitigation Assessment Process
GHG	Greenhouse Gas
GIS	Geographical Information System
Ha	Hectare 100x100 meters (0.01 km^2)
	India: 328 Million hectare (Mha) total land area
	Sweden: 45 Mha total land area
IPCC	Intergovernmental Panel on Climate Change
LULUCF	Land Use, Land Use Change and Forestry
N	Nitrogen
NRSA	National Remote Sensing Agency
P	Phosphorous
PES	Payment for Environmental Services
REDD	Reducing Emissions from Deforestation and Forest Degradation
SBSTA	Subsidiary Body for Scientific and Technological Advice
t	Metric tone
UNEP	United Nations Environmental Programme
UNCBD	United Nations Convention on Biological Diversity
UNFCCC	United Nations Framework Convention on Climate Change
UNCCD	United Nations Convention on Combating Desertification
USDA	lit. United States Department of Agriculture
	In this thesis: The USDA vegetation and erosion assessment

TABLE OF CONTENT

Introduction

In recent years, global climate change has become a seriously acknowledged issue in the international research community and in political arenas. Actions to mitigate an accelerating climate change are increasing and new, innovative concepts, including both emission reductions and sequestrations of greenhouse gases (GHGs), have been proposed. Among GHGs, carbon dioxide (CO_2) is the most important (IPCC 2007). The rate of build-up of CO_2 in the atmosphere can be reduced by taking advantage of the fact that carbon can accumulate in vegetation and soils in terrestrial ecosystems acting as "sinks". The United Nation Framework Convention on Climate Change (UNFCCC) (1992) defined a sink as "any process, activity or mechanism which removes a greenhouse gas, an aerosol, or a precursor of a greenhouse gas from the atmosphere." Actions to mitigate climate change require the collaborative efforts of countries all over the globe. At present, and as stated in the UNFCCC, the developed countries are to lead the way with these actions (UNFCCC 1992). However, large, densely populated developing countries such as China and India also need to take an active part in the mitigation of GHGs in order to restrain this rapid negative development.

India, with its large and still growing population, needs to maintain the delicate balance between the interrelated factors of production and consumption of food, clean water and energy in a way that is sustainable for the future. The demand for water for use in industries, as well as for human needs and environmental services is increasing; at the same time, an increase in food production requires higher amounts of energy for use in irrigation and the production and distribution of fertilizers. Since fertile agricultural land is limited and the demand for sustainable energy production is increasing the expansion into degraded lands or the wasteland, sustainable water conservation strategies may be an option. Almost 20% of the total land area in India, 64 million hectares (Mha), is classified as wasteland (NRSA 2005). Soil degradation processes on wasteland have severely reduced the soil organic carbon. This is primarily due to a combination of low biomass productivity and excessive crop residue removals, which have left wasteland lying almost barren for decades. For environmental and socioeconomic reasons, the land needs to be rehabilitated through different land management strategies.

Outlined in this thesis, Papers I, III and IV present the environmental and socioeconomic benefits that can be obtained from establishing multifunctional plantation systems by contributing to the rehabilitation of wasteland. Papers I and IV analyse the Clean Development Mechanism (CDM) and other financial systems that can potentially influence the development of plantation systems in the state of Karnataka, India. Paper IV also investigates the incentives and barriers for forest plantations on wasteland in different agro-ecological zones of Karnataka and the requirements to overcome these barriers. Paper II analyses the science-policy interaction between peer-reviewed literature and decisions and declarations on Land Use Land Use Change and Forestry (LULUCF) projects in the CDM taken at the Conference of Parties (COP). Finally, Paper V investigates the best usage of wasteland in an area that is characterised by natural hardship.

Background

Land use and forest

"Land use is characterized by the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it. Definition of land use in this way establishes a direct link between land cover and the actions of people in their environment." (FAO 2000)

This thesis looks at several different classes of land primarily at degraded land, including forests, grassland, agricultural land and village common land. Land use change, together with the usage of fossil fuels, is the major anthropogenic source of CO_2 emissions but constitutes both a sink and a source of atmospheric CO_2 (IPCC 2007, Oreskes 2004). Forest ecosystems absorb carbon through photosynthesis, store carbon in the biomass and add to the pool of soil organic matter, but also emit carbon through respiration, the decomposition of organic matter and combustion due to anthropogenic and natural causes. The global forest cover is 3 952 Mha, about 30% of the world's total land area (FAO 2006). The IPCC (2007) reports the total terrestrial sink for 1993-2003 to be 3 300 $MtCO_2$/yr, excluding emissions from land use changes. In the context of climate change, land use, land use change and forestry (LULUCF) activities can provide a relatively cost-effective way to mitigate climate change, either by increasing the sequestration of greenhouse gases from the atmosphere (e.g. by planting trees or managing forests), or by reducing emissions (e.g. by curbing deforestation) (Sathaye et al., 2001, Nabuurs et al. 2007, Sathaye et al. 2007). The carbon mitigation potential from reducing deforestation, forest management, afforestation, reforestation and agro-forestry differs greatly from region to region. In the short term, the mitigation benefits from reducing deforestation will likely exceed the benefits from afforestation activities. In the longer term, however, a sustainable forest management strategy aimed at maintaining carbon stocks, while producing a sustained yield of timber, fibre and energy from the forest, will generate the largest sustained mitigation benefit (Nabuurs et al. 2007).

An increase in tree cover will also have positive environmental effects on a degraded land area and an increase in soil organic matter will enhance the fertility of the soil. With the exception of monocultures, there will also be increased biodiversity (IPCC 2000). Furthermore, the increase in tree cover will also decrease the rate of erosion and decrease the loss of fertile clay minerals. Forest cover would also protect the land from further degradation (Sathaye et al. 2007, Ravindranath and Sathaye 2002, IPCC 2000). Even if the direct emissions from the forest are small, the emission and sequestration related to land cover change to/from the forest are very large. Policies affecting land use and land use change are likely to have strong implications for the net emission from forest and land use (Sathaye et al. 2007). Policies aimed at promoting mitigation efforts in the tropics are likely to have the largest payoff, given the significant potential for carbon conservation and sequestration in tropical forests. According to the IPCC, approximately 560 Mha might be available for carbon conservation and sequestration (Watson et al. 1996). Even though there is a substantial potential for the forest to function as a carbon sink, there are several institutional and technical difficulties to managing forests for the sequestration of carbon. In India, for example, the demands on the forests are very high, which results in an unsustainable usage. Hence the option of managing the forests solely for carbon sequestration may not be possible (Haripriya 2003).

Sustainable development

Climate policy research –broadly defined – spans over many fields of academia (Ostwald and Kuchler 2009). Building on the predicament of sustainable development and a sustainable future, climate policy research development includes a large and gripping set of questions and answers as of today (UNFCCC 2009).

In general terms, the state of the environment reflects the interaction of past and present human activity with its underlying characteristics. Some natural features are relatively fixed or finite, such as topography and soil quality, while others are highly variable, such as climate or flora and fauna. Some of the key determinants of human impact are population numbers, the type and efficiency of production systems, and the level and pattern of final consumption. As a result, the most effective ways to improve environmental outcomes and secure high living standards are to extract natural resources at sustainable rates and maximise the efficiency of production systems. A healthy environment provides the economy with natural resources. A flourishing economy allows investment in environmental protection and the avoidance of injustices such as extreme poverty, thereby handling issues of inter- and intra-generational equity. This in turn ensures that natural resources are maintained and well managed and economic gains distributed fairly (Victor 2006). Managing resources and living according to this understanding is crucial for the long-term wellbeing of civilization.

With this theory in mind sustainable development was defined in the 1987 report "Our Common Future" by the World Commission on Environment and Development (Bruntland 1987). The report states that "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Sustainable development has since been defined and discussed in many ways. For example Daly (2002) argues that *utility* should be sustained, meaning that the utility of future generations is to be non-declining i.e., that future generations should be at least as well off as the present in terms of its utility. He also suggests a more suitable definition of sustainable development where *throughput* should be sustained, meaning that the entropic physical flow of natural resources through the society and back to nature's sinks is to be non-declining. This means that the capacity of the ecosystem or the natural capital is to be kept intact. Sustainable development has officially been leading the way in climate policy and related research ever since the World Summit in 1992 (UNFCCC 1992). Outlined in Article 2 of the UNFCCC, it is meant to objectively influence both negotiations and implementations. In the IPCC's fourth assessment report, the sustainable development criteria are matched against different land use categories (Sathaye et al. 2007). The results show that restoration of degraded lands is considered beneficial for sustainable development, together with agro-forestry and to a certain extent, bioenergy production (Table 1).

Table 1. Sustainable implications for agro-forestry, restoration of degraded soils and bioenergy (Modified from Sathaye et al. 2007).

Activity category	Sustainable development			Note
	Social	Economic	Environmental	
Agro-forestry	+	?	+	Likely environmental benefits, less travel required for fuel wood; positive societal benefits; economic impact uncertain.
Restoration of degraded soils	+	+	+	Restoration of degraded lands will provide higher yields and economic returns, less new cropland and provide societal benefits via production stability.
Bioenergy	+	?	+/-	Bioenergy crops could yield environmental co-benefits or could lead to loss of bio-diversity (depending on the land use they replace). Economic impact uncertain. Social benefits could arise from diversified income stream.

+ denotes beneficial impact on component of SD
- denotes negative impact
? denotes uncertain impact

Policy context

Clean Development Mechanism

The cost of limiting emission reduction activities varies considerably between regions, while the global benefits of reducing GHG emissions are the same wherever the action is taken. To reduce the cost for mitigating climate change the UNFCCC defined three flexible mechanisms within the Kyoto Protocol, a political decision that was announced in 1997. The three flexible mechanisms are the Clean Development Mechanism (CDM)[1], Emissions Trading and Joint Implementation (UNFCCC 1998). The CDM is a project-based mechanism where the mitigation effect, i.e., reduced or sequestered GHG are equated to carbon credits. This means that all GHG are expressed in carbon dioxide equivalents as a common commodity; one tonne of CO_2 corresponds to one carbon credit, called certified emission reduction – CER. Any CDM project must show that the planned activities have additional merits in comparison to a hypothetical business-as-usual (baseline) scenario in terms

1 The purpose of the CDM is outlined in Article 12 of the Kyoto protocol: "The purpose of the clean development mechanism shall be to assist Parties not included in Annex I in achieving sustainable development and in contributing to the ultimate objective of the Convention, and to assist Parties included in Annex I in achieving compliance with their quantified emission limitation and reduction commitments under Article 3" (UNFCCC 1998).

of sequestration or non-emitted GHGs, i.e., additionality. Further, the project should contribute to the adoption of sustainable development practices in the host country, which has to be categorised as a non Annex I, i.e., a developing country. Several different sectors can use the CDM mechanism to gain additional funding for a project; the most common sectors are renewable energy, methane and coalmine/coal bed projects, energy efficiency projects and fuel source switching. The focus of this thesis is mainly the afforestation and reforestation (A/R) sector, which is only responsible for 0,4% of all the CDM projects as of October 2009 (UNFCCC 2009). The thesis also looks at the biomass energy sector which is included in the renewable energy category, responsible for over 73% of all the projects (UNEP Risoe 2009).

Forest-based CDM projects

Projects developed in the A/R sector have certain rules and regulations which were established during UNFCCC COP meetings (Table 2). To address the permanence issue, i.e., the risk that emission removals by sinks are reversed because forests are cut down or destroyed by natural disaster, the COP has ruled that carbon credits from A/R activities can only be valid temporarily, i.e., they expire after a certain period. This period depends on the project developer’s choice of schedule; he can decide to use temporary (valid for 5 years) or long-term (valid for up to 25 years) CERs (tCER or lCER) according to the suitability (prospect, aim, potential) of the project. According to the Marrakech Accords, a forest is defined as an area of at least 0.05 – 1 ha, with a tree cover of 10 – 30% and a minimum tree height of 2 - 5 meters at maturity (UNFCCC 2001). For the first commitment period, stretching from 2008 to 2012, only afforestation and reforestation is eligible under the CDM within the Kyoto Protocol; however, other project types such as the regeneration of exhausted forest land might be included in future commitment periods. During the COP/MOP 13/3 in Bali 2007, the small-scale afforestation and reforestation project activities under the CDM were defined as those that are expected to result in net anthropogenic GHG removals by sinks of less than 16 kT of CO_2 per year and are developed or implemented by low-income communities and individuals as determined by the host country (UNFCCC 2008). These small-scale projects are granted simplified methodology requirements to ease the financial and knowledge pressure they face. Small-scale projects are also able to create a bundle in which several projects of the same or different sectors are brought together to form a single CDM project without the loss of the distinctive characteristics of each project activity (UNFCCC 2004, UNFCCC 2005). Projects within a bundle can be arranged in one or more sub-bundles, with each project activity retaining its distinctive characteristics. Recently, several approaches to CDM projects have been proposed in order to deal with the limitations of the project-based approach[2].

[2] Three approached need to be mentioned: *Programmatic CDM* which is similar to the bundling approach has already been accepted for small scale-projects. It allows a multitude of actions developed as a result of a deliberate programme to be considered as small parts of one large project. This approach is already present in project in the pipeline. *Sectoral CDM* would be one large project covering one whole sector within one country, while *policy CDM* would allow any activity under a certain governmental policy to be included in one larger CDM project.

Table 2. Key decisions and declarations for LULUCF CDM projects during COP meetings, ranging from COP 6 in 2000 to COP 15 in 2009.

Meeting	Decisions and declarations	Issues
COP 6, The Hague/Bonn Part 1 2000 and 2 2001	• Inclusion of sinks divides the parties and is partly responsible for the dual meetings. Proposal to only include afforestation and reforestation (A/R) in the CDM	**Draft decision:** Inclusion of sinks in CDM
COP 7, Marrakech 2001	• Only afforestation and reforestation (A/R) are eligible under the CDM • Cap on demand – A/R the CDM can be used for 1 % of of base year emissions of the Annex B countries per year	**Decision:** Inclusion of sinks in CDM
COP 8, New Delhi 2002	• Delhi ministerial declaration on climate change and sustainable development was adopted *No decisions taken referring to LULUCF under the CDM*	**Declaration:** Sustainable Development
COP 9, Milan 2003	• Modalities and procedures for A/R were adopted, including: Crediting period, tCERs and lCERs, Baseline year, Size limits for small scale A/R projects (8 kT/y)	**Decision:** Leakage*, Additionality**,** Baseline**,** Permanence and Scale
COP 10, Buenos Aires 2004	• Good Practice Guidance (GPG) for LULUCF was accepted by the COP • Simplified modalities and procedures for small scale A/R CDM projects were adopted.	**Decision:** Monitoring
COP/MOP 11/1, Montreal 2005	• COP advances the discussion on avoiding deforestation in developing countries: approaches to stimulate action to SBSTA 27 in 2007 after a proposal by several non-Annex B countries • COP/MOP states that large-scale project activities can be bundled	**General discussion:** Avoided deforestation
COP/MOP 12/2, Nairobi 2006	*No decisions referring to LULUCF taken under the CDM or REDD*	
COP/MOP 13/3, Bali 2007	• The Bali Action Plan: "Policy approaches and positive incentives on issues relating to reducing emissions from deforestation and forest degradation in developing countries; and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries." • COP/MOP decides to revise the limit for A/R project activities under the CDM to 16 kt of CO_2 per year	**Decision:** REDD **and** small-scale CDM limits
COP/MOP 14/4, Poznan 2008	*No decisions referring to LULUCF taken under the CDM or REDD*	
COP/MOP 15/5, Copenhagen 2009	*To be decided...*	

* Leakage is defined as the net change of anthropogenic emissions by sources and/or removals by sinks of greenhouse gases which occurs outside the project boundary (UNFCCC 2002).

The rules and modalities for forestry CDM were set during COP 9 in Milan 2003, as opposed to general CDM ruled established at COP 7 in Marrakesh 2001, however the first A/R project was not registered until November 2006. The slow development in the A/R CDM sector is partly due to complex regulations and requirements in combination with very complicated accounting rules which need to be expressed in the methodologies. Therefore, approval of the first methodology took a very long time and subsequent methodologies were approved only slowly. Another reason for the slow A/R development is the exclusion of A/R CERs in the European Union Emissions Trading (EU ETS) scheme. According to a recent amendment to the EU ETS Directive, A/R CERs will continue to be excluded until 2020 (Streck et al. 2009). Until October 2005 no methodologies had been approved and hence no projects that had to be based on an approved methodology existed. As of October 2009, nine large-scale methodologies and two consolidated methodologies have been approved and several others are in the pipeline. This slow process has obstructed many projects that are waiting to be registered; it is also the reason why out of a total number of 1870 registered CDM projects, there are currently only eight registered A/R CDM projects. Two of these projects are located in India, one in China, one in the Republic of Moldova, one in Bolivia, one in Vietnam, one in Uganda and one in Paraguay. Another 49 A/R projects have since been waiting in the pipeline. The number of registered forestry projects is likely to keep rising in the future (UNFCCC 2009).

Another option for land use under the CDM is biomass energy, in the renewable energy sector (Table 3). Among the projects in the CDM pipeline, bioenergy accounts for 14% of the total activity and is thus among the most popular project types. There are currently 662 projects out of 4673 at different stages of the application process (14% of the total number), of which 265 are registered (UNEP Risoe 2009). Within the bioenergy sector the distribution of projects is uneven, with almost no biofuel for transport or for household use. Only four biodiesel projects have reached the validation stage; as yet, there are no registered projects. The situation is similar to the early phase of the A/R CDM development, where a lack of defined methodologies halted the development of new projects and hindered the progress of the ones that had been developed but not yet registered.

Energy for domestic use in developing countries is dominated by biomass energy; this is also true of India, where fuel wood is the dominant source of energy in the rural parts of the country. An increased availability of fuel and wood products from plantations grown on degraded lands and wasteland can lead to a reduced pressure on adjacent natural forests. A study from Orissa, India showed that with the introduction of village plantations, biomass consumption increased (as a consequence of increased availability) while at the same time, the pressure on the surrounding natural forests would decrease (Köhlin and Ostwald 2001).

Table 3. The table present the two sectors within the CDM relevant for this thesis with specified project types (ENEP Risoe 2009).

Sector	Type	Number			kCERs	
		At validation*	Registered	Registered	Until 2012	Issued
Forestry	Afforestation	3	1	12	44	0
	Reforestation	36	7	277	1457	0
Biomass energy	Residue and waste	366	258			
	Forest biomass	12	2			
	Gasification of biomass	9	3			
	Fuel switch	1	0	14884**	92956**	14146**
	Biomass briquettes	3	3			
	Biodiesel	4	0			
	Ethanol	0	0			

* Projects at validation including the projects requesting registration
** Total for biomass energy

Options other than CDM

CDM is not the only option for land use activities. Due to the initial difficulties within A/R CDM, additional options for projects located, designed, integrated and managed to provide specific environmental services emerged. The concept of promoting synergies between the three Rio Conventions[3] provides several advantages and is well documented (UNCCD 1994, Nabuurs et al. 2007, Kok and de Coninck 2007, UNCBD 2009). Too narrow a focus on one problem at a time can at worst aggravate another problem, or at best prevent projects from taking advantage of potential synergy effects. Costanza et al. (1997) estimated the global value of natural capital and ecosystems producing additional services in an attempt to make such ecosystems visible and thus adequately considered in the decision-making process. One of the problems is that changes in these systems occur on such different scales, with many (if not all) being dependent on each other, so that changes on the global scale of one system result in changes to another system on a local scale.

Many ecosystem services have an acknowledged financial value, although the entire scale of their value may not be recognised. For example, a forest may be valued based on the timber it can provide but not on the biodiversity it supports, the microclimate it creates or the soil erosion control – all of which contribute to human welfare. At present, carbon is one environmental service that has already achieved a financial value; however, other services urgently need to follow. These services include hydrological regulation, protection from natural hazards (Mattsson et al. 2009), nutrient cycling,

[3] United Nation Framework Convention on Climate Change (UNFCCC), United Nation Convention to Combat Desertification (UNCCD), United Nation Convention on Biological Diversity (UNCBD).

energy, waste treatment and freshwater provisioning (FAO 2009). Although there is no global regulation system, numerous payments for environmental services (PES) and PES-like initiatives are being implemented all over the world. Scale-wise, these range from small watersheds to nationwide projects (Wunder et al. 2008). Costa Rica is at the forefront in the development of PES . Since 1997, the country pays landowners for several ecosystem services such as carbon sequestration, watershed protection, biodiversity and scenic beauty (Redondo-Brenes 2005). Financed partly by a tax on fossil fuels, this scheme has resulted in major forest conservation and restoration. It is important to get an idea of the extent to which different multifunctional applications can be implemented, as well as how they can be combined. The majority of environmental services is specific to a particular type of soil, localisation in the landscape, or geographical region and therefore often cannot be obtained simultaneously. It is also crucial to understand the ways in which the land owner/user can benefit from establishing multifunctional biomass plantations, since it is these benefits that are the motivation for participating in the compensation schemes.

The most well-established market for environmental services is the global carbon markets where financial compensation is paid for the mitigation of carbon emissions. The global carbon market can be divided into two segments: the voluntary markets and the regulatory (compliance) markets (where CDM is represented). As the name implies, the voluntary carbon markets include all carbon offset trades that are not required by regulation. Over the past several years, these markets have not only become an opportunity for citizen consumer action, but also an alternative source of carbon finance and an incubator for carbon market innovation (Hamilton et al. 2009). The voluntary carbon markets themselves have two distinct components: the Chicago Climate Exchange (CCX), which is a voluntary but legally binding cap-and-trade system (CCX 2009) and the broader, non-binding “Over-the-Counter” (OTC) offset market which is based on bilateral deals and operates largely outside of exchanges. The voluntary carbon markets nearly doubled in 2008 reaching 123.4 MtCO_2 equivalents (eq). However, the voluntary markets remain marginal with respect to the global carbon market (which includes the voluntary markets), representing only 2.9% of its volume and 0.6% of its value. Both the OTC and the CCX deal with several sectors including forest. The CCX allows GHG offsets from no-tillage and the conversion of cropland to grassland, as well as forest carbon sequestration (Smith et al. 2007, CCX 2009). Forestry plays a small part in the voluntary trading mechanism. During 2008, the A/R conservation stood for 7% of transactions by volume at OTC, and avoided deforestation and A/R plantations for 1% respectively (Hamilton et al. 2009). Biomass energy was responsible for 3% of the transaction by volume. At CCX, forestry projects increased its annual share of registered project types from 1% in 2007 to 22% in 2008 (Hamilton et al. 2009). As of 2007, the World Bank is among the few buyers of CDM forestry credits. The BioCarbon Fund, a World Bank fund, has bought carbon credits from forestry projects for prices of 3.75 – 4.35 US$/t CO_2 eq (Neef and Henders 2007). The prices of voluntary forest credits range from 6.3 – 7.7 US$/t CO_2 eq, including projects of afforestation/reforestation plantations, afforestation/reforestation conservation, forest management and avoided deforestation (Hamilton et al. 2009).

India has submitted a proposal for compensation and positive incentives for sustainable forest management and A/R, where the host country retains and manages the forest and afforests land for carbon sequestration (Ministry of Environment and Forest 2009). These measures will include both the direct costs of protection, monitoring and enforcement and opportunity cost for not felling the trees or using the land for other, more economically viable options. The proposal for positive incentives for sustainable forest management and A/R include: annual payment for the remaining forest area to compensate the host country for the avoided global annual damage and annual payment for the direct costs of afforestation as well as the opportunity cost of the land.

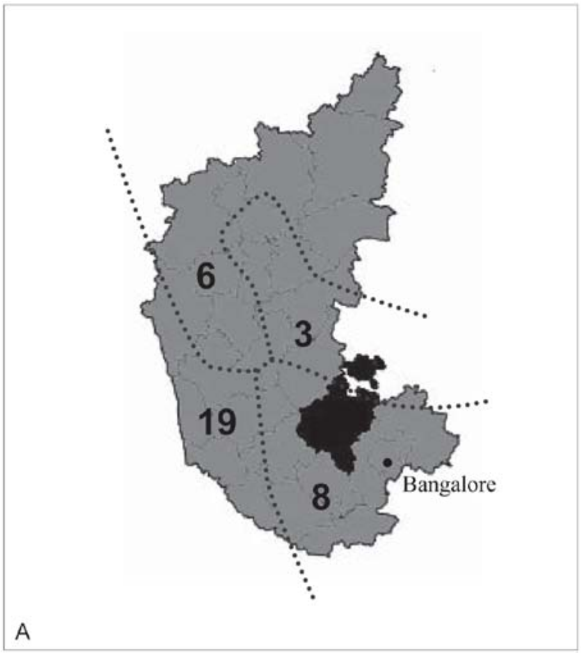
Geographical focus

Study area – the state of Karnataka, India

Forests cover about 19% of the total area of 328.8 Mha in India (Ministry of Environment and Forests 2004, Sathaye et al. 2001) and include both natural forests and forest plantations. Due to a large population, the forests are subject to increasing pressure, however, India has succeeded relatively well in reducing the net deforestation rate (Ravindranath et al. 2001). India is also one of the few developing countries that have made a net addition to its forest cover and tree cover over the last two decades which mean that Indian forest serve as a major sink of CO_2. This is partly due to the forest conservation act where the conversion of forest land for non-forest land is banned (Ravindranath et al. 2009) and large scale reforestation programs.

Most sections of this thesis concern the state of Karnataka in southwest India where data collection and fieldwork were carried out (Papers I, III, IV and V). Karnataka is one of India's 27 states and has 52.8 million people, with a population density of 276 people/km^2. 66% of the population lives in rural areas and these are mainly employed within the agricultural sector. The geographical area of Karnataka is about 19 Mha. It is the eighth largest state by area, the ninth largest by population and it comprises 29 districts. Most of the forest in Karnataka is located within the costal belt and includes four forest types: tropical dense evergreen, tropical semi-evergreen, moist deciduous and dry deciduous. The percentage of forested area (16-20% of the state's geographical area) might be less than the total Indian average of about 19%, and significantly less than the 33% prescribed in the National Forest Policy (FSI 2005). From 1995-2005 the carbon stored in India forest and trees have increased from 6 245 Mt to 6 662 Mt, with an annual increment of 38 Mt of carbon or 132 CO_2eq (Kishwan et al 2009).

Figure 1 (A) Map of Karnataka state with Tumkur district highlighted. Agro-ecological zones of Karnataka area marked in the map. (B) The map shows India and the location of Karnataka state and Tumkur district.



The state of Karnataka is diversified when it comes to temperature, rainfall, soil, vegetation type and socioeconomic conditions. Karnataka is divided into four agro-ecological zones[4] which differ in both precipitation and available water capacity, see Figure 1. The diverse rainfall pattern is not only dependent on the season – the area receives 80% of its rainfall during the southwest monsoon period in June to September – there are also geographical differences, with the coastal zone receiving more than 1 700 mm/year, while the central plateau receives less than 1 200 mm/year.

The geographical focus of Paper V was the district of Tumkur, located in the southeast of Karnataka, where the suitability of the land to different land use options was assessed. Tumkur is categorised as agro-ecological Zone 8 and is described as the Central Karnataka Plateau and has semi-arid conditions, with an average rainfall of 688 mm/year (CST 2006). The district covers 1.06 Mha, of which 0.28 Mha comprises wasteland (NRSA 2005). Tumkur district shares a border with Bangalore district, a city of geographical and population expansion, and is subject to increased pressure on the land. The climate conditions in the district are challenging for the people and with the projected decreases in precipitation and increase in temperature (Paper IV), the conditions will worsen. These factors motivate an assessment of the best utilisation of wasteland.

[4] The FAO agro-ecological zone classification which is based on the length of growing period (LGP) concept which in turn, is derived from climate, soil and topography data and evaluated using a water balance model and knowledge about crop requirements (FAO 1996).

Wasteland in India

Degraded land, called wasteland in India (Ravindranath and Hall 1995), is often technically suitable for growing trees and can be regarded as promising land type for LULUCF activities such as those suggested under the CDM, as well as other schemes. Almost 20 % of the land in India, totalling approximately 64 Mha, is classified as wasteland (NRSA 2005). According to Sathaye et al. (2001) about 40 % of the wasteland is considered available for afforestation. Overgrazing and the removal of vegetation, particularly in the semi-arid parts of India, have resulted in rapid erosion of topsoil and finally converted cultivable land into wasteland (Ogunwole et al. 2008). The degradation process of the wasteland is defined as a decline in soil quality with a subsequent reduction in biomass productivity and environment moderating capacity i.e., the ability of soil to perform specific functions of interest to humans (Lal 2004). It is estimated that the average Indian wasteland has a biomass productivity of less than 20% of its overall potential (Ramachandra and Kumar 2003). The protection or introduction of vegetative cover can be a major instrument for the prevention of desertification (MER 2005). Despite attempts from the Indian government to reforest the lands through programmes such as the Social Forestry Projects and Joint Forest Management, the current rate of afforestation and reforestation is inadequate, considering what is required to cover all wasteland within a reasonable timeframe (Murali et al. 2002, Ravindranath and Hall 1995). In 2003, the Indian government announced the National Mission on Biofuel which anticipated that 4 Mha of wasteland across the country would be transformed into bioenergy crops such as Jatropha (*Jatropha curcas L*) and sweet sorghum (*Sorghum bicolor*) plantations by 2008-09. However, the programme was aborted in 2008 (The Economic Times 2008) due to a fear of large land-grabbing exercises by big energy companies. Even though the mission was supposed to target wasteland, the Finance Minister P Chidambaram had raised the issue of how biofuel production would increasingly use farmland, leading to a shortfall in grain production.

Figure 2. Illustration of wasteland in Karnatatka (Photo Palm).

Unmanaged wasteland in India is vulnerable and suffers from high intensity rain during the monsoon season, which usually contributes to topsoil erosion. Due to low soil organic matter status and loss of silt and clay, the water (moisture) holding capacity is low (Paper IV). Measures to reduce soil erosion rates and enhance moisture retention are important in areas that are dependent on monsoon precipitation. One option to increase the infiltration rate and reduce runoff is to increase the vegetation cover or implement soil management practices such as ditching and countering of gully formation. Well-managed crops can regulate water flows and reduce the risks of floods and droughts, particularly so for perennial crops with non-annual harvesting schemes (Gehua et al. 2005).

Re-vegetation of wasteland can be one way to reclaim the productivity and restore the carbon storage in the soils (Smith et al. 2007). According to Balooni (2003) the afforestation of India's wasteland is not only being considered for environmental reasons, but also for the anticipated benefits to the economy. However, the implementation of plantation projects on wasteland is hampered by social, environmental and economic constraints. Soil degradation processes on wasteland have severely reduced the soil's organic carbon content, which is primarily induced by a combination of low biomass productivity and excessive crop residue removals. At the same time, low soil productivity, together with financial difficulties such as a lack of funding and long investment periods are themselves barriers to the implementation of plantation schemes (Balooni and Singh 2003, Ravindranath and Hall 1995). A rehabilitation project for wasteland must promote an income-generating activity in such a way that it reduces or alleviates poverty (Ogunwole et al. 2008).

Aim and scope

The overall scope of the thesis is to analyse global mechanisms for funding land use change and to investigate the local socioeconomic and environmental implications.

The study was initiated in two small southern Indian villages, where the local sustainable development and potential GHG mitigation were assessed (Paper I). Based on the practical experience from the first paper, a literature review on science policy interaction with regards to LULUCF issues in the climate change debate was undertaken (Paper II). The result, in which it was revealed that research would face obstacles to influencing policy development, provided a theoretical foundation on which the subsequent papers could be constructed. The original presentation of the problem led to a conceptual paper (Paper III) in which multifunctional plantation systems and the idea of payment for several environmental services were treated. The concept of designing multifunctional plantation projects where co-benefits were a fundamental term was explored for the real case scenario of rehabilitating wasteland with forest plantation systems in Karnataka. Paper IV investigates the incentives and barriers for such systems on wasteland and adds the financial dimension to the result. How much would it cost to stimulate the establishment of plantation systems with multiple benefits? Paper V asks what the best usage of these wasteland and suggest suitable species which are tested in a land suitability analysis.

Combining these five papers in this thesis results in an improved understanding of the local, regional and global implications of different initiatives on land use change and help analyse the environmental and socioeconomic effects of different efforts, both theoretical and practical. Ideally, the thesis could be read as a reality check for policymakers, but also as guidance for communities that are interested in investing time and eventually money in their land use for rural development schemes[5].

The more specific aims of this thesis have been to:

- Present the environmental benefits that can be obtained from multifunctional plantation systems and analyse how these can contribute to the rehabilitation of wasteland in terms of environmental and socioeconomic sustainability (Papers I, III & IV).
- Analyse how the CDM and other financial mechanisms can influence the development of plantation systems in Karnataka (Papers I & IV).
- Investigate the incentives and barriers for forest plantations on wasteland in different agro-ecological zones of Karnataka and what would be required to overcome these barriers (Paper IV).
- Analyse the best usage of wasteland in an area characterised by natural hardships (Papers I, IV & V).
- Analyse the science-policy interaction between peer-reviewed literature and decisions and declarations on LULUCF projects in the CDM taken at the COP meetings (Paper II).

[5] Rural development can be defined as "development that benefits rural populations; where development is understood as the *sustained* improvement of the population's standards of living or welfare" (Andriquez and Stamoulis 2007).

Methods and tools

Climate policy research covers a variety of disciplines including social and natural sciences. It applies interdisciplinary approaches, including both qualitative and quantitative methods. Traditionally, quantitative research identifies what, where and when, while the qualitative research tries to answer the question of why, how and sometimes who. To include both qualitative and quantitative methods in the research process is not uncommon (Dwyer and Limb 2001) and it is what many researchers do in practice. There can be several reasons for combining methods: either the question requires it or the researcher experiences that a multidisciplinary study would result in improved and more complete results. It should, however, be noted that mixing methods will not always result in an easier analysis of the results. Valentine (2001) writes that one should be aware that a combined approach can result in contradictory results and the researcher should prepare for the more difficult analysis. Widerberg (2002) claims that the choice of methods is very important and is in many cases based on tradition rather than reflections on which method is best suited to answer which question. This thesis includes a combination of qualitative and quantitative methods to cover the different approaches in the specified aims. The methods were chosen to complement each other in a field where the dual objective of carbon mitigation and sustainable development can create a wide span of methods. There is a fine line between qualitative and quantitative methods. In many cases this division of methods functions only in theory and the insight of their close relationship becomes clear when it comes down to the usage of the data. For example, the USDA assessment (Paper IV) in this project was done in a qualitative manner, but the result was subsequently transformed into a quantitative result by using area measurements and transforming the data into diagrams. The same goes for the text analysis, in which the method and aims had a more qualitative focus, but where the results were handled in a quantitative manner to a large extent (Paper II).

Environmental factors

Soil sampling

The soil samples were collected from a total of 56 plots measuring 50x50 m, with up to four plots in each land-use system. A total of five different land-use systems were investigated, giving 336 individual soil samples for Paper IV and 70 for Paper I. Three pits, 30 cm in depth, were dug to collect 200 g samples at two depths in each pit, one at 0-15 cm and one at 15-30 cm, giving six samples from each plot, as suggested by the Ravindranath and Ostwald (2008). The samples were aggregated to composite samples, one for each depth and each land use, resulting in 48 samples. They were analysed for carbon content using the Walkely-Black method (Hesse 1971), nitrogen (N) using the Kjeldahl method, phosphorous (P) using the Olsen method, cation exchange capacity[6] and particle

[6] Cation exchange capacity (CEC) can be used as a measure of the fertility of the soil. A high CEC is considered favourable as it contributes to the capacity of the soil to retain plant nutrient cations. CEC can also be used to estimate the possible response to fertilisation and a rough guide to the clay minerals present (Landon 1991).

size (Landon 1991) and available water-holding capacity[7] (AWC). The particle size distributions were measured and expressed in the form of the sand:silt:clay ratio.

The USDA vegetation and erosion assessment

The USDA vegetation and erosion assessment is a visual interpretation assessment. It is conducted to obtain knowledge about the quality of the land including existing vegetation, erosion and physical characteristics such as soil cover and measures to preserve the soil. The overview of erosion, ground vegetation, shrub vegetation, crown cover and soil cover was divided into six classes, 0, 0-24, 25-49, 50-74, 75-99 and 100% (USDA 1993). The plots were mapped on a scale of 1:500 and systematically drawn and photographed. The different classes were used to compare different land-use systems in terms of the percentage of the categories.

Biomass measuring

To obtain above-ground biomass (AGB) data in natural forest and in plantations, the field quadrate method was used to collect data on the number of stems and girth (Ravindranath and Ostwald, 2008). The 50x40 m plots were chosen randomly. Basal area/ha (BA) was calculated and used to estimate the amount of carbon:

$$C_{AGB} = (50.66 + 6.52BA) \times 0.85 / 2 \qquad (1)$$

The numerator gives the dry matter weight of biomass calculated from the basal area using regression coefficients from Ravindranath et al. (2000) and accounting for a moisture content of air dry wood at 15% (FAO 1983). The denominator arises from the fact that half of the dry matter in biomass consists of carbon. The formula is general for Indian forest and holds limitations, since crown size and height are not considered.

Economic incentive for plantation activities

Generalized Comprehensive Mitigation Assessment Process (GCOMAP)

To estimate the future investment necessary for plantation implementation and the effect of those investments on the plantation rate, the GCOMAP model was used (Sathaye et al. 2005). The linear model establishes a baseline scenario which has no financial revenues from carbon and represents the current plantation rate in different zones in which future development is predicted. Using this as a starting point, areas under plantation for carbon mitigation, the overall mitigation activity and the potential for the period 2005-2100 were assessed. GCOMAP simulates the response of forest and wasteland uses to changes in the carbon price at different plantation rates and estimates the amount of additional land brought under the mitigation activity above the baseline level. The GCOMAP

[7] Available Water-holding Capacity (AWC) is the amount water perceived available for the plant.

model used a baseline scenario of 0 US$/tC with price laps of 5, 50 or 100 US$/ tC sequestered. The results show the predicted rate of reforestation and the land available for plantation activities in the future. The assumed prices can be compared to reported prices for forestry credits either under the CDM or the voluntary market.

Barriers and incentives

Interviews

Three types of interview methods were used, all with the assistance of an interpreter. There were several informal interviews for acquiring general information (Papers I and IV), contact with key informants for local information to distinguish relevance of further investigation (Papers I and IV), and the distribution of 30 quantitative questionnaires for collecting personal information regarding forests and plantations (Paper I). The interviews with the key informants were also used to assess the socioeconomic factors affecting the usage of the wasteland (Mikkelsen 1998). The aim of the interviews was also to assess the availability of land for plantation purposes from a local perspective, to obtain information regarding the usage of the existing forest from the people who were directly influenced by a plantation project and finally, to estimate the potential for the villagers to play an active role in such a project. The interviews provided information about how the villages viewed the plantation projects and their willingness to be involved in further development projects.

Land use options

Ranking tool

In Paper I, a simple and transparent ranking tool for processing empirical data in an integrated analysis of suitability of possible CDM project activities was suggested. Mendoza and Prabhu (2000) describe ranking as parameters judged by their degrees of importance and are then given ranks accordingly, compared to one-on-one analysis. Further they conclude that ranking is an excellent technique to use as crude or coarse filters designed to prioritize a long list. The data were to be processed from the perspective of sustainable development and climate benefit. The ranking system was developed and applied to the studied forests and plantations. The procedure can of course be adapted to the evaluation of other candidate LULUCF activities under the CDM and to plantation projects in general. Four different parameters were used for this ranking procedure. To enable the ranking, a certain time-frame was set, i.e., a 30-year crediting period based on the maximum carbon stored during this time. In the ranking, the parameters AGB carbon and soil carbon were chosen to exemplify carbon sequestration and therefore climate benefits. Acceptance from villagers and land availability were chosen as sustainable development parameters. These parameters are not directly sustainable criteria but function as the basis for several sustainability co-benefits such as a financial flow to the project area, employment and development in infrastructure. Other potential parameters that could be used in the same ranking tool are other carbon pools, employment effects, social and community development, equity of returns and leakage.

Geographical Information System (GIS)

Different options for rehabilitation of the wasteland will have different environmental demands, and are therefore better or worse suited for the wasteland. This can be demonstrated in a land suitability analysis presented in Paper V. Assessed in a boleean GIS analysis, the suitability of the wasteland is based on environmental limitations for each of the land-use suggested, i.e., the thresholds. The thresholds are in turn based on physical requirements of the different land-use options and gathered from literature. The different layers will include these parameters:

- Soil depth,
- slope,
- temperature,
- precipitation and
- available water holding capacity (AWC) and
- soil quality.

Agro-ecological zone

With the FAO agro-ecological zone, yet another mapping approach has been used. The separation into agro-ecological zones serves to fine-tune the regional analyses in Paper IV (FAO 1996, FAO 1981). The agro-ecological zone approach is based on the length of growing period (LGP) concept. This, in turn, is derived from climate, soil and topography data and evaluated using a water balance model and knowledge about crop requirements. The agro-ecological zone approach has been globally adopted for assessing the growth potential of crops and can also be extended to the growth of forest or plantation biomass. The use of zone classification for this assessment is logical due to the geographical differences that greatly influence the potential of any plantation activity. India has categorised its entire geographic area into 20 zones, four of which can be found Karnataka.

Policy-science interaction

Literature review and meta-analysis

The literature search method is a further development of Oreskes (2004) and is based on literature collected from five databases for the period January 1997 to December 2005. The search also included articles in press[8]. The search used different central search words which were combined with secondary search words to capture relevant articles. The search resulted in 88 articles which were analysed with the help of a matrix that was especially developed for this purpose. In the matrix, issues of scale, author's discipline and country of affiliation, attitude towards A/R CDM and year of publication were noted. The matrix also dealt with specific questions, all related to A/R CDM, such as additionality, leakage, baseline, permanence, monitoring, sustainable development and general climate benefit.

[8] As of December 2005

Results

Environmental factors

Soil analysis

In Paper I, the soil carbon in natural forest and acacia (*Acacia aculiformis*) plantations of 10 and 5-year rotation periods respectively was compared. The soil sampling resulted in a soil carbon analysis showing that the natural forest (56tC/ha) has a higher carbon density than the plantations at which the 10 year rotation plantation had 40tC/ha and the 5 year plantation had 51tC/ha. It is worth noticing that soil carbon in the 5-year old acacia plantation is higher than in the 10-year old plantation, indicating a decline in soil carbon from the former land use, i.e., natural degraded forest, to a lower soil carbon stock under acacia plantations. However, the difference in carbon stocks between the two plantations is probably too large to be affected by time only (IPCC 2000), which indicates that the land use history may have had an influence on the results.

In Paper IV, six other parameters were included in the analysis. These were phosphorous, nitrogen, CEC, particle size, soil texture and AWC. Based on these parameters, soil analyses in different land-use systems were conducted. Generally, the results show that all the investigated parameters have lower values in wasteland than in natural forests. The plantations have a higher soil organic carbon value, CEC and clay content than the wasteland.

The plantations also differ in age, which makes direct comparisons difficult. The plantations have therefore been divided into two categories in the analysis of the entire state, new (up to 10 years) and old (over 10 years), as shown in Table 4. The results show that the old plantations have higher values for all parameters than the newly established plantations and wasteland, with the exception of phosphorus. When the newly-established plantations are compared to wasteland, only the CEC and the clay content are higher in the plantations. This illustrates the poor quality of the land in places where plantations are established.

The soil texture, given by the sand:silt:clay ratio, can be used to determine the relationship between land use and the available water capacity for the different sampled areas in this study. The soil texture analysis shows that the wasteland and plantation categories have an average available water capacity of 154 mm/m soil (Table 4), while the natural forest category has an average available water capacity of 188 mm/m soil (NMSU 1996).

Table 4. The results from the soil analysis divided into different land-use systems in different agro-ecological zones (AEZ) in Karnataka. The wasteland category includes grassland and degraded forestland.

Parameter / Land use	Organic C%	Nitrogen %	Phosphorus ppm	CEC	Particle size % sand	silt	clay	Soil texture*	AWC mm/m
AEZ mean									
Natural forest	1.1	0.27	38	9.2	37	30	32	CL	188
Wasteland	0.37	0.13	28	8.4	61	15	24	SCL	154
Plantation	0.42	0.12	24	9,5	62	12	25	SCL	154
*Old***	*0.49*	*0.14*	*20*	*9,6*	*48*	*20*	*32*	SC	171
*New***	*0.37*	*0.10*	*26*	*9,4*	*57*	*15*	*28*	SCL	154
AEZ 3									
Wasteland	0.45	0.11	23	13.2	47	29	24	L	169
Plantation	0.17	0.08	14	7.9	68	13	19	SL	118
AEZ 6									
Wasteland	0.39	0.14	27	8.9	63	11	26	SCL	154
Plantation	0.44	0.11	25	10	50	16	33	SC	171
AEZ 8									
Wasteland	0.25	0.07	35	5.5	75	9	16	SL	118
Plantation	0.51	0.15	25	9.4	53	21	26	SCL	154
AEZ 19									
Natural Forest	1.1	0.27	38	9.2	37	30	32	CL	188
Wasteland	0.55	0.19	32	9.1	51	17	33	SC	171

* CL: Clay Loam, SC: Sandy Clay, L: Loam, SCL: Sandy Clay Loam, SL: Sandy Loam

AWC source (NMSU 1996)

** Old plantation implies plantations older than 10 years and new plantation implies plantations younger than 10 years

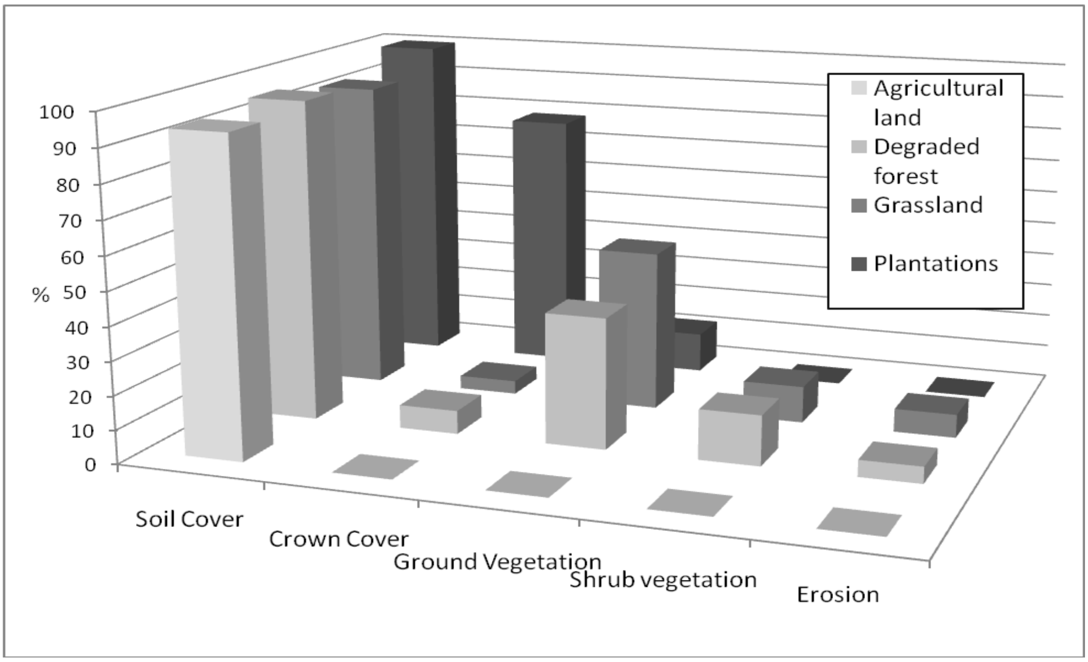
The USDA vegetation and erosion assessment

The USDA analysis divides the wasteland category into grassland and degraded forest land and compares the result with plantations and agricultural land. The USDA analysis shows that the wasteland with the largest areas of erosion are located in zones 6 and 19, with a total of 10% erosion in each zone (Figure 3). The grasslands and the degraded forests show a high degree of erosion; they have less soil cover than other land-use systems where the impact of erosion is low because some kind of land management, such as plantation or agricultural development, has taken place. The degraded forests hold some tree cover, but not enough to be defined as a forest under India's definition of a forest under the CDM[9]. The grassland has a high grass cover but very little tree or shrub cover. This makes the grassland ideal for plantation establishment, since no vegetation needs to be cleared prior to the plantation.

9

Tree crown cover value of 15%, with a land area of at least 0.05 hectare and a tree height of at least 2 meters (UNFCCC 2009).

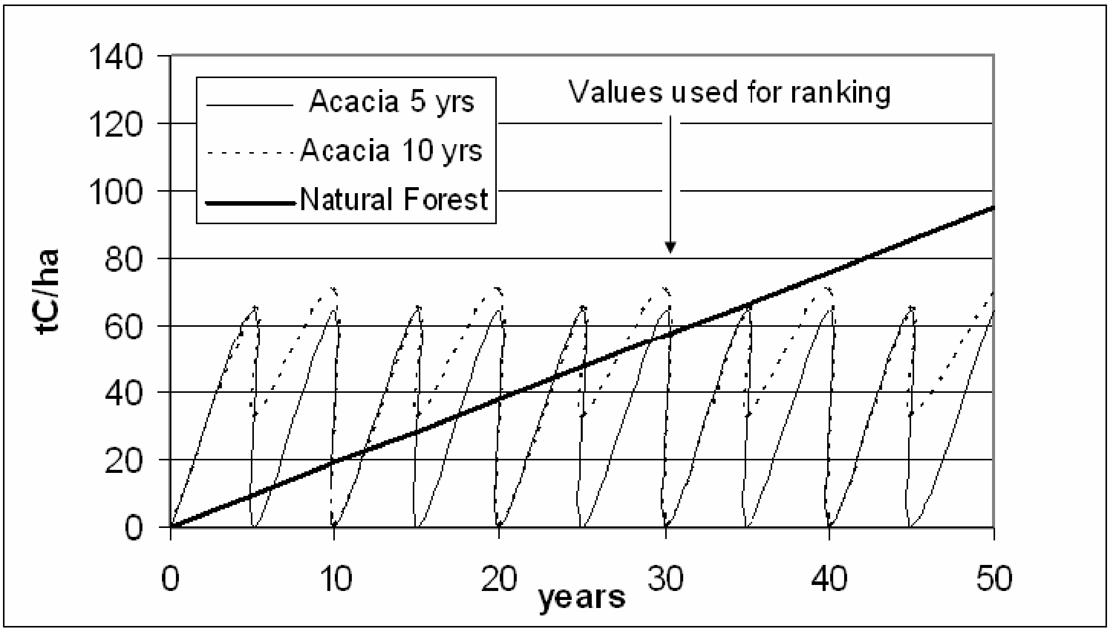
Figure 3. Results from the USDA vegetation and erosion assessment. The results of the USDA analyses are expressed in percentage.



Biomass

Biomass measurements were conducted for Paper I to compare carbon content in above ground biomass (AGB) in different land-use systems. The analyses show that the natural forest has the highest AGB and hence the highest carbon density compared to the plantations. There were twice the number of stems in the 5-year plantation compared to the 10-year plantation. The decline in the number of trees in the acacia plantations over time indicates the practice of thinning as the plantation grows. The above ground carbon varies between 65tC/ha for the short rotation plantation to 117tC/ha for the natural forest (Figure 4). The carbon levels found in assessments for Paper I are much lower than the numbers given by IPCC assessments for primary and logged forest at the margins of the humid tropics (192 to 276 tC/ha) (IPCC 2000).

Figure 4 Modelled contributions to emission reductions from the studied plantation systems under the different rotation schemes.

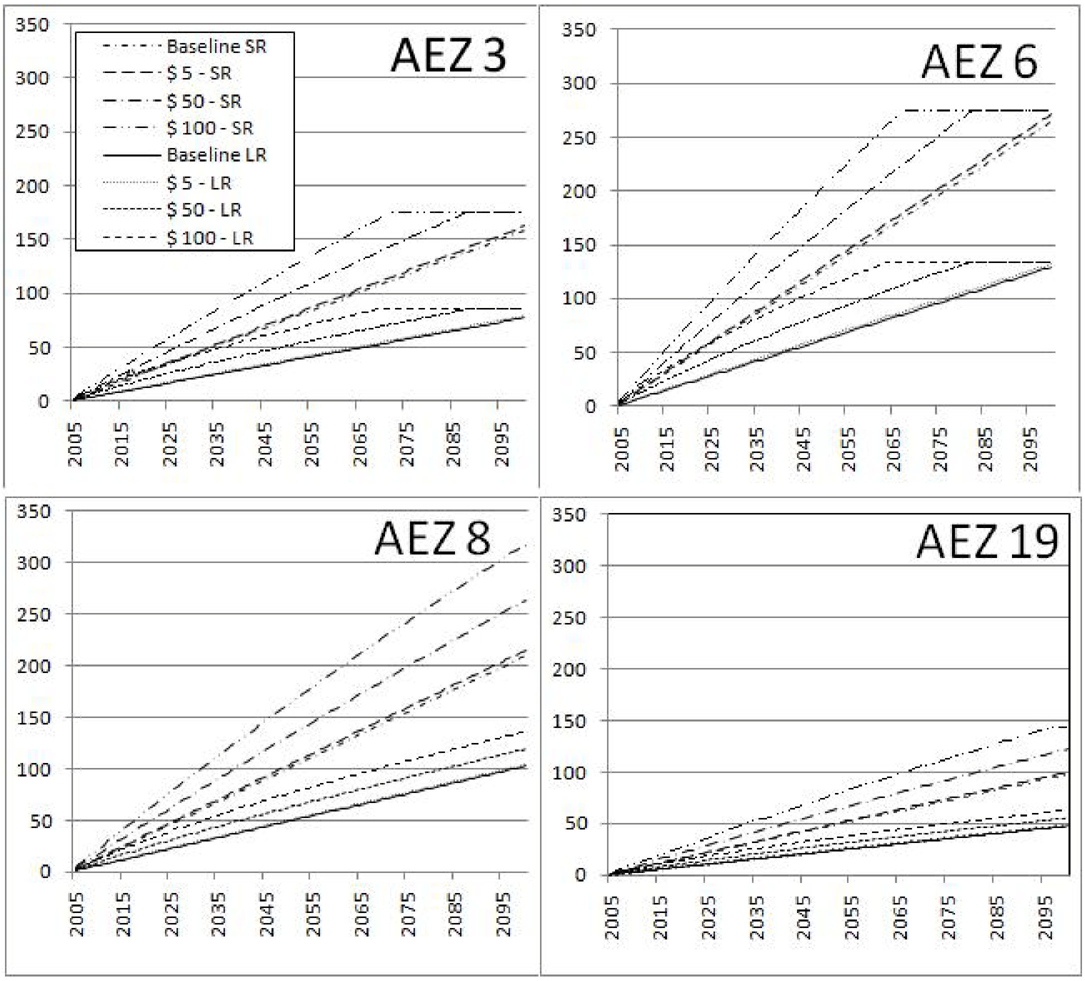


Economic incentive for plantation activities

Since India and the state of Karnataka already have a large plantation programme, it is necessary to predict the plantation rate and how much can potentially be covered with different planting speeds using different carbon price scenarios. The results from the GCOMAP model, which used a baseline scenario of 0 US$/tC, show the predicted rate of reforestation and the land available for plantation activities in the future.

Figure 5 illustrates the rate of plantation activities with different carbon price scenario model runs according to the GCOMAP model, in this case from agro-ecological zones 3, 6, 8 and 19. An increase in the carbon price from 0 in the baseline to 5, 50 or 100 US$/tC sequestered would increase the plantation rate. The result shows that the rate of plantation activities would be higher for a short rotation management period than for a long rotation management period, regardless of the carbon price. For the short rotation option in zone 8, a maximum planted area of 0.3 Mha is reached by the year 2100 (carbon price level 100 US$/tC). For the long rotation option and a carbon price of 100 US$/tC, there will be no available wasteland for plantation in zone 8 by 2064. Thus, a higher carbon price incentive is necessary to bring larger areas under plantation in the near future.

Figure 5. The two different rotation options, long rotation (LR) and short rotation (SR), with four alternative price scenarios for the agro-ecological zones in Karnataka state, from the baseline value of 0 US$/tC to 5, 50 or US$ 100/tC.



Financial opportunities such as the CDM or other compensatory mechanisms could possibly help to overcome financial constraints. However, the area planted at a carbon price of 5 US$/tC would be marginal. The price has to increase to bring about an increase in the current plantation rate. Comparing this rate with the current prices for forestry credits as described above in the section entitled Policy Context, an increase in prices to any level of importance is unlikely.

Barriers and incentives

Environmental

The results illustrate both environmental and socioeconomic barriers when it comes to establishing plantation activities on wasteland in Karnataka state. According to the NRSA (2005), the availability of wasteland in this area is substantial; however, the wasteland is of poor quality, being badly eroded and lacking soil nutrients. Compared to natural forest land or already established plantations, the quality of the wasteland is lower than its potential in many cases, which is one environmental argument for increasing the rate of plantation. During the interviews (Paper IV), the eight key informants identified several barriers to, and merits for the establishment of plantation activities on their land. The villagers identified a shortage of water and soil quality concerns, meaning that plantations would use too much of the already scarce water resources in the villages as well as extract nutrients from the soil that would be needed for other crops. However, the rate of erosion would decrease after the establishment of a plantation, the infiltration capacity would increase and the plantations would contribute to better local climates. These are clear incentives for the potential implementation of a plantation project. The villagers point out that plantation projects on privately-owned wasteland are welcomed by the villagers; on the other hand, experience had shown that plantations introduced by the government tended to occupy too vast an area of the villages. The results also indicate that the plantations already established in the villages do not have the same soil quality as the natural forest. The plantations investigated were almost exclusively established on severely degraded forest land. This is illustrated by the low quality of the newly-established plantations (under 10 years), which can be compared to the quality of the wasteland. On the other hand the results show an improvement in most of the soil quality parameters when the wasteland were transferred into plantations.

Socio-economic factors

The results from Paper I show that the villagers use a majority of the goods and services from the natural forest and can do so legally, as long as they don't cut down the trees. However, the local usage of the plantations was limited or even totally non-existent. In the villagers' opinion the acacia plantations in this study do not provide the services expected. A large part of the informants (47%) state that the government benefits more from the plantations than the villagers, while only 7% expressed this opinion for natural forest. The majority of respondents agreed that all forest resources, including plantations, were beneficial for the village. Thus, the attitudes towards natural forests among villagers are positive but a certain amount of resistance against the plantations was identified. This was mainly found in situations where the plantations were raised and managed by the Forest Department with no or little involvement in the project or user-rights to the village community, similar to that found in Latin America (Boyd et al. 2007).

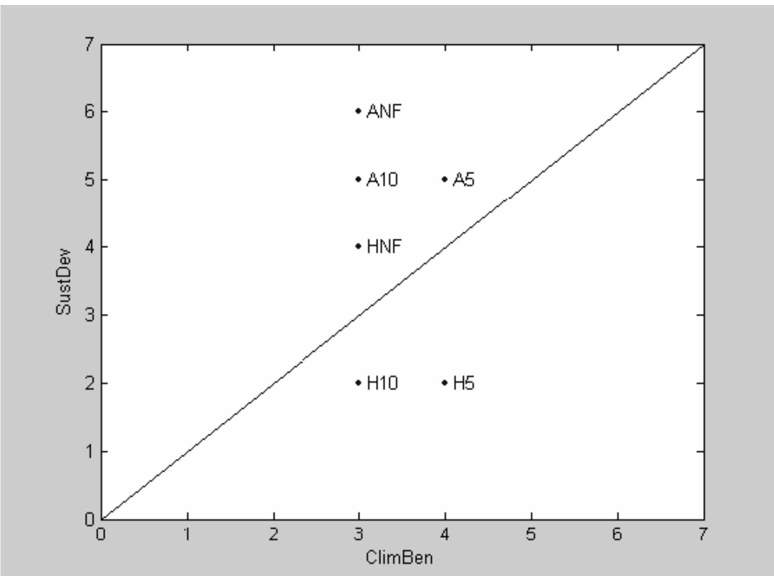
When the key informants in Paper IV were asked for their opinions and experiences regarding plantation projects and their possible involvement in such a project their responses were similar regardless of the geographical location. Many of the villages have had negative experiences with government-run plantations, where neither the revenues nor the harvest have benefited the locals. However, previous plantation activities have increased the rate of employment in the villages. Even though the villagers do not manage these plantations themselves, the accessibility of forest products increases with the establishment of plantation activities. The villagers state that they are interested in, and have the capacity to invest their time and devote land to an eventual plantation project, as they see a plantation on the wasteland as an investment for future needs. The villagers would prefer a mixed plantation with indigenous species and would like to receive an income, as well as pulp and fruit yield from a potential plantation on the wasteland. Such a project would ideally be locally rooted and managed by the villagers. However, financial resources are scarce in the villages and the funding needed for the establishment of plantation projects is not locally available.

Land use options

Ranking tool

Paper I suggests a ranking tool for managing the balance between the dual objectives of CDM projects, the climate benefit and the sustainable development. The ranking tool results both in a table where the different land use options are ranked according to pre-determined criteria and a diagram where these rankings are plotted for a visual interpretation (Figure 6). From the ranking, it becomes clear that the natural forest is ranked high both in terms of climate benefits and sustainable development, in some cases higher than the plantations. The example of natural forest is included in the study only as a comparison, since a mature natural forest would never develop in a 30-year time frame with the present modalities of the CDM. However, with a slow A/R CDM development and with a globally increasing concern regarding avoided deforestation, the issue of natural forests and their benefits are worth pointing out. Among the plantations, climate benefit ranks the short rotation project highest whilst sustainable development ranks both of the plantation projects from one specific village the highest. This indicates the sensitivity of the tool to changes in the parameters included, both the number of parameters and their alignment. The proposed ranking tool proved to be flexible and transparent for assessing local sustainable development and carbon sequestration potential. Hence, it is not limited to only A/R CDM projects and can be seen as a pre-option to the various climate and developing standards in the carbon market as of 2009.

Figure 6. Conceptual position of the possible projects based on the data from the ranking exercise.



NF - Natural forest, 10 - 10-year plantation, 5 - 5-year plantation, A - Akkunji, B – Huladevansara.

Land suitability analysis

The suitability of different land use options depends on several factors which will be of greater or lesser importance, depending on the aim of the project. Based on the illustrative results, Paper IV gives recommendations for a potential CDM strategy based on the regional results from the AEZ approach (Table 5). The recommendations consider both environmental and socioeconomic results and show both which barriers need to be overcome and what incentives there are for implementing plantation projects. This zone approach can be useful in feasibility studies and evaluations of plantation activities. The four zones considered in this study show several similarities when it comes to both climate and socioeconomic factors. The interviews illustrated that plantation activities were welcome and needed in all four zones. A future increased temperature, lack of financial resources and limited water availability are the main barriers to the establishment of plantation projects. The USDA, GCOMAP, soil quality and available water capacity analyses reveal some differences between the four zones. Depending on the requirements for a plantation project, different zones will be more or less suitable.

Table 5. A comparison of assessed indicators of wasteland potential in different agro-ecological zones for plantation activities based on the field work cases.

	Climate trend	**Wasteland Availability (in ha)**	**USDA (% land erosion)***	**GCOMAP**	**Soil quality**	**AWC mm/m**	**Local socio-economy**	**Local barriers for A/R establishment**
AEZ 3	Precipitation: decrease Temperature: increase	211 355	3	Least favourable	Low potential	167	Available land: Y Interest: Y	Partly financial and lack of water
AEZ 6	Precipitation: decrease (an increase the last 20 yrs) Temperature: increase	341 148	10	Most favourable	Most suitable	154	Available private: Y Interest: Y	Financial and lack of water
AZE 8	Precipitation: decrease (an increase the last 20 yrs) Temperature: increase	421 526	2	Most favourable	Most suitable	118	Available land: N** Interest: Y	Financial and lack of water
AEZ 19	Precipitation: decrease Temperature: increase	166 590	10	Least favourable	Good quality of land	171	Available land: Y Interest: Y	Financial

* To obtain the actual characteristics of the five land types included, the mean of each USDA class was divided by the number of plots investigated in each land type.

** Only if there are financial means and the rate of return is higher from the A/R activities than from the present land use.

Y = yes N = no

Results presented in Table 5 show that plantation activities can either aim at wasteland rehabilitation, preferably targeting areas in Zone 6, or aim at maximising productivity, targeting areas in Zone 8. When the available water capacity is taken into account, Zone 19 appears to be the most favourable and Zone 8 the least favourable. An evaluation of soil quality, including the carbon content, cation exchange capacity and clay content would point to Zones 6 and 8 as both having a significant potential for improvement. According to the GCOMAP results, zones 6 and 8 appear to be most favourable since an increased carbon price would result in the highest increase in the plantation rate. A synthesis of the results of the different analyses point to Zone 6 as the preferable AEZ for plantation activities followed by Zones 8 and 19, with Zone 3 being the least suitable.

The GIS analysis in Paper V reports 73 300 ha of the wasteland area available for plantation out of a total district area of 1, 060 Mha. The land suitability analysis show that the land use that could potentially cover the largest area is Jatropha plantations, covering 51 500 ha, while Teak only cover about 19 000 ha. Sweet sorghum could cover the least area, only app. 11 000 ha whereas Acacia, Eucalyptus and Pongamia could cover substantial areas, just less than Jatropha (Table 6). The wasteland areas suitable for planting one or more species are 52 600 Ha which can be compared to the total amount of wasteland of 73 300. The area available for planting four or five species is dominating with slightly less than 20 000 Ha each. The area suitable for one and six species potentially only can cover approximately 4000 Ha each while the area where only one species out of six can be suitable for plantation are just over 700 Ha.

Table 6. The amount available wasteland for suggested species.

Suggested species	Available wasteland (ha)	% of total wasteland
Teak (*Tectona grandis*)	18 900	25.8
Eucalyptus (*Ecualyptus tereticornis*)	42 500	58.0
Acacia (*Acacia auriculiformis*)	45 700	62.3
Jatropha (*Jatropha curcas L*)	51 500	70.3
Pongamia (*Pongamia pinnata*)	42 500	58.0
Sweet Sorghum (*Sorghum bicolor*)	10 900	14.9

Policy-science interaction

The analysis of the peer-reviewed articles in Paper III showed that out of the 88 article only 19% had a first author based in a developing country while the same number for the contributing authors was 38% (Table 6). The results show that authors from developing countries tend to discuss fewer barriers than possibilities in comparison to authors from developed countries. For a mechanism built on cooperation between developing and developed countries it may seem strange that the share of research from the developing world is not larger than the results in this study show.

A majority (49%) of the articles had first authors who were trained in the natural sciences, 18% from economics, and 26% from multidisciplinary institutions. The largest proportion (60 %) of the 88 articles had a global/general focus on the LULUCF issue, 19% of the articles focused on a country-based scale and 6% percent of the articles focused on a country-specific regional scale. The rest of the articles had either a local (2%) or a larger regional focus (11%) (Table 6).

Category		Number	Percentage (%)
Total		88	100
Year	1997	2	2
	1998	1	1
	1999	6	7
	2000	11	13
	2001	13	15
	2002	14	16
	2003	12	14
	2004	19	22
	2005	9	10
	2006 + in press	1	1
Affiliation (1 author)	Natural	43	49
	Economic	16	18
	Social	4	5
	Multi inst	23	26
	Multi Uni	2	2
Affiliation (cont. author)	Natural	94	64
	Economic	9	6
	Social	7	5
	Multi inst	29	20
	Multi Uni	9	6
Scale	Local	3	2
	Region (small)	5	6
	Country	17	19
	Region (large)	10	11
	Global/General	53	60
Country of affiliation (1 author)	Developed[10]	71	81
	Developing[11]	17	19
Country of affiliation (cont. author)	Developed	92	62
	Developing	56	38

Table 6 The parameters used in the analysis are presented with the number of articles in each category and the percentage of the total number.

[10] Developed countries in this study: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Italy, Japan, New Zeeland, the Netherlands, Russia, Spain, Sweden, UK and the US.

[11] Developing countries in this study: Brazil, China, Costa Rica, India, Indonesia, Kenya, Mexico, the Philippines and South Africa.

Generally, the analysis shows that the discussions supporting the inclusion of LULUCF in the CDM constitute the majority (66%) and that authors from social sciences tend to be more critical of the inclusion of LULUCF (see Table 3 in Paper II). The most widely discussed issue was that of sustainable development and general climate benefit. Out of 88 articles, 44 discussed general climate benefit and 42 discussed sustainable development as a positive outcome of LULUCF CDM. Compared to the above, 22 articles mentioned general climate benefit from a critical point of view and 23 articles were critical of sustainable development (see Table 3 Paper II).

The majority of the articles had a positive attitude towards the inclusion of LULUCF in the CDM. One result is the trend towards increasingly critical views from 1998 onwards, which may reflect the optimism that existed in the early years of CDM. The trend shows a more positive view at the local/case study levels or at the global/general level in relation to the regional levels, whether small, large or country.

This literature assessment could not clearly illustrate interaction between peer-reviewed scientific research and COP decisions. This could be because (a) the process of publishing peer-reviewed literature is slow and is formally available to others only a considerable time after its production and (b) input to decision-makers may be found in scientific working papers and publications from NGO and lobby organisations. Hence peer-reviewed work can be regarded as more of an evaluation of policy decisions. From the results, it is evident that the declarations and decisions differ in their relationship to peer-reviewed articles. The results indicate that policymakers set the research agenda by declaration with low levels of detail, which provides the focus for researchers, while researchers feed the decision-making process with highly detailed research up until the point at which a decision is made.

Discussion

Based on all the information in all five papers included in this thesis, one overall question presents itself:

How should the wasteland be utilised?

Clearly, there are several answers to that question. Depending on views on environmental and socioeconomic feasibility of alternatives, financing, barriers and incentive structures different stakeholders come up with different preferred land use options. A discussion of environmental, social and financial considerations that need to be taken into account when a plantation project is to be implemented is outlined below.

Environmental considerations

The results from Paper IV give a somewhat contradicting conclusion. When the wasteland is compared to adjacent natural forest land or already established plantations it becomes obvious that the quality of the wasteland is in many cases lower than its potential, which is one argument for increasing the rate of plantation. On the other hand, poor land quality and poor water availability are difficult environmental barriers to plantation projects in the area, as indicated by the results. Plantation projects can facilitate soil rehabilitation and enhance the soil carbon content: several experiments with well-selected trees and intensive management on severely degraded Indian wasteland (such as alkaline sodic or salt-affected lands) showed increases in soil carbon, nitrogen and available phosphorous after three to thirteen years. (Sing 1990, Pal and Sharma 2001, Mishra et al. 2003). When the plantations in this thesis are compared to the wasteland there is a clear indication that soil quality improves with time. This makes the case for long-term plantation projects, which could be harvested in a shorter rotation scheme, preferably with trees that are coppiced for minimal soil disturbance. However, even a slight increase in vegetation cover from the baseline can be beneficial for the restoration of wasteland in terms of erosion control and an increase in the organic matter. LULUCF projects have a broad range of environmental and socio-economic impacts that need to be taken into account when assessing suitability for the CDM. The dual —and potentially conflicting— set of objectives in the definition of the CDM adds an extra challenge. The design of a LULUCF-based CDM project activity may become a process of balancing the disparate objectives of the parties involved (i.e., the objective of local sustainable development may require a project design that is different from the one that maximises cost-efficiency in CER generation). This balancing process will be unique for each CDM project activity.

Water is currently scarce in Karnataka, particularly in the eastern parts. The climate in the recent past (Paper IV) shows an increase in temperature and a decrease in rainfall. If the increasing trend in temperature and the decreasing trend in precipitation continue in the future, then the prediction is a drier and warmer climate. The lack of water is already a problem when establishing new plantations. In a country such as India, which is dependent on season-regulated monsoons, there is an even higher pressure on land management schemes aimed at an increasing infiltration and decreasing surface run-off. Soil water infiltration influences groundwater recharge and potentially top soil loss by erosion together with dividing the runoff into a slow and a quick flow. A systematic review and meta-analysis conducted by Ilstedt et al. (2007) show that the infiltration capacity increased on an average approximately three-fold after afforestation of replanting trees in agricultural fields. This result indicates that a low infiltration rate on wasteland would increase by introducing a land use option where the planting of trees plays a major role. However, Ilstedt et al. (2007) further discusses the lack in statistical studies related to the issue which in turn affects the growing demand for model the hydrological effects of land use change. If an increase in the productivity of the wasteland is to be achieved then improved land management is necessary, with water conservation as the main goal. All possible practices, such as increasing soil organic matter, clay content and cation exchange capacity are necessary for sustainable water resource management. Papers III and IV illustrate the environmental benefits following the rehabilitation of wasteland through re-vegetation. The establishment of biomass plantations on wasteland can contribute to the reclamation of wasteland for productive uses in several ways.

The results show an improvement in most of the soil quality parameters when the wasteland was transformed into plantations. During the interviews (Paper IV), the eight key informants identified several barriers to, and merits for the establishment of plantation activities on their land. The villagers identified a decreased rate of erosion after the establishment of a plantation, an increase in the infiltration capacity and improved local climate, giving clear incentives for the potential implementation of a plantation project.

The land suitability in Paper V shows the area available for implementing various land use options and species for wasteland rehabilitation. The results show that the area one or more species option could be implemented is 52 600 Ha, about 71% of the total wasteland in the district. It doesn't present a ranking of the land use options and species choice nor does it weight the implication of such a plantation. The results show that even if the wasteland is degraded, the results show that with a carefully assessed land suitability analysis more than two thirds of the wasteland could be covered with vegetation aiming for land rehabilitation. Both Jatropha and Pongamia have shown large potential in this area. Even plantations with a short rotation management, both Eucalyptus and Acacia plantations would be well suited in wasteland development. This implicates an advantage for the land owner of that specific land and function as a great stimulus for sustainable development, the possible choice of actions. The assessment has the advantage of an unbiased analysis, as far as possible, not favoring any specific end-use or implication. This view, however, is not granted the local land owner who need to make trade-offs with parameters such as investment cost, land rehabilitation, financial revenues and end products. It is likely that the land owner's options are limited by constraints of environmental parameters, financial means and time.

Socioeconomic considerations

In general, plantation activities will take place in rural areas and benefit the rural economies. However, care has to be taken in determining where the plantation takes place, since plantations on agricultural land may threaten food security. In most cases, the wasteland investigated in this study are unsuitable for agricultural purposes and would instead be better suited for plantation purposes; however, this does not mean that plantations are the only option for land-less farmers to generate an income. Paper V outlines how the wasteland should best be utilised within a range of options. To obtain a comprehensive picture of the different alternatives, as Paper V considers, several more analyses need to be carried out, for example a cost-benefit analysis, a land suitability investigation and an eligibility analysis for different financial options. The rising concerns over land-use competition, food vs. fuel or mitigation, should not be taken lightly (Naylor et al. 2007, Tenenbaum 2008, Runge and Senauer 2008, Pingali et al. 2008). However, Runge and Seanuer (2008), and Naylor et al. (2007) recognised that the right policies could curb this risk. A United Nations publication on sustainable bioenergy emphasised the need for a more comprehensive analysis, arguing that the current debate around food security and biofuel is "too simplistic and fails to reflect the full complexity of factors that determine food security at any given place and time" (UN-Energy 2007). The land competition issue will play a major role in determining the availability of land for plantations in the future (Ravindranath et al. 2009). Intensification in agricultural production capacity could potentially lower the pressure on forests, while on the other hand it might trigger migration which might increase deforestation elsewhere (Sathaye et al. 2007).

Even though plantations create employment, they often do not create enough employment to provide economic long-term opportunities for a large number of local people. The plantation work is often not very labour-intensive and very often the jobs go to non-locals, or to well-educated and trained candidates (Charnley 2006). This differs however between different land-use systems. In Paper IV, the farmers state that they have received an income from government-run plantations and would accept the same from any plantation activity in the future. Another example are the Jatropha plantations which are labour-intensive and likely to generate jobs and income for rural people. Harvesting bioenergy crops such as sugar cane and sweet sorghum, on the other hand, does not require the same amount of labour and consequently provides fewer jobs for the rural population (Biofuelwatch 2007).

In Paper IV, the GCOMAP model is used to illustrate the effect a financial incentive would have on plantation activities on wasteland. It should be observed that the model used in the thesis only yields general regional results; it cannot be applied on a local scale without carefully examining the potential at the local level. As seen in the interviews (Papers I and IV), some of the key informants highlight several environmental barriers to plantation implementation. Local conditions are crucial since they determine the failure or success of plantation implementation to a large extent. Generally, it can be concluded that the villagers are not satisfied with the outcome of the government-introduced plantations, which only led to a small amount of employment and poor revenues. At the same time, several key informants describe multiple co-benefits that would follow the establishment of new plantations under a private regime. Perez et al. (2007) conclude that the introduction of a financial system for carbon trading should never be forced on local communities by regional, national or global institutions. The importance of local farmers' participation in management and species selection is illustrated in a paper by Blay et al. (2008). Based on consultation with the participants, the researchers were able to identify the local people's needs. This approach minimised the differences in interests and encouraged greater participation.

One major problem with the implementation of forestry projects which generate an income from carbon credits is a complexity in the documentation (the World Bank 2008). Albeit a simplification, the use of regional baselines (Sudha et al. 2006) together with the suggested ranking tool in Paper I and the land suitability analyses in Papers IV and V may support a fast track for the implementation of forestry projects, as the local conditions are taken into account. The wide use of the concept of 'sustainability' reflects a broad agreement that people living today have an obligation to protect the health, diversity and productivity of the environment for the benefit of both current and future generations. This is mainly because a healthy environment is a necessary element of a productive economy, and hence human wellbeing (Victor 2006). By definition, unsustainable practices cannot continue indefinitely without degrading current conditions and reducing future opportunities.

Financial considerations

Paper IV shows that the major socio-economic constraint for establishing plantation activities on wasteland is the lack of financial resources to establish a new plantation scheme, despite a wealth of interest and experience. The investments required for wasteland rehabilitation may be too large for small-scale farmers or even a village. Joshi (1997) shows that many farmers consider a rotation period of 7-10 years to be too long in relation to their need for revenue and are therefore unwilling to invest. The modalities of the CDM, where the certified emission reductions, i.e., carbon credits, can be issued for temporary credits may be one way of getting around this problem. Involving a larger group of farmers may be another way forward, where the risk could be spread and common resources shared during the years where no revenues are obtained from the plantations. A substantial increase in carbon prices is necessary before a clear difference in plantation rate can be seen in Karnataka state, illustrated in Paper IV. The IPCC (Smith et al. 2007) shows that there can be a significant change in the potential for global mitigation, for example by increasing the price of carbon when it comes to the restoration of degraded lands and agro-forestry.

Other options for financing plantation activities in Karnataka state could, for example, be verified emission reductions or PES. Verified emission reductions are, in this case, carbon credits obtained through plantation projects offered to the voluntary market (World Bank 2008, Hamilton et al. 2009, Taiyab 2005). The concept of PES requires stakeholders to pay for the protection or production of environmental services. These services could include an option to ensure climate change mitigation at the lowest cost, an option to ensure environmental services of local or regional interest such as the regulation or filtration of water flows and a possibility to strengthen rural livelihoods and revalue rural landscapes, their diversity of practices and ecosystems (Rosa et al. 2003). Since the reforestation of wasteland generates benefits for the public good from local to global level, it could be argued that some of the costs should be covered by national means or international aid (FAO 2006). When environmental services are being restored or protected, the public would benefit, in addition the concept of PES offering financial revenues for such restoration and protection. Zilberman et al. (2008) and Wunder (2008) ask a question that is just as important to CDM as it is to PES: would PES benefit the poor? Zilberman et al. (2008) conclude that meeting two objectives – improving environmental quality and reducing poverty – with only one policy instrument can be challenging. It appears that land owners will be directly benefiting from a PES scheme while the landless people are more likely to benefit when the action will increase the labour intensity. Finally, PES is based on the marketing of different environmental commodities. The question therefore remains, is it possible to put a price on natural capital? If not, is it then necessary to develop systems that guide development in attractive directions?

Over recent years, there has been an extensive global effort to develop new tools and approaches to reduce the complexity of meeting sustainability requirements and highlight the fundamental links between the economy, society and the environment (Gold Standard 2009, CCBA 2009, Plan Vivo 2008). While these are fully integrated with traditional economic and social accounting frameworks, they are providing information for planners, decision-makers and individuals around the globe to help chart the pathways toward sustainability. With a wider interest in the effects humans have on nature and a greater degree of corporate responsibility, the definition of PES could provide such a pathway towards sustainability. By putting a financial value on our natural capital, wider than the traditional sectors, the sustainability dimension could be incorporated in any usage of resources and be seen as almost “natural”.

It should also be noted that the use of market mechanisms as incentives to establish plantations on wasteland requires strong and well-functioning local institutions to ensure a flow of financial benefits to the locals involved. The well-established Joint Forest Management (JFM) programme in India has created a community-based approach to manage forest fringe margin areas to reduce forest logging for fuel wood and encroachment on forest lands from agriculture (Behera and Engel 2005). The JFM has developed institutions that empower and enable local communities to participate effectively in forest management to some extent. These institutions could be adjusted to manage a financial flow based on a market mechanism (Ravindranath et al. 2003). Perez et al. (2007) highlights the importance of well-functioning institutions based on an alliance of stakeholders such as community-based organisations, producer associations, NGOs, research institutions and the private sector, in addition to government agencies, for the successful establishment of a carbon sequestration market.

The long term mitigation potentials of these financial systems, as well as the environmental and socioeconomic factors that influence their realisation are not well-known due to the short time span since the emergence of the systems. The carbon market has rapidly gained momentum, while the questions and the answers related to the implementation of projects and marketplaces have become increasingly important to investors, policymakers and environmentalists (Hamilton et al. 2009). Unrealistic expectations about the potential of wasteland in India and ignorance of the constraining environmental and socioeconomic factors for plantation projects therefore risk hampering the implementation. This may also lead to a false impression of the CDM or other financial mechanisms as a quick ride to land development and carbon credits for project developers. The definition and analysis of possibilities and constraints for plantation projects at both local and regional levels will help policy development by identifying areas where the plantation process may need to be altered or simplified.

Conclusions

The following main conclusions can be drawn from this thesis:

The performance of individual forest-based project activities will depend on local conditions. Sensitivity analysis shows that when parameters are varied, other forest types can become the preferred option. Based on a combination of the sensitivity analysis and results from the fieldwork, it can be concluded that successful implementation of forest-based project activities in India will require local participation and is likely to involve multiple forest products and environmental services demanded by the local community (**Paper I**).

Policymakers set the research agenda by declaration, which states the focus, while researchers feed the decision-making process until a decision is made. The results also show the trend, confirmed by Fogel (2005), that most authors are based in developed countries and trained in natural sciences, creating a somewhat insular discussion (**Paper II**).

The environmental and socioeconomic benefits from a large-scale establishment of multi-functional biomass production systems could be substantial. Given that suitable mechanisms to put a premium on the provided environmental services can be identified and implemented, additional revenues could be linked to biomass production systems and this could significantly improve the competitiveness of the produced biomass on the market. The provision of additional environmental services also contributes to local sustainable development, which in many cases is a prerequisite for local support for the production systems (**Paper III**).

Rehabilitation of wasteland based on afforestation and reforestation activities is not only possible, but also anticipated by the local population and would lead to positive environmental and socioeconomic effects at a local level. However, in many cases, the establishment of afforestation and reforestation activities is hindered by a lack of financial resources for investments, low land productivity and water scarcity. Based on the model used and the results from the field work, it can be concluded that certified emission reductions such as carbon credits or other compensatory systems may help to overcome the financial barrier, however the price needs to be significantly increased if these measures are to have any substantial impact in Karnataka state (**Paper IV**).

Being work in progress, **Paper V** does not provide a conclusion at this stage. However, the paper illustrates the area available for implementing various land use options and species for wasteland rehabilitation. The results show that the area one or more species option could be implemented is 52 600 Ha, about 71% of the total wasteland in the district. The results show that even if the wasteland is degraded, the results show that with a carefully assessed land suitability analysis more than two thirds of the wasteland could be covered with vegetation aiming for land rehabilitation.

Further research

A theoretical beneficial approach, combining sustainable development and GHG mitigation, seems difficult to implement under the rules and regulations of the UNFCCC (Boyd et al. 2009, Sirohi 2007, Sutter and Parreño 2007). The fourth IPCC assessment report discusses the necessity of mainstreaming climate change into developmental choices and policies where setting priorities will be crucial. In this case, mainstreaming means that development programmes and/or individual actions that would not take climate change into consideration explicitly include it when making choices for development which make the development more sustainable (Sathaye et al. 2007). With this in mind, three research areas that need more attention emerge.

Land use changes, primarily deforestation, are responsible for approximately 25% of the global CO_2 emissions[12] (IPCC 2007) and there is an urgent need to address this in global climate policy. Policymakers and scientists are working on feasible rules and regulations, while financing options and the monitoring of such changes are challenging. The policies affecting land use change are strongly correlated to environmental changes and need to promote sustainable development (Victor 2006). Detailed studies of the environmental impacts of land use changes and the sustainable development gained, if presented transparently, would give feedback to policymakers and hopefully lead to developments that are positive for the environment.

The idea of payment for small-scale land use changes that have positive effects on both the environmental and socioeconomic parameters is an interesting concept, potentially leading to rural development. Synergies from the three Rio Conventions realised in PES schemes, for example, are already established in a few cases and could benefit both the environment and the livelihood on a local scale. So far, PES seems to be limited to national interests, with few PES projects operating outside of a central state's umbrella. A comprehensive review of the performance of projects involving sustainable forest management and land rehabilitation is warranted.

With different developmental goals the wasteland can be used for different purposes; carbon sequestration and the production of bioenergy are options that are likely to generate financial returns. Paper V, with its land suitability analysis, initiates an assessment of the optimal land use on wasteland in India. To find the best option parameters need to be weighed against each other. The analysis needs to be continued in an optimisation model. All the data and analyses in the thesis can be a basis for discussions on how benefits and drawbacks of different options can be valued. This

[12] Cited from the IPCC ”The term “land use, land use change and forestry” is used here to describe the aggregated emissions of CO2, CH4, N2O from deforestation, biomass and burning, decay of biomass from logging and deforestation, decay of peat and peat fires. This is broader than emissions from deforestation, which is included as a subset. The emissions reported here do not include carbon uptake (removals)” (IPCC 2007).

could lead to an agreement regarding the best option for a given land use scenario and stakeholder group.

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Paper I

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Application of Clean Development Mechanism to forest plantation projects and rural development in India

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ABSTRACT

This paper analyses the prospects for establishing afforestation and reforestation Clean Development Mechanism (CDM) projects in Karnataka State, India. Building on multi-disciplinary fieldwork, the aim is to: (i) establish what type of plantations and forests that would best suit a forest-based project activity, considering global climate benefits and local sustainable development objectives; (ii) identify the parameters that are important for ensuring sustainable development at the local level and (iii) develop a transparent ranking tool for the assessment of possible forest-based project activities. Using equal weights for the ranking parameters and a 30-year time horizon, the ranking shows that plantations managed with the shortest rotation period (5 years) would be most suitable for forest-based project activities. However, the performance of individual forest-based project activities will depend on local conditions, which need to be reflected in the weighting procedure. Sensitivity analysis shows that when weights are varied, other forest types can become the preferred option. Based on a combination of the sensitivity analysis and results from the fieldwork, it can be concluded that successful implementation of forest-based project activities will require local participation and are likely to involve multiple forest products and environmental services demanded by the local community.

Introduction

The Clean Developing Mechanism (CDM) was established as one of the flexible mechanisms within the Kyoto Protocol and subsequent climate negotiations. CDM is based on the fact that greenhouse gas (GHGs) emissions lead to the same climate benefits regardless of where they occur. Defined in Article 12, the CDM provides for Annex I Parties (in essence industrialized countries) to implement projects hosted by non-Annex I Parties (in essence developing countries) that lead to emissions

Abbreviation: AGB, above ground biomass; BGB, below ground biomass; CDM, Clean Development Mechanism; CER, certified emission reductions; FAO, Forest and Agriculture Organization; GHG, greenhouse gases; IPCC, Intergovernmental Panel on Climate Change; LULUCF, land use land-use change and forestry; SBSTA, subsidiary body for scientific and technological advice; SOM, soil organic matter; UNEP, United Nation Environmental Programme; UNFCCC, United Nation Framework Convention on Climate Change.

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reductions and thus to climate benefits and a contribution to the ultimate objective of the Convention.[1] In return, the Annex I Parties obtain certified emission reductions (CERs) that can be used to meet their own emissions reduction commitments. One condition is that the CDM project activities are designed so that they assist the host Parties in achieving sustainable development. In addition, the investor will require that the CERs are generated in a cost-competitive way.

This study evaluates forest-based projects in India, based on a survey of the perceptions of the local villagers concerning different forest types and forest management. We also estimate the carbon stocks in above ground biomass (AGB) and soils in different land-use systems. The overall aim is to establish what kind of forest system that would be best suited for a CDM project activity, i.e. to the best extent meets the two objectives, local sustainable development and carbon sequestration. The empirical data comes from two villages in India, a country with great capacity and interest in CDM project activities; both with different experiences of plantations projects. The specific aims of this study are:

- Identification of plantations and forest types that will best suit a CDM project activity in terms of local sustainable development and climate benefits.
- Identification of parameters that are important to consider for ensuring sustainable development on the local level.
- Development of a transparent ranking tool for the assessment of possible CDM activities.

Even though we have used afforestation and reforestation (A/R) CDM as a possible case in this study, the overall scope of method and result can be applicable in a wider forest-based or carbon sequestration project implementation.

Background

Land use, land-use change and forestry under the Kyoto Protocol

Land use, land-use change and forestry (LULUCF) activities can provide a relatively cost-effective way of combating climate change, either by increasing the sinks of GHG from the atmosphere (e.g. by planting trees or managing forests), or by reducing emissions (e.g. by curbing deforestation) (Sathaye et al., 2001). An increase in forest cover will also have positive environmental effects on a degraded land area: an increase of soil organic matter (SOM) will enhance the fertility of the soil, and, with the exception of monocultures, there will also be an increased biodiversity. The forestry projects would also protect the land from further degradation (IPCC, 2000; Ravindranath & Sathaye, 2002).

However, there are uncertainties regarding the methods for estimating GHG emissions and removals. Further, the *permanence* of carbon stocks created is an issue due to the potential reversibility of carbon benefits due to fire and unplanned harvesting. An attempt to deal with this problem has been the launching of two different CERs, one for long-term CERs (lCER) and one for temporary CERs (tCER) (UNFCCC, 2004a). The idea is basically to issue credits that have a defined lifetime and that has to be replaced if lost. Further, there have been worries that the inclusion of LULUCF activities under the CDM would undermine the environmental integrity of the Kyoto Protocol, and result in the reaping of “low hanging fruits” in developing countries and postponed actions for emission reduction in Annex 1 countries. Thus, LULUCF activities under the CDM have been a controversial issue during the global negotiations under United Nations Framework Convention on Climate Change.

In addition to genuine uncertainties connected to the difficulties in monitoring and verifying the climate benefits of LULUCF activities, there are several important issues that have to be addressed for satisfactory accounting of carbon credits from such projects. In order to establish *additionality* of the project, a *baseline* (i.e. a scenario depicting the development in the absence of the proposed project) must be set as a reference (Mendis & Openshaw, 2004). This is a difficult task since all eventual future scenarios in the absence of the project must be evaluated. This requires knowledge about the history in the specific area, the local socio-economic situation and wider economic trends, which may affect the future land use and carbon stocks. The risk of *leakage* must be minimized. Such leakage can occur if the project leads to local access to land, food, fuel and timber resources becoming restricted, forcing people to find needed supplies elsewhere. One basic principle is to take a debit for the lost carbon at the time of its occurrence, e.g. when abandonment of activities leading to carbon sequestration results in a loss of the stored carbon (Ravindranath & Sathaye, 2002). Finally, socio-economic and environmental impacts need to be addressed, including impacts on biodiversity and natural ecosystems (Boyd, May, Chang, & Veiga, 2007).

The rules for LULUCF activities that were agreed upon as part of the Marrakech Accords (COP7) also include specific regulations limiting the use of such activities to meet emission targets for the first commitment period. According to these regulations, only afforestation (planting of non-forested land) and reforestation (replanting of forest land) projects are eligible under the CDM (UNFCCC, 2001). Further, greenhouse gas removals from such projects may only be used to help meet emission targets up to 1% of an Annex 1 country’s baseline for each year of the commitment period. The five carbon pools eligible within CDM is: AGB, below ground biomass (BGB), soil carbon, dead wood and litter.

The market for forestry CERs is still small with a limited supply and demand for credits. This is exemplified by only one registered A/R project today (March 2008) while there are 10 approved methodologies. The fact that there is only one registered project is a result of the complex methodological issues resulting in expensive procedures of validation

[1] “… stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system”.

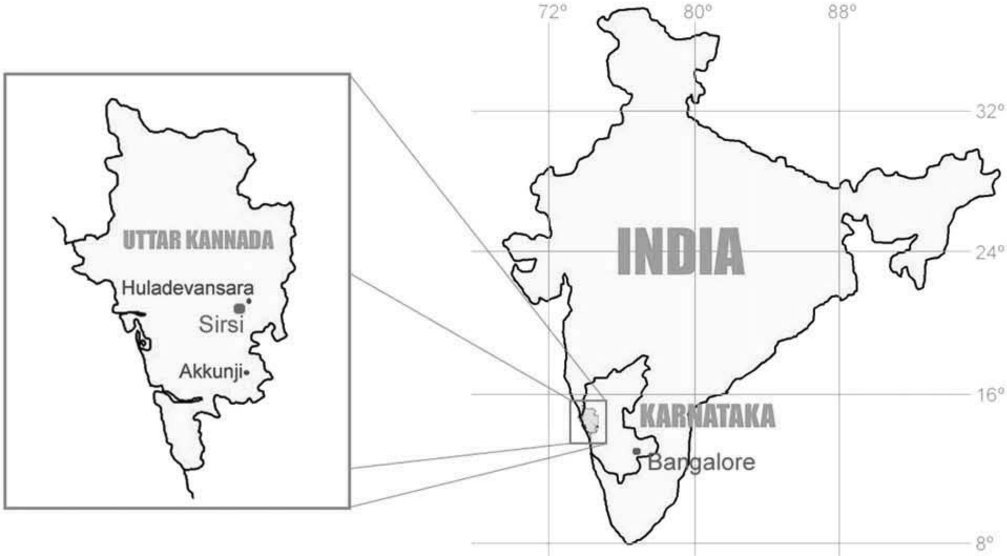

Fig. 1. Map of the study area: Karnataka state, Uttar Kannada District, Sirsi and the villages, Huladevansara and Akkunji used in this study.

and verification of the yet more complex crediting system. This complex process halter many project waiting to be registered.

The prospects for LULUCF activities in India

In India, estimates of the land classified as forest land ranges from 19% to 23% of the total area of 328.8 Mha (Ministry of Environment and Forests, 2004; Sathaye et al., 2001). This includes both natural forest and forest plantations. Forests are subjected to increasing pressure. However, India has succeeded relatively well in reducing the net deforestation rate (Ravindranath, Sudha, & Sandhya, 2001). This is mostly due to large afforestation programs. Plantations account for almost half of the forested land; giving a plantation area of 32.58 Mha, of which approximately 20% are planted with different acacia species. Estimates of the carbon stock in primary and logged forest in the humid tropics range from 192 to 276 tC/ha (IPCC, 2000). The estimated average carbon stock in the Indian ecosystems is 46 tC/ha (Haripriya, 2003). These figures include both AGB and BGB while our model figures consider AGB only.

Degraded land, in India called wasteland (Ravindranath & Hall, 1995), is often technically suitable for growing trees and can be regarded a promising land type to be used for LULUCF activities under the CDM. About 23% (75 million ha) of the Indian land area is considered wasteland. According to Sathaye et al. (2001) about 40% of this wasteland is considered available for forestation. The available area includes degraded forestland as well as pasture land, marginal cropland and other privately owned non-crop land categories (excluding the forest land and the area under roads, settlement, water bodies, sand, snow, etc.).

In addition to biomass, atmospheric carbon can be sequestered as SOM. Apart from being a carbon sink, increased SOM leads to stabilized soil structure, reduced erosion risk, improved ability to store and transmit air and water and nutrients needed for the growth of plants and soil organisms. Thus, SOM increases leads to benefits in addition to the climate benefits arising from the carbon sequestration. For India, a mean value of soil carbon has been estimated to 79.8 tC/ha, while estimates from the study area are 90.5 tC/ha (Haripriya, 2003).

There exists several possibilities to increase the rate of carbon sequestration in SOM in the agricultural sector (Olsson & Ardö, 2002), including: (i) crop rotations that contribute more biomass to the soil, (ii) increased use of green fallow rotation, (iii) use of natural fertilizers (green manure) and (iv) erosion control. Erosion control and the saving of waste biomass on the ground can also be applied in the management of forests and plantations.

The study site

Karnataka, Uttar Kannada, Sirsi

The state of Karnataka is situated on the West Coast in southern India and the district of Uttar Kannada is located along the coast in the north (Fig. 1). The area was chosen because of the mixture of natural forest and plantations. The district has a high forest cover at about 75% of the total area of 10,291 km^2 with four categories of forest: tropical evergreen, semi evergreen, moist deciduous and dry deciduous. The mean annual precipitation is 2742 mm and is driven by the southwest monsoon during June to September. The forest division of Sirsi (Fig. 1) contains smaller villages with an agrarian population. Main crops are rice and areca nuts.

Forests and plantations in the villages

Two villages were included in this study: Huladevansara and Akkunji (Fig. 1). The villages were chosen because of their different experiences of plantations and their accessibility to natural forest. Three forest types were included in the assessment; natural forest and plantations with 5- and 10-year rotation periods. The natural forest is owned by the Forest Department but can be used by the village for non-timber forest products. The plantations are dominated by acacia (*Acacia aculiformis*) in short rotations and belong to the Forest Department. The soils in the natural forest are fertile and the plantations were established in more or less degraded forest areas. Cattle grazing and collection of dry leaves are allowed in both land uses.

The population in Akkunji is twice the size of the Huladevansara population (Fig. 2), while the village land size is somewhat similar in the two villages. The per capita land availability is consequently much lower in Akkunji than Huladevansara. The average household sizes also differ: Akkunji have seven persons per household while Huladevansara have four persons per household. These differences are important when discussing forest/plantation needs and pressures.

Data and methods

Fieldwork

Mapping

Existing village maps were used. The maps date back to the 1860s and have been rewritten continuously over the years. Based on land-use information from the maps, information from key-informants and walk-abouts with farmers, information of present day land use was obtained, according to methods by Bernard (1995). Through digitalization of the maps and analyses in geographical information system, the extent of the different land use was calculated.

Biomass

To get AGB data in natural forest and in homogeneous acacia plantations of two different ages, 5- and 10-year old, field quadrate method was used collecting data on number of stems and girth (Ravindranath & Ostwald, 2008). The 50×40 m plots were chosen randomly. Basal area/ha (BA) was calculated and used to estimate the amount of carbon from:

$$C_{AGB} = (50.66 + 6.52BA) \times \frac{0.85}{2} \quad (1)$$

The numerator gives the dry matter weight of biomass, calculated from the BA using regression coefficients from Ravindranath, Murali, and Malhortra (2000) and accounting for a moisture content of air dry wood at 15% (FAO, 1983). The denominator arises from that half of the dry matter in biomass consists of carbon. The formula is general for Indian forest and holds limitations since crown size and height is not considered.

Soil sampling

Five evenly spread soil samples from top soil to 30 cm depth, as suggested by the IPCC (2003), were taken from the same biomass quadrates. Composite samples of 200 g from each quadrate gave mean values for each forest category. Soil carbon was analyzed using the Walkley-Black method (Hesse, 1971).

Interviews

Three types of interview methods were used, all with the assistance of an interpreter; several informal interviews for general information, two key informants for local information to distinguish relevance of further investigation, and 30

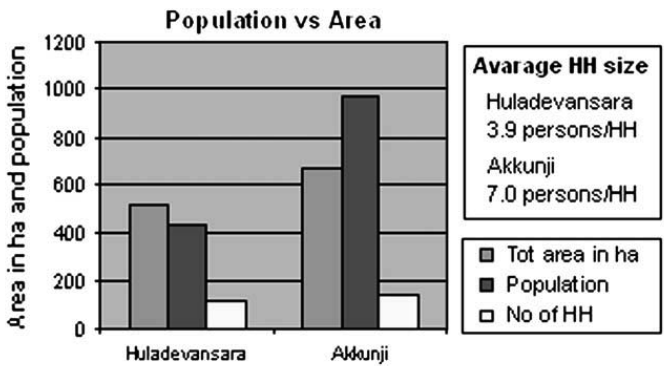

Fig. 2. Number of households, population and land is the two studied villages.

questionnaires for personal information regarding forest and plantation to be analyzed quantitatively. The last methods used three general groups to get village representation; farmers with privileged forest land,[2] rice farmers and landless villagers.

Data processing and analysis

Assessment of yearly biomass carbon increments

The climate benefits due to carbon sequestration in AGB and soils in the different forest systems were assessed based on a 50-year perspective. For the acacia plantations we used our empirical field data for 5- and 10-year-old plantations, where the 5-year plantation are clearcut and replanted every 5 years, and for 10-year plantations a thinning practice every 5 years, clearcut and replanted every 10 years. Annual increment for primary forest stated by the IPCC is 1.75 tC/ha/yr (IPCC, 2000). According to Sathaye et al. (2001) figures ranging from 0.8 to 3.0 tC/ha/yr are acceptable for regenerated tropical forest. We used the mean value of this range, i.e. 1.9 tC/ha, as an annual increment for natural forest. The increment was assumed to proceed during the whole monitoring period of 50 years.

Since an A/R CDM project activities cannot include the use of the harvested wood within the system boundary, an assessment using project's boundary cannot consider the effects of different land use options in combination with different carbon storage times in wood products and/or fossil fuel substitution patterns. This result in a limited climate benefit modelling for CDM projects but is not a limiting factor for our assessment.

Ranking procedure

LULUCF projects have a broad range of environmental and socio-economic impacts that need to be taken into account when assessing the suitability for the CDM. The dual—and potentially conflicting—set of objectives in the definition of CDM adds an extra challenge: the design of a LULUCF-based CDM project activities may become a process of balancing disparate objectives of the parties involved (i.e. the objective of local sustainable development may require a project design that is different from the one maximizing cost-efficiency in CERs generation). This balancing process will be unique for each CDM project activity.

Here, we suggest a simple and transparent ranking procedure as a tool for processing the collected data in an integrated analysis of suitability of possible CDM project activities from the perspective of sustainable development and climate benefit. The ranking system is developed and applied on the studied forests and plantations. The procedure can of course be adapted for the evaluation of other candidate LULUCF activities under the CDM as well as of CDM project activities in general. Worth mentioning is that we have used parameters that were available from our study. Other parameters that could be relevant in a similar situation are issues such as other carbon pools, employment effects, social and community development, equity of returns and leakage.

To enable the ranking, a certain time frame has to be set, i.e. crediting period. The options for LULUCF based CDM project activities are either: (1) a maximum of 20 years which may be renewed up to two times, i.e. 60 years, if a Designated Operational Entity confirms that the original baseline is still valid or (2) a maximum of 30 years (UNFCCC, 2004b). The original baseline will be valid for the whole crediting period regardless of changes that may affect the additionality (UNEP, 2004). Here, the ranking was done considering a 30-year crediting period based on the maximum carbon stored during this time.

In the ranking, the parameters AGB carbon and soil carbon were chosen to exemplify carbon sequestration and therefore climate benefits and acceptance from villagers and land availability were chosen as sustainable development parameters. These parameters are not direct sustainable criteria but function as the basis for several sustainability co-benefits such as a financial flow to the project area, employment and development in infrastructure (Berndes, Börjesson, Ostwald, & Palm, 2008). Acceptance from villagers was used as one parameter which had already been revealed in the interviews as important for local sustainable development.[3] These two parameters are closely interlinked as a large acceptance will open up the possibility for larger areas planted. These parameters were assigned a ranking value of low (1), medium (2) and high (3) (for a full description of the weighing of these parameters see Appendix).

The assessment is based on the data collected for the two villages as well as AGB carbon from our increment model taken at 30 years. The AGB carbon values used for the ranking are 57 tC/ha for natural forest, 65 tC/ha for the plantation with a 5-year rotation and 70 tC/ha for the plantation with a 10-year rotation as found in Fig. 4.

Results

Fieldwork

The mapping exercise showed very little change over the past 100 years. Changes that were found included divided fields caused by partial conversion from rice to areca nut plantations, and encroachment in forest land due to agriculture and tree logging, and construction of water tanks.

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[2] Forest land with user-rights belonging to a specific farmer who owns an areca garden.

[3] Rasul, Thapa, and Zoebisch (2004) show that sustainable land-use systems such as agroforestry, commercial plantation and horticulture evolve and flourish in areas where support and facilities were favourable. They suggest secure land tenure (available land) and necessary institutional support as an incitement for farmers to shift to an economically and environmentally suitable land use.

Table 1
Above ground biomass and soil carbon in the three different forest/plantation types.

	Natural forest	Acacia 10 years	Acacia 5 years
AGB[a] carbon (tC/ha/yr)	117	70	65
Soil carbon (tC/ha/yr)	56	40	51
Total stock (tC/ha/yr)	173	110	116

[a] Above ground biomass.

AGB and soil carbon analyses show that the natural forest has the highest AGB and hence carbon density (see Table 1). Worth noticing is that soil carbon in the 5-year old acacia plantation is higher than in the 10-year old, indicating a decline in soil carbon from the former land use, i.e. natural degraded forest, to a lower soil carbon stock under acacia plantations. However, the difference in carbon stock between the two plantations is probably too large to be affected by time only (IPCC, 2000), which indicates that the unknown land use history could have an influence. We found twice the number of stems in the 5-year plantation compared to the 10-year plantation. The decline in trees in the acacia plantations over time indicates thinning practice.

The total carbon stock figure for natural forest is however lower than earlier assessments on primary and logged forest at margins of the humid tropics (192–276 tC/ha) (IPCC, 2000). The variation in AGB carbon (65–117 tC/ha) of the different forest/plantation types is larger than that seen in the soil carbon (40–56 tC/ha).

From the questionnaires a general view concerning lack of timber for construction purposes was obtained. The group that had access to the privileged forest land received more forest products from privileged forest land compared to the natural forest, which can be explained by the geographical closeness of the privileged forest land compared to the natural forest and by the fact that the privileged forest land users have access to forest products unlike the natural or reserve forests. Plantations were used for grazing, collection of dry leaves, which can explain part of the low soil carbon in the acacia plantations (Table 1).

The number of products available to the farmers from the different forest types shows that all forest sources are used, although natural forest to a larger extent than privileged forest land (only used by the holders). Least products were taken from the plantations. Acacia plantations do not provide multiple products. A large part of the informants (47%) state that the government benefits more from the plantations than the villagers, while only 7% expressed this opinion for natural forest. The negative attitudes towards plantations are exemplified by the following quotations from respondents.

> Plantations brings problem to the ground water
> I don't like monocultures, they are not beneficial for local species and the biodiversity
> Monocultures benefit smugglers
> We don't need plantations. There is enough natural forest in this area

However, the majority of respondents agreed that all forest resources, including plantations, were beneficial for the village. Thus, the attitudes towards forests among villagers are positive but certain resistance was found against the plantations. This was mainly found in situations were the plantations were raised and managed by the Forest Department with no or little involvement of or user-rights to the village community similar to that found in Latin America (Boyd et al., 2007). Also in Nigeria Odihi (2003) found that government bodies does not consider the needs and demands of the local people in an afforestation programme. This ignorance results in major deforestation of the area. Odihi shows further that the success in a plantation project needs both the confidence and the participation of the people that work the land. Involvement and acceptance of the local people, supported by clear modalities on user-rights and revenue sharing, would be the crucial for a CDM project activity and its success and hence sustainable development.

Data processing and analysis

Based on the data given in Table 1 and the above quotations from respondents, natural forest regeneration appears to be the most attractive CDM project activity, both when considering the long term potential for carbon sequestration and local sustainable development. However, the presentation of the carbon dynamics over a 50-year period in Fig. 3 provides additional perspectives. It is clear from Fig. 3 that plantations sequester more carbon per year than natural forests, which in this case is modelled as natural regeneration with an initial carbon stock of 0 tC/ha. It is also clear that each time the plantation is harvested and the wood products are sold, the export of the wood to outside the CDM project boundary will lead to biomass carbon losses from the CDM project activity similar in size as the carbon gained during plantation growth.

The two plantation options may also differ when it comes to the economic performance and the local sustainable development objective. For example, the 5-year plantation may generate a larger accumulated climate benefit over time (depending on how the wood products are used, an issue for future CDM development). But it is also subject to larger costs than the 10-year plantation, since it will include additional labour managing the plantation. On the other hand, the additional labour requirements are beneficial in a CDM context, since employment generation as a rule is regarded positive for the local population. The choice of a plantation with a 5-year rotation could also be positive in terms of flexibility since the crediting period is short and the risks following a long rotation projects are less. If the soil carbon is taken into consideration, the

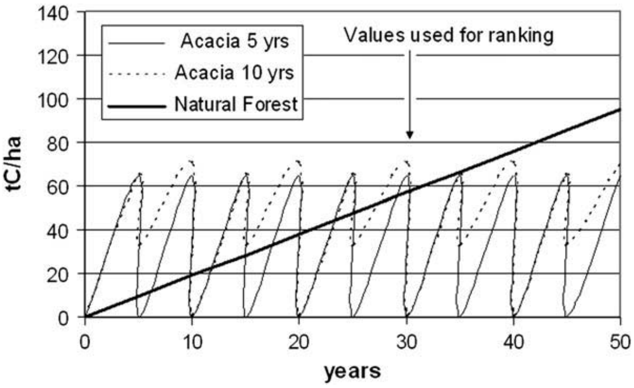

Fig. 3. Modelled sequestration potential from the studied natural forest plantation systems under the different rotation schemes; 10 years and 5 years. The 10-year rotation system practiced thinning on the 5th year, hence a dip in carbon content.

10-year plantation would be more beneficial since the soil would be less disturbed leading to a larger accumulation of soil carbon (Olsson & Ardö, 2002).

From the ranking it is clear that the natural forest is ranked high both in terms of climate benefits and sustainable development, higher than the plantations in some cases. However, a mature natural forest would never exist in a 30-year time frame with the present modalities for CDM (Table 2). However, with a slow A/R CDM development and with a global increased concern regarding avoided deforestation, the issue of natural forest and its benefits are worth pointing out. Conserving natural forest and functional plantations are interlinked (e.g. found by Köhlin & Ostwald, 2001). Plantation is a more likely CDM alternative and will be discussed from hereon. According to our result based on the four parameters (AGB carbon, soil carbon, acceptance and land availability), the 5-year rotation plantation in Akkunji is the most suitable project for CDM. This is due to high AGB carbon and high land availability. The least suitable project type would be the 10-year rotation plantation in Huladevansara. This is due to low soil carbon, low acceptance and low land availability.

The proposed method can preferably be used on any implementation initiative that would like to assess sustainable local development and carbon sequestration potential. Hence, its strength in flexibility and transparency is not limited to A/R CDM projects.

When different parameters are excluded the variations in local condition becomes visible. This will help pinpointing the differences, which can show great importance when it comes to choosing the area for a project. In this case the exclusion of parameters shows the effect of land availability. Akkunji has a high availability, while Huladevansara has little available land for a plantation. Such local variations will be of great importance for parameterization of the appropriate variables in a possible bundling scenario for A/R CDM project activities (UNFCCC, 2004a).

Discussion

One of the reasons behind earlier land use changes, which were stated by farmers, was maximization of returns from farm work. Sections of the traditional land area used for rice have been converted into areca nut plantations, due to a higher profit

Table 2
Ranking of suitability of forest project implementation.

Parameters	Villages					
	NF		10 yrs		5 yrs	
	A	H	A	H	A	H
C sequestration i.e. climate benefits						
C AGB[a]	M	M	M	M	M	M
C soil	M	M	L	L	M	M
Local sustainable development						
Acceptance	H	H	M	L	M	L
Land availability	H	L	H	L	H	L
Total	10	8	8	5	9	6
w/o C AGB	8	6	6	3	7	4
w/o C soil	8	6	7	4	7	4
w/o Acceptance	7	5	6	4	7	5
w/o Land availability	7	7	5	4	6	5

NF, natural forest; 10 yrs, 10-year plantation; 5 yrs, 5-year plantation; A, Akkunji; H, Huladevansara; L, low (1); M, medium (2); H, high (3); w/o, without. For parameterization, see Appendix.

[a] Above ground biomass.

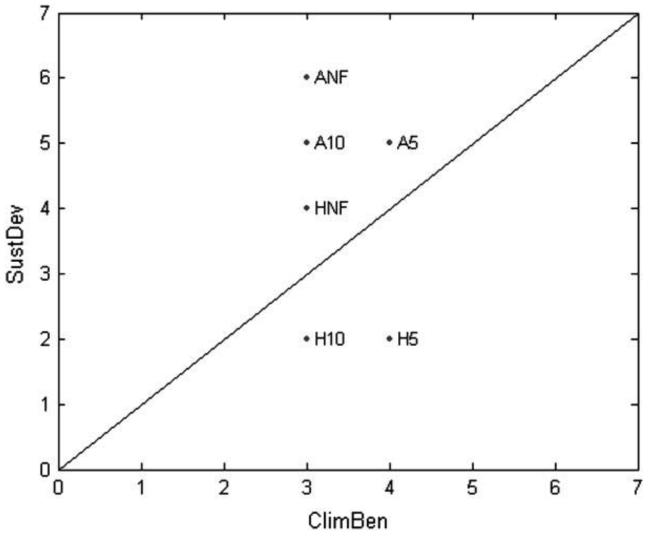

Fig. 4. Conceptual position, in terms of local sustainable development and climate benefit, of the possible projects based on the data from our ranking exercise in Table 2. NF, natural forest; 10, 10-year plantation; 5, 5-year plantation; A, Akkunji; B, Huladevansara.

from areca nuts production. Thus, farmers with access to land will change to the practice that gives the highest return. This indicates that potential CDM project activities that will result in direct financial benefits to the land users are likely to be accepted on the local level.

The results generated from this study are site specific. Two variables of particular importance are: (i) the local populations' need of forests and forest products and (ii) land availability. In this area, the forest cover is in general high and thus raising new forest resource is less desired than what is the case in many other parts of the Karnataka State, although there is a large difference between the two studied villages. Land availability in the study area is also low compared to eastern Karnataka, making A/R CDM establishment less attractive. However, land availability is not necessarily associated with the presence of wasteland alone since degraded forest, still classified as forest, and unsuccessful plantation areas might be locally available.

Data gathered from another location would most likely bring about other variable that could be important for the ranking procedure. To explore these crucial factors to sustain forest initiatives such as A/R CDM projects, a great meta-study of a larger number of cases would have to be assessed. This is a recommendation for future research.

The ranking exercise considers four parameters that are central from a CDM project perspective. However, for a successful CDM project implementation there will be more factors that will be of importance, such as increased job opportunities and barriers related to lack of technical competence, as mentioned above. Here, it is also relevant to mention co-benefits that can be associated with a project, dealing with impact on economy, environment and social aspects (Berndes et al., 2008). Those co-benefits are considered in this paper by using the parameter of local acceptance but could be separated into individual components to ensure specific attention in a ranking exercise. Furthermore, a ranking within a widened system, e.g. considering the effects of different uses of the harvested wood, could change the picture.

This study illustrates the sometimes conflicting aims in the CDM objectives, i.e. the climate benefit and the sustainable development. The ranking exercise provides a tool which considers parameters of relevance in an objective manner, while at the same time showing that the effect varies from different types of forest projects at local level.

However, the implication of this type of assessment integrating multiple local specific issues into a flexible and transparent ranking tool can be a way forward for any forest and land sequestration proposal within the scope of international climate negotiations, particularly the post-Kyoto setup.

Conclusions

Based on the results of the ranking exercise, a visualization of the relation between sustainable development and climate benefits can be made (Fig. 4). From this, the following conclusions can be noted:

- Natural forests are the most preferred forest resource in both villages, when sustainable development parameters are considered.
- Fulfilment of the sustainable development criteria is to a higher extent associated with finding the right village than finding the right forest type for a CDM project activity.
- The 5-year rotation is consistently ranked higher than the 10-year rotation.
- The proposed ranking tool proved to be flexible and transparent for assessing local sustainable development and carbon sequestration potential. Hence, it is not limited to only A/R CDM projects.

One recommendation that can be made based on these observations is a two-step procedure. Initially, in order to ensure sustainable development, carefully select a village having land available for forest activities and also an adequate forest resource need. After that, CDM project activities can focus on maximizing the climate benefits, preferably associated with multiple co-benefits.

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Appendix. Ranking parameters

Sustainable development

- Land availability
  (1) No land
  (2) Land available for alternate land use
  (3) Available wasteland and degraded forestland
- Acceptance
  (1) Majority of negative views on plantations
  (2) Mixed views on plantations
  (3) Majority of positive views on plantations

Climate benefit

- AGB carbon[4]
  (1) $<$55 tC/ha
  (2) 55–125 tC/ha
  (3) $>$125 tC/ha
- Soil carbon[5]
  (1) $<$50 tC/ha
  (2) 50–110 tC/ha
  (3) $>$110 tC/ha

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[4] Mean calculated from study data, Haripriya (2003) and IPCC (2000) ±35 tC/ha, 73% of total biomass gives AGB (IPCC, 2003).
[5] Mean figures taken from Haripriya (2003) ±30 tC/ha.

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Paper II

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ORIGINAL PAPER

Land use and forestry based CDM in scientific peer-reviewed literature pre-and post-COP 9 in Milan

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Abstract This article explores the science-policy interactions between peer-reviewed literature and decisions and declarations on Land Use, Land-Use Change and Forestry (LULUCF) projects in the Clean Development Mechanism (CDM) taken at Conference of the Parties (COP) meetings. The results are based on a literature analysis capturing 88 articles published from 1997 to 2005. By using a matrix search method and a structured reading form, the method and analysis focussed on whether issues of CDM and LULUCF were presented as 'supportive of the inclusion of LULUCF' and 'critical of the inclusion of LULUCF'. A matrix search method and a structured reading form were applied. Of the 88 articles, 66% included discussions supportive to the inclusion of LULUCF. Forty-nine percent had a first author affiliated in natural sciences. Only 19% had first authors affiliated in developing countries while the same number for contributing authors was 38%. The results show no clear connection between scientific literature and decisions and declarations, but indicate that policymakers set the research agenda by declarations, while researchers feed the process up until decisions are made.

Keywords CDM · COP · Land-use change · Forestry · Literature study · Negotiations · Policy · Research

Abbreviations

A/R	Afforestation and Reforestation
CDM	Clean Development Mechanism
CER	Certified Emission Reduction
CO_2	Carbon dioxide
COP	Conference of Parties

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GHG	Greenhouse Gases
IPCC	Intergovernmental Panel on Climate Change
KP	Kyoto Protocol
LULUCF	Land Use, Land-Use Change and Forestry
NGO	Non Governmental Organisations
OECD	Organization of Economic Cooperation and Development
PDD	Project Design Document
SBSTA	Subsidiary Body for Scientific and Technological Advice
UNFCCC	United Nations Framework Convention of Climate Change

1 Introduction

One of the few arenas within the Kyoto Protocol (KP) and the United Nations Framework Convention on Climate Change (UNFCCC) in which developing countries, i.e. non-Annex B[1] Parties to the KP, can be directly involved in combating climate change is within the Clean Development Mechanism (CDM). The CDM is established as one of the flexibility mechanisms, together with Emissions Trading and Joint Implementation, and is based on the fact that greenhouse gas (GHG) emission reductions lead to the same climate benefits regardless of where they occur. Defined in Article 12 of the KP, the CDM provides for Annex B Parties (in essence industrialised countries) to implement projects hosted by non-Annex B Parties (in essence developing countries) that lead to the reduction of emissions and thus to climate benefits and a contribution to the ultimate objective[2] of the UNFCCC. In return, the Annex B Parties obtain certified emission reductions (CERs) that can be used to meet their own emission reduction commitments.

Land Use, Land-Use Change and Forestry (LULUCF) activities have been suggested as a possible means of combating climate change, whether by increasing the sinks of GHGs (e.g. by planting trees or managing forests), or by reducing emissions (e.g. by curbing deforestation) (Sathaye et al. 2001). According to the present regulations, only afforestation[3] and reforestation (A/R)[4] projects are eligible under the CDM. Furthermore, GHG removals from such projects may only be used to help meet emission reduction targets of up to 1% of an Annex B country's baseline for each year of the commitment period.

LULUCF has historically been a politically contested issue, partly due to the lack of scientific consensus regarding issues such as permanence, monitoring and leakage. Several countries involved in the negotiation process have long fought for flexibility with regards to emission inventories. Including carbon sinks in forests and agriculture would lower the costs for emission reductions, both with regards to domestic sinks and the use of sinks in

[1] Annex B and non-Annex B countries are countries with and without assigned emission reduction commitments under the Kyoto Protocol, respectively. Not to be confused with Annex I and non-Annex I (all the countries in the Organization of Economic Cooperation and Development (OECD), plus countries with economies in transition, Central and Eastern Europe (excluding the former Yugoslav Republic and Albania). By default, the other countries are referred to as Non-Annex I countries. Countries included in Annex B are those countries listed in Annex I of the UNFCCC, with the exception of Turkey and Czechoslovakia. New countries added to Annex B include Croatia, the Czech Republic, Liechtenstein, Monaco, Slovakia and Slovenia.

[2] "…stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system".

[3] Forestation on land that has not been forested for 50 years.

[4] Forestation on land that has not been forested since 31 December 1989.

flexible mechanisms. Other countries negotiated to limit the potential role of sinks in meeting reduction targets. Concerns about the ability to accurately measure and monitor sinks probably contributed to this stance. The issue was so contentious that it was one of the key obstacles to negotiations at the COP 6 meeting in the Hague in 2000, forcing discussions to be postponed to the convening of COP 6 Part 2 in Bonn in early 2001. Without scientific consensus, and in the absence of the USA, the parties reached a political agreement on a broad set of activities eligible for sink-related credits, including forest management, cropland management and re-vegetation. Further issues related to sinks were agreed to in the Marrakech Accords 2001 (UNFCCC 2001, decision 11/CP.7).

Researchers have highlighted the important role of science in defining the size, scope, geographical distribution and timing of environmental issues (Lidskog and Sundqvist 2002). Leaf (2001), for example, describes how early identification of the stratospheric ozone depletion issue by the science community eventually led to the Montreal Protocol, the international agreement to phase out ozone-depleting substances, in 1987. Jordan and O'Riordan (1998) highlight the further role of science in creating technological alternatives to ozone-depleting substances. Lidskog and Sundqvist (2002) identify science not only as an input to policy, but also as an important source of influence on the public's view of environmental issues. Skodvin (1999) claims that research is a key component in the development of effective international cooperation on environmental issues, envisaging a particularly important role for science when knowledge has not yet been widely accepted beyond the disciplinary scientists who study the issue (i.e. is not yet seen as 'core' knowledge). Berlin (2007) states that producers of scientific data are widely regarded as prime movers in global environmental politics. Numerous scholars in the field of science and technology illustrate the connection between science and policy (Jasanoff and Whynne 1998; Lidskog and Sundqvist 2002; Berlin 2007). Lidskog and Sundqvist (2002) describe negotiated results as a co-product of science and policy, highlighting the integral nature of these two inputs. The goal of this article is to search for evidence that scientific discussions/articles influence ULUCF and CDM in international policy and vice versa. The article also investigates the influence of this co-production in peer-reviewed literature and the difference in focus related to CDM and LULUCF between different groups, e.g. research fields and research location.

Published in 2000, the Intergovernmental Panel on Climate Change (IPCC) Special report on Land Use, Land Use Change and Forestry (IPCC 2000) was presented as an independent literature study on the topic and meant to support the negotiation process with scientific data. Apart from this report, no independent literature study has been conducted on the relationship between peer-reviewed literature and policy decisions regarding LULUCF-based CDM. In an article by Jung (2005) the role of forestry projects in the CDM is discussed with an emphasis on the implications of different policy decisions. Jung starts with the decisions to include LULUCF in the CDM and subsequently analyses the consequences of this decision for the carbon market using a clear economic focus. A literature review covering two decades was conducted to develop a set of cost curves, and was then further used to conduct a scenario analysis. Jung concludes that the role of forestry projects due to the inclusion of LULUCF under the CDM in the first commitment period is rather small. This can be seen in the number of forestry CDM projects registered: only one by early 2008. Another study by Fogel (2005) discusses how science-based knowledge plays a role in the negotiations and in the policy decisions. The study shows how easily the scientific community, in this case the IPCC is influenced by the negotiation agenda of individual states and diverted from its original, unbiased objective.

Figure 1 present the process by which science and policy decisions and declarations interact as a conceptual framework. In order to examine the role of science in policy and

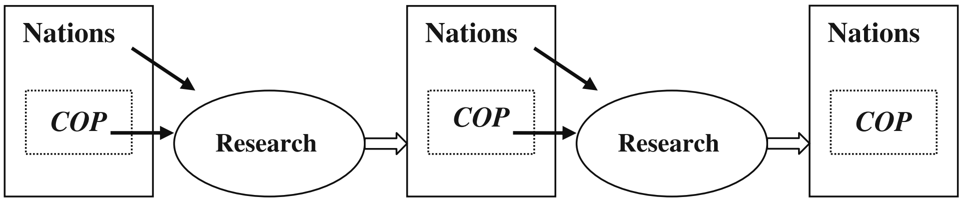

Fig. 1 A conceptual framework that shows the theoretical process of policy decisions and research inputs with the COP meetings. The figure is modified from Kothari et al. (2005)

vice versa, we identify scientific research that was published in international peer-reviewed journals between 1997 and 2005 (published by January 2006). This covers a period 7 years before and 2 years after COP 9 in Milan, a meeting that was crucial for the development of LULUCF within the Protocol.

Questions of interest include: What are the characteristics of the peer-reviewed material in terms of scientific discipline, geographical focus and researcher affiliation? How have the LULUCF-CDM related issues been treated prior to, and post-COP in peer-reviewed literature? How have the decisions and declarations from the negotiations at COP 9 been reflected by academia and vice versa? In what way was research reflected in the policy decisions and declarations?

2 CDM and LULUCF

As with other policy issues, discussions on CDM and LULUCF use a particular vocabulary. Several of these terms are used in this study with the following definitions: The *baseline* is the sum of the changes in carbon stock that would have occurred in the absence of the CDM project, i.e., in a 'business as usual' scenario (UNFCCC 2003, decision 19/CP.9). A CDM project must show *additionality*, i.e. show additional GHG removals or conservation against the baseline. This means that it should be demonstrated that the project-related activity could not have been implemented without the CDM project, based on economic difficulties or other barriers for implementation. *Leakage* is the increase in GHG emissions that occurs outside the project boundary and which is directly linked to the implementation of the project. *Monitoring* is the collection and archiving of all relevant data necessary for determining the net greenhouse gas removals by sinks during a crediting period (UNFCCC 2004). The emission removals from a CDM project should be verifiable and long-term: *permanenc*e is the definition of long-term emission removal or conservation.

Sinks under the CDM were already an issue during COP 6 in 2000; they were partly responsible for the abrupt ending of COP 6 in The Hague and the follow-up meeting, COP 6 bis in Bonn. The potential contribution of sinks in lowering the cost of abatement action was discussed. The problem seemed to be the definition of 'forest' and how to treat net changes in emissions from LULUCF activities that have occurred since 1990. At this stage the discussion of the LULUCF issue was not limited to the CDM but also included actions in Annex B countries, i.e. national inventories. In the end it was proposed that afforestation and reforestation (A/R) be the only eligible LULUCF projects under the CDM, but that the Annex B countries could use other LULUCF options as well. This formulation was subsequently agreed upon during COP 7 in Marrakech, 2001. While the decision at COP 7 endorses LULUCF activities in the CDM, it requests the Subsidiary Body for Scientific and Technological Advice (SBSTA) to work out the methodological issues such as baselines, additionality, leakages and permanence (UNFCCC 2003, decision 17/CP.7).

The Delhi Declaration was adopted in 2002. This declaration included a strong developing country perspective, emphasising the issue of sustainable development, adaptation and implementation of commitments under the UNFCCC (UNFCCC 2002, decision 1/CP.8) by developed countries.

COP 9 in Milan 2003 was an important meeting from a LULUCF perspective (Table 1). The COP decided on the modalities and procedures for A/R project activities under the CDM for the first commitment period (2008–2012) (UNFCCC 2003, decision 19/CP.9), a decision that included sections on the stringency of the project baseline, leakage and both environmental and socio-economic impacts. The COP 9 decision also addressed the issues of additionality for LULUCF projects. The decision included a solution to the problem of non-permanence of carbon removal by sink projects, since the forest may be cut down or release its carbon in some other way, thus becoming a source. The solution included two types of non-permanent CERs, a temporary CER (tCER) that expires after 5 years and a long-term CER (lCER) that expires at the end of the crediting period (Dessai et al. 2005). The crediting period of either 20 or 30 years for A/R projects was decided on with the possibility of renewing it twice (covering 60 years). The baseline year was fixed at 31 December 1989 and decisions were made regarding the information that was required in the project documentation. The SBSTA was charged by the COP with the task of developing simplified modalities and procedures for small-scale A/R projects under the CDM, which would be considered during COP 10 in Buenos Aires, 2004. The simplified rules which applied to the first commitment period of the Kyoto Protocol were intended to reduce transaction costs and facilitate approval and implementation of small-scale sinks projects (those sequestering less than 8 kT of CO_2 per year). These simplified modalities were later adopted at COP 10 together with the reporting of LULUCF under the KP (UNFCCC 2004, decision 14/CP.10), including Chap. 4 of the IPCC report: Good Practice Guidance for LULUCF (IPCC 2003, UNFCCC 2004, decision 15/CP.10). Key decisions for LULUCF-based CDM projects are presented in Table 1.

3 Method

The literature search method is a further development of Oreskes (2004) where 928 abstracts are analysed with the aim of investigating how well research diverges from, or coincides with the IPCC. The literature analysed for this study was collected from five databases, Elsevier (Sciencedirect.com), Kluwer (springerlink.com), the Science Citation Index Expanded, the Social Sciences Citation Index and the Arts & Humanities Citation Index (all three from webofknowledge.com) for the period January 1997 to December 2005, as well as articles included in the press. The resulting list of journals on these sites can be found in Appendix 1. It is worth noticing that one journal included in this study, Climate Policy, changed its ownership structure in 2004 and moved from Kluwer to James and James, Earthscan. For consistency, we expanded our search to include this journal under its new publisher even though it was not included in either of the databases we initially searched. The search had four different central search words that were combined with keywords, all linked to the LULUCF issue. The central search words used were: ‘CDM’, ‘clean development mechanism’, ‘activities implemented jointly’ and ‘climate change’. This first search screened the publications according to title, abstract and

Table 1 Key decisions and declarations for LULUCF-CDM projects during COP meetings from COP 6 in 2000 to COP 11 in November/December 2005

Meeting	Decisions and declarations	Issues
COP 6, The Hague/Bonn Part 1 2000 and 2 2001	• Inclusion of sinks divides the parties and is partly responsible for the dual meetings. Proposal to only include afforestation and reforestation (A/R) in the CDM	Draft decision: • Inclusion of sinks in CDM
COP 7, Marrakech 2001	• Only afforestation and reforestation (A/R) are eligible under the CDM • Cap on demand—A/R the CDM can be used for 1% of the Annex B countries commitments per year	Decision: • Inclusion of sinks in CDM
COP 8, New Delhi 2002	• Delhi ministerial declaration on climate change and sustainable development was adopted No decisions taken referring to LULUCF under the CDM	Declaration: • Sustainable development
COP 9, Milan 2003	• Modalities and procedures for A/R were adopted, including: –Crediting period –tCERs and lCERs –Baseline year –Size limits for small scale A/R projects (8 kT/y)	Decision: • Leakage • Additionality • Baseline • Permanence • Scale
COP 10, Buenos Aires 2004	• Good Practice Guidance (GPG) for LULUCF was accepted by the COP • Simplified modalities and procedures for small scale A/R CDM projects were adopted.	Decision: • Monitoring
COP/MOP 11/1, Montreal 2005	COP forwards the discussion on avoiding deforestation in developing countries: approaches to stimulate action to SBSTA 27 in 2007 after a proposal by several non-Annex B countries	General discussion: • Avoided • Deforestation

keywords. In order to systematise the search of the articles, a matrix was developed to obtain an objective search routine. The basis for the matrix was the four central search words mentioned above. The central search words were then combined with secondary search words to capture relevant articles. The 11 secondary search words used were: reforestation, afforestation, soil carbon, sinks, trees or tree, LULUCF, agroforestry, carbon sequestration, biomass, land use, forest or forestry, all with direct relevance to LULUCF based CDM. With the help of these 11 secondary search words, 4×11 searches were conducted for each database. The result of the search combinations on 'climate change' were cross checked with the term 'clean development mechanism' in a full text search to rule out the irrelevant articles on general climate change.

The analysis of the resulting 88 articles covered the issues related to LULUCF and CDM: additionality, leakage, permanence, baseline, sustainable development, general climate benefit and monitoring. When the issues were discussed, they were either marked as 'supportive of inclusion of LULUCF' or 'critical of inclusion of LULUCF'. The analysis also assigned issues a spatial score from 1 to 5, where 1 denoted a case study of local scale while 5 denoted a global or a more general scale. Also noted was the title of the journal, the first author's discipline and that of the contributing author (both based on affiliation), the country of affiliation for both first author and contributing authors and the year of publication. General comments were also added to the form. The separation of the authors' disciplines into five categories: natural sciences, economics, social sciences other than economics, multidisciplinary institutions and multidisciplinary university affiliations, is a reflection of the character of LULUCF-CDM. The mechanism is market-based, hence the economic view, the mechanism aims to achieve sustainable development, hence the social sciences view and finally, LULUCF describes a physical system which requires a natural science view.

An analysis based on the terms 'supportive of inclusion of LULUCF' and 'critical of inclusion of LULUCF' can easily be followed by posing the following question: supportive and critical of what and for whom, i.e. what is each actor's own agenda? Our analysis is based on a straightforward approach, focusing on how the issues are presented in the articles, i.e. which issue is presented and how, rather than why. This is in order to analyse the central LULUCF-CDM issues objectively as they are stated in each article and hence, as they are presented to readers. It is also in order to compare the different groups, based on the affiliation and countries of the authors.

The different issues in the analysis were considered using the following approach: *Additionality*, *leakage*, *baseline*, *permanence* and *monitoring* were all dealt with in the same manner. If the issues were related to LULUCF A/R project in a CDM context and the text explicitly treated either of the issues, it was included. In order to be regarded as 'supportive' a positive outlook on the issue or a demonstrative or calculated solution was needed and to be classified as 'critical', a more extensive discussion of the issue needed to be demonstrated through results. Examples of critical views were those pointing to the high cost of reliable measurements and verification. Conversely, the text was classified as supportive when solutions, such as valuable co-benefits, were shown. *Sustainable development* was, in this case, a wide definition where environmental, economical and social sustainable development were treated. For inclusion, the discussion needed to point in a direction where the author regarded A/R projects as positive or negative for sustainable development. This could, for example, be positive or negative impacts of LULUCF projects, whether social, environmental or economic. *General climate benefit* was included to capture the academic discussion of LULUCF as a climate change mitigation option, i.e.

whether an A/R-CDM project could play a positive, an insignificant or a negative role in combating climate change.

Issues not included were avoided deforestation, improved logging techniques or sustainable forest management; neither action is eligible under the CDM. However, examples which could be practiced in an A/R project scenario were taken into consideration when they arose. The spatial scale was defined as: (1) local/case study (2) region within a country (3) single country (4) larger region/group of countries (5) global/general.

The articles were further analysed based on the country of affiliation and the disciplines of both the first and the contributing authors. This part of the analysis was conducted in order to get a better overall picture of the scientific, geographical and disciplinary interest and potential influence of this topic. All the authors were included to illustrate the often dynamic author teams which present a multidisciplinary approach and a broad range of countries.

4 Results

4.1 General results

The search based on the matrix resulted in a total of 152 articles, all of which were related to the central search words in combination with the secondary search words. Of these articles, 64 did not return any hits regarding the issues of interest for this study when analysed using the form, leaving 88 articles for analysis. All 88 articles included in the analysis are shown in Appendix 1 with full references. The large number of excluded articles is due to the structure of our analysis, which reflects the nomenclature of the LULUCF in CDM today. This means that more articles from the early years were not relevant to the analysis, such as the discussion on methodological issues which was used. The search routine may be viewed as having been too wide. However, the decision to maintain the width resulted in a rigorous attempt to pinpoint the relevant articles during the search and thereafter phase out those that were not relevant to the study. Some of the excluded articles did indeed deal with LULUCF and climate change, but did not cover the issues that were of specific interest to this article.

Of the 88 articles, only 19% had a first author who was based in a developing country, while the percentage of contributing authors from similar regions was 38%. The discipline analysis shows that 43 of the articles had a first author from the natural sciences, 16 from economics, 23 from multidisciplinary institutions and only 4 from social sciences other than economics (Table 2). Finally, 2 had a multidisciplinary university affiliation.

The 88 articles had a total of 148 contributing authors. Of these contributing authors, 92 were based in a developed country and 56 were based in a developing country. Furthermore, 94 of the contributing authors were affiliated with the natural sciences, 7 with economics, 29 with multidisciplinary institutions and 7 with social sciences other than economics. Amongst the contributing authors, 9 were affiliated with a multidisciplinary university environment.

There was further discussion regarding the limitations of sinks in the CDM in articles that were published at an early stage, 1997–2001, before the decisions of COP 7 in Marrakech were made, with a broader CDM focus. The number of articles published each year is presented in Table 2. The analysis also focussed on the geographical scale of the articles. Most (53) of the 88 articles had a global/general focus on the LULUCF issue, 17

Table 2 Results from the search conducted through a screening of five databases: Elsevier (Sciencedirect.com), Kluwer (springerlink.com), the science citation index expanded, the social sciences citation index and the arts & humanities citation index (all three from webofknowledge.com)

Category		Number	Percentage (%)
Total		88	100
Year	1997	2	2
	1998	1	1
	1999	6	7
	2000	11	13
	2001	13	15
	2002	14	16
	2003	12	14
	2004	19	22
	2005	9	10
	2006 + in press	1	1
Affiliation (1 author)	Natural	43	49
	Economic	16	18
	Social	4	5
	Multi inst.	23	26
	Multi Uni.	2	2
Affiliation (cont. author)	Natural	94	64
	Economic	9	6
	Social	7	5
	Multi inst.	29	20
	Multi Uni.	9	6
Scale	Local	3	2
	Region (small)	5	6
	Country	17	19
	Region (large)	10	11
	Global/General	53	60
Country of affiliation (1 author)	Developed[a]	71	81
	Developing[b]	17	19
Country of affiliation (cont. author)	Developed[a]	92	62
	Developing[b]	56	38

[a] Developed countries in this study: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Italy, Japan, New Zeeland, the Netherlands, Russia, Spain, Sweden, the UK and the US

[b] Developing countries in this study: Brazil, China, Costa Rica, India, Indonesia, Kenya, Mexico, the Philippines and South Africa

The parameters used in the analysis are presented with the number of articles in each category and the percentage of the total number. Articles without any hits are excluded from the analysis

articles focussed on a countrywide scale and 5 focussed on a country-specific regional scale. The rest of the articles had either a local (3) or a larger regional focus (10) (Table 2).

4.2 Analysis of key issues

While Table 2 shows the results of the search, Table 3 shows the analysis of the issues from the form, based on the 88 articles. Generally, the analysis shows that there is more focus on discussions which support the inclusion of LULUCF (66%) than on those that are critical of the inclusion of LULUCF in the CDM (34%).

There are a few categories in which an issue was more frequently discussed as being a barrier, rather than a potential. However, supportive arguments were more common. The authors from social science disciplines tended to be more critical of the inclusion of LULUCF. In our sample, the largest number of articles discussing sustainable development and general climate benefit as a potential in a single year was published in 2004.

Table 3 The table illustrates the results from the form which was used to study the articles

Category		A+	A−	L+	L−	P+	P−	B+	B−	S+	S−	G+	G−	M+	M−	Tot +	Tot −
Total		18	15	24	10	26	9	31	17	42	23	44	22	35	17	220	113
Year	1997	–	–	–	–	1	–	–	–	2	1	2	–	2	1	7	2
	1998	–	–	–	–	1	–	–	–	–	–	–	–	1	–	2	0
	1999	1	1	4	2	4	1	4	1	3	2	2	1	3	–	21	8
	2000	5	3	5	1	5	2	4	3	8	3	7	3	5	3	39	18
	2001	5	3	3	1	2	–	6	2	6	3	8	2	5	3	35	14
	2002	2	2	6	3	4	2	4	2	3	4	7	5	4	3	30	21
	2003	4	1	2	1	4	1	5	3	5	2	2	3	4	2	26	13
	2004	2	4	3	2	4	2	4	3	13	7	11	4	5	3	42	25
	2005	1	1	1	1	2	2	4	5	7	4	4	5	6	3	25	21
	2006 + in press	–	–	–	–	–	–	1	–	–	–	–	–	–	–	1	0
Affiliation	Natural	8	5	9	2	9	1	13	7	16	9	13	7	13	10	81	41
	Economic	2	2	3	2	5	2	4	2	4	4	7	5	4	2	29	19
	Social	1	2	–	1	–	–	1	1	1	–	1	1	1	1	5	6
	Multi Inst.	5	2	6	4	6	4	6	3	11	6	11	6	7	4	52	29
	Multi Uni.	–	–	–	–	1	–	1	–	2	1	1	–	2	–	7	1
	Multi Discip.	2	3	6	1	5	2	6	4	8	2	10	3	8	–	43	15
Scale	Local (1)	3	–	1	1	1	1	2	2	2	–	2	–	2	–	13	4
	Region (small) (2)	–	–	1	–	2	–	1	–	2	1	2	1	–	–	8	2
	Country (3)	3	2	2	2	2	–	3	2	3	1	3	1	3	–	19	8
	Region (large) (4)	1	3	2	1	1	1	2	2	4	2	4	–	3	2	17	11
	Case/General (5)	4	5	8	4	10	6	10	7	20	13	20	16	14	10	87	61

Table 3 continued

Category		A+	A−	L+	L−	P+	P−	B+	B−	S+	S−	G+	G−	M+	M−	Tot +	Tot −
Total		18	15	24	10	26	9	31	17	42	23	44	22	35	17	220	113
Country of Affiliation	Developed	9	8	14	6	19	5	19	11	27	15	30	15	26	15	142	75
	Developing	4	2	6	1	2	1	5	1	7	4	7	2	1	2	32	13
	Mixed	5	5	6	3	5	3	7	5	8	4	7	5	8	–	44	25

+ = Supportive of the inclusion of LULUCF

− = Critical of the inclusion of LULUCF

A = Additionality, L = leakage, P = permanence, B baseline, S = sustainable development, G = general climate benefit and M = monitoring (see the section on Methods for a more detailed explanation)

Affiliations: Natural, Economic and Social refers to university affiliations. Multi Inst. refers to multidisciplinary institutions or organisations. Multi Uni. refers to multidisciplinary university affiliations. Multi Discip. refers to a combination of authors from both universities and multidisciplinary institutions and organisations

Country of affiliation: The terms "developed" and "developing" in this case refers to authors affiliated with developed and developing countries respectively. The mixed category refers to the cases where the authors of one article are affiliated with both developed and developing countries

Note that the numbers given here are not related to the search result; they are instead the result from the marks/hits the different articles received with respect to the issues in question

Almost all issues discussed had two or three times as many articles by a first author from the natural sciences than those from economics disciplines. This is not surprising, since over half of the articles were written by authors from the natural sciences. The observation held true for all issues except when permanence and leakage were the subjects of critical discussion. In this case, the dominant articles were written by authors from multidisciplinary institutions together with authors from the field of economics and the articles that were produced in a collaborative manner. Only articles written by scientists affiliated with social science dominated the critical discussions, although in the case of sustainable development, the supportive discussions outnumbered the critical discussions. Nevertheless, there were few articles from the social sciences in comparison to those from the other affiliations. The authors from a multidisciplinary affiliation were generally supportive of the inclusion of LULUCF and this was obvious with respect to sustainable development and general climate benefits. Generally, the authors from the natural sciences were positive to all issues, especially those related to leakage and permanence.

General climate benefits and sustainable development were mainly seen as a positive benefit of A/R CDM projects. Of the 88 articles, 44 discussed general climate benefits and 42 discussed sustainable development as a positive outcome of LULUCF-CDM issues. Compared to the above, 22 articles were critical of general climate benefits and 23 were critical of sustainable development.

Researchers affiliated with institutes or research centres based in developing countries were responsible for a very small proportion of the articles. When only the first author is being considered, the difference was approximately a quarter. When contributing authors were taken into account the numbers increased by slightly less than half. In addition, the country of origin of the work does not always reflect the nationality of an author, since many researchers from developing countries are active in developed countries. The analysis shows that two-thirds of the articles with discussions supporting the inclusion of LULUCF were written by authors based in a developing country, compared to half whose authors were based in developed countries or where there were several countries of affiliation.

All the issues, both supportive and critical, were discussed on a general/global scale. The general climate benefit and sustainable development were the most discussed issues on a global/general scale, whether in a positive or critical light. The general/global scale was also the only platform upon which all issues were discussed at least once (Table 3).

The majority of the articles were positive towards the inclusion of LULUCF in the CDM. One emergent trend is the growing critical view from 1998 onwards, which might reflect the optimism that existed in the early years of CDM. The authors with affiliations in economics and the social sciences were generally more critical of the inclusion of LULUCF than authors with natural science affiliations and authors from multidisciplinary institutions and universities. As seen in Fig. 2, authors from a multidisciplinary university environment and social scientists were the least pro-CDM according to the analysis. However, due to the limited number of published papers from the field of social sciences, it is difficult to draw any firm conclusions. Scale-wise, there was a trend towards more positive discussions in the articles that focussed on a local/case study level, with fewer authors being optimistic on the larger scales. However, positive discussions are dominant even on global/general level. There is a slight difference between authors from developing and developed countries, with the articles having only authors from developed and articles written as a collaborative effort between developed and developing countries presenting a few more barriers than authors from developing countries.

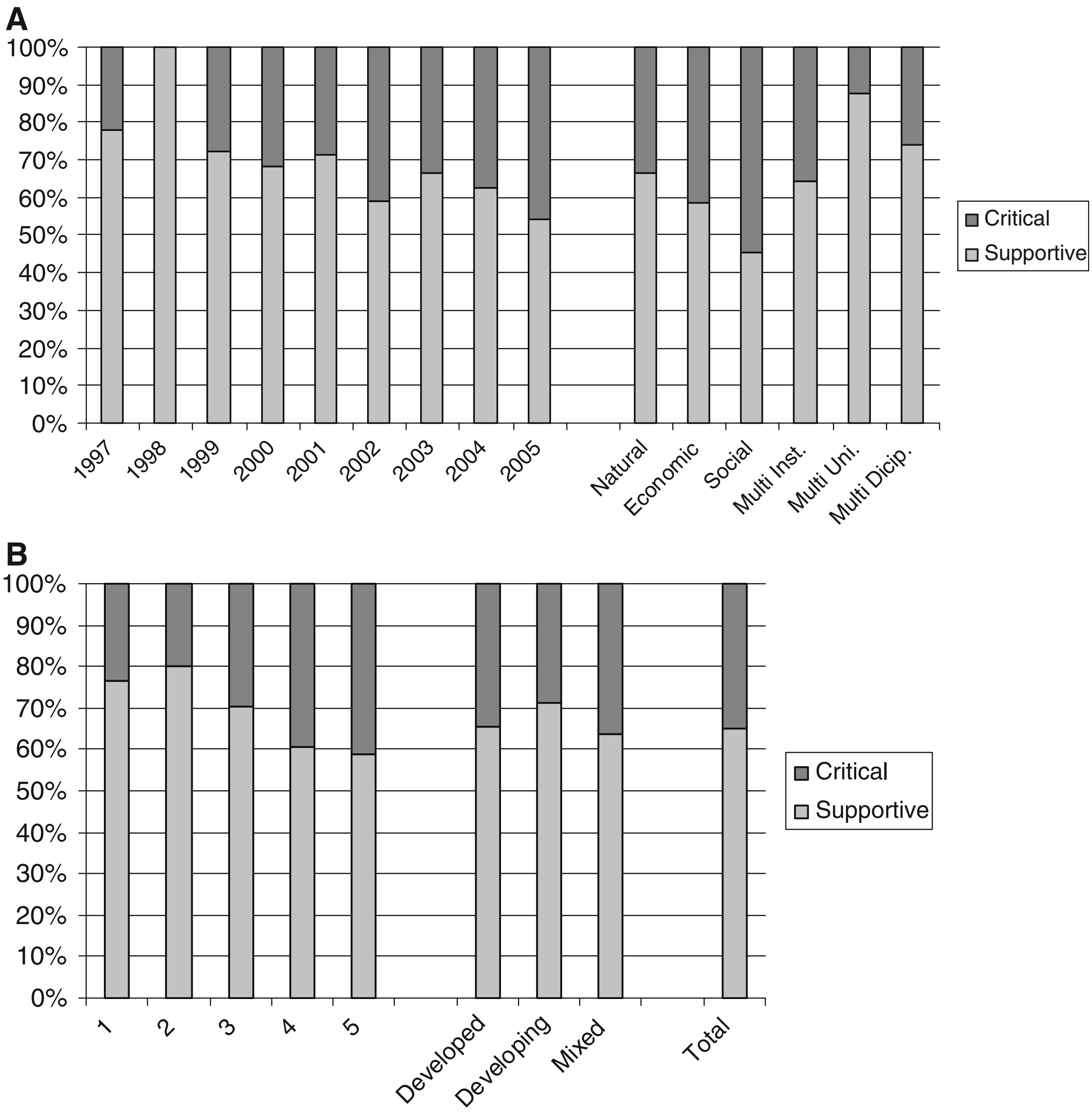

Fig. 2 The percentage of the articles viewing issues of interest for this article as either a potential or barrier (**a**) over the time period included in the study and with respect to the disciplinary affiliation of the first author and (**b**) with respect to geographical level (1 = Local/Case study scale, 2 = Region (small), 3 = Country, 4 = Region (large) and 5 = Global/General and country origin of affiliation. Issues of interest are additionality, leakage, permanence, baseline, sustainable development, general climate benefit and monitoring. Note that only one article was included in the analysis in 1998

4.3 Trends in relation to COP meetings

The issues discussed at the different COP meetings are presented in the third column of Table 1. In 2000, during COP 6 Part 1 in the Hague, the potential contribution of sinks in lowering the cost of abatement action was discussed. The issue was discussed not only as a potential subject for inclusion in the CDM, but also in more general terms such as actions in Annex B countries. The results from this study show that the sink issue has generally been discussed on a global scale, as can be seen in Fig. 3. The figure also shows that the geographical scale became increasingly focussed on a national scale, peaking in the year 2000, where no discussions took place on a local or regional level; there was another peak

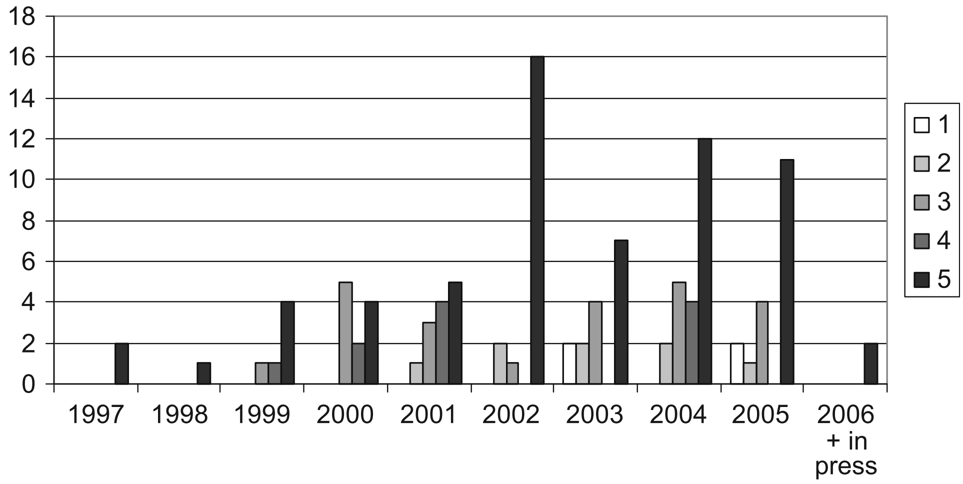

Fig. 3 The number of articles dealing with the questions on different scales versus the year of publication: 1 = Local/Case study scale, 2 = Region (small), 3 = Country, 4 = Region (large) and 5 = Global/General

in the 2004, where the general focus was on a global scale. After COP 7 in 2001, the discussion evolved to a scale that was smaller than the national scale.

The Marrakech Accords were adopted at COP 7, which took place in 2001. This decision allowed the inclusion of LULUCF in the CDM, although it was limited to A/R. From 1997 to 2001 there was a clear increase in discussions related to issues tabled at COP 7, and hence an increase in number of articles dealing with LULUCF-CDM questions (Table 2). The Accords did not include any clear modalities and procedures, which is evidenced by the continuing discussion of the issues of interest in terms of the number of articles produced.

At the end of 2002, at COP 8, a declaration on sustainable development was adopted. In 2002 only seven articles discussed the issue at all; three as a potential and four as a barrier. The discussion on sustainable development from a supportive viewpoint intensified after 2003, with a maximum of 13 discussions in 2004. The critical views of sustainable development increased slightly, to seven in 2004. However, there was a slight peak in the discussions on sustainable development even before the Delhi Declaration, in the year 2000.

At the end of 2003, at COP 9 the modalities and procedures for A/R were adopted. This included formalisation stages regarding regulation on additionality, leakage, permanence and baseline. There are few changes in terms of frequency of discussions on these issues over the period before and after 2003 (Table 3). From 1999 to the year the decisions were made, there is a strong and diversified discussion regarding these issues, only the critical view of additionality, permanence and baseline peaked after 2003. Discussions on most of these issues ceased after 2003, except baseline-related discussions, which continued until 2005. The discussions show a slight change in scale, with the majority of the discussions throughout the years being found on a global/general scale (Fig. 3). However, the diagram illustrates that discussions in recent years have taken place on a more diversified scale. Only in the year 2000 was the discussion more focussed on a countrywide scale.

The Good Practice Guidance for LULUCF was adopted during COP 10 at the end of 2004. It provides guidelines for modalities and monitoring, which can in turn be applied to CDM projects. There is some impact to be seen in terms of academic discussion before this adoption, with strong discussions on many technical issues occurring until 2004.

5 Discussion

The findings illustrate the difficulty in identifying a clear path of influence on policy on science as a product of peer-reviewed articles or vice versa. While we are able to find evidence of cross-fertilisation of research by policy decisions and declarations in some cases, the overall evidence is mixed. One conclusion that can be drawn from the results is that the number of studies involving research and discussions at a highly detailed level (e.g. detailed technical issues on additionality, leakage, baseline and monitoring) is higher before the related decision is made. In contrast, it would appear that a decision regarding issues with low levels of detail, such as general climate benefit and sustainable development triggers more research and discussion after the decision is made, which we have illustrated in a revised conceptual model in Fig. 4. Part of this process can, of course, be a result of the long processing time for peer-reviewed literature. The exact registration and acceptance process of some journals provides us with good insight on the slow process of publishing literature in this format. This information however, is not registered for all journals, which is the reason for not including it in the analysis. The timing of publication depends to a large extent on the choice of the journals rather than the news value of the information. This can be a problem when negotiations take place once a year during the COPs.

One example of the above-described influence is the increased frequency of discussions on sustainability since the Declaration on Sustainable Development in New Delhi in 2002 was signed (Table 3). This increase can be seen as a reaction to the focus that was put on sustainability in the Declaration and hence directs researchers to an issue that is touted as important by policymakers. The increased focus on sustainable development was also most likely influenced by the World Summit on Sustainable Development which was held in Johannesburg, South Africa in the same year. The situation, however, is quite the opposite when it comes to the issues included in the decision on leakage, additionality and permanence from COP 9 in 2003, where the discussion ceased just after the decision was made. In other words, policy declarations differ from policy decisions. The discussion continued with a few baseline issues, which might indicate that the decisions were incomplete, at least from a research point of view. A generalised statement could be that policymakers set the research agenda by declaration, which states the focus, while researchers feed the decision-making process until a decision is made.

The difference in the relations between declarations and policy decisions contra peer-reviewed articles could also be explained by the possibility that declaration statements at policy level also influence the research programmes' key focuses, i.e. they essentially determine the content of research that is to be conducted.

Given the unclear evidence regarding such influences from the peer-reviewed literature on policy and negotiations, it can be concluded that negotiations are not only influenced by peer-reviewed articles, but that other instances such as research presented in a non-peer reviewed format, Non-Governmental Organisations (NGO), consultancies, lobby agencies and the business world also set the agenda for nations' policies. Berlin (2007), however, concludes that expertise and science are widely considered to be prime movers in global environmental politics and that scientific input is commonly regarded as an alternative to interest-based argumentation and employed by governmental decision-makers to ward off conflicts in times of uncertainty. Is it possible that a faster publishing forum, in the form of working papers and reports, is setting the agenda for negotiations and decisions, while the academics are evaluating the outcome? Researchers are involved in the negotiation process and can influence it by other means than peer-reviewed literature. However, the use of peer-reviewed material is not exclusive to this study. The IPCC process is mainly based on

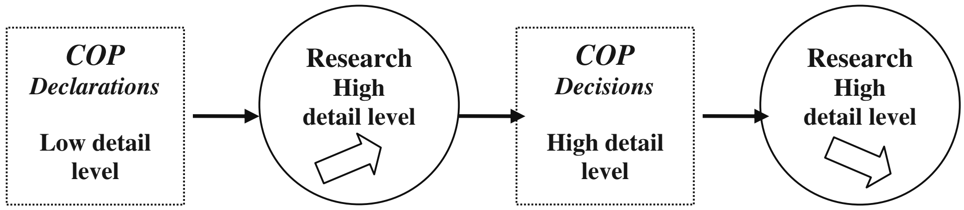

Fig. 4 A revised conceptual model describing the relationship between declarations and decisions regarding LULUCF CDM and the frequency and content of the research process as a function of time. Declarations with low levels of detail and broad statements trigger increased research with high levels of detail; this in turn feeds that policymaking process, resulting in a decision with a high level of detail, after which the amount of research with high levels of detail ceases

peer-reviewed and internationally available literature, with few exceptions for selected non-peer-reviewed literature, such as information from the private sector. The authors of the IPCC will then critically assess the source, quality and validity of the non-peer-reviewed material. The method used in this study supports this approach, since it concludes that the speed of publication is slow and that results may not be immediately reflected in policy. A long and proportionately relevant timeframe of 9 years should be sufficient for this type of analysis. However, the difficulties in finding relevant influences in both research and policy are largely due to the slowness of the review process for published articles. This study does not imply that peer-reviewed material constitutes the only influence on policy decisions; on the contrary, the authors are well aware of the impact of other sources. This study has attempted to determine whether policy and research are closely linked, and we have established that this is not always the case.

Another example of the influential research that NGOs, consultancies and lobby agencies can have on a related topic is the issue of avoided deforestation. Within the next century, tropical deforestation is expected to contribute 9–22% of the increase of the CO_2 concentration in the atmosphere (Stitch et al. 2005). Avoided deforestation is an issue that is much discussed in the literature that was analysed for this study, even if the search did not focus on this particular issue. In 21 cases, papers point out that the terrestrial carbon sink is, and will be, a very important part of the attempt to limit emissions; indeed, several researchers argue that the greatest benefit comes from avoided deforestation. The issue was previously discussed as a possibility for the CDM; however the issue was put on hold since its exclusion from the Marrakech Accords in 2001. The issue was once again raised during COP 11 in Montreal following a proposal from several non-Annex B countries[5]. The COP subsequently initiated a new process under the SBSTA to consider possible approaches for reducing GHG emissions from deforestation. The discussion in the literature regarding avoided deforestation indicates that researchers are aware of both its effect and the problematic issue of making it a functional policy. The fact that the issue has returned to the spotlight shows that the influence of research on climate change policy might be greater than first thought.

The fact that few first authors in this study work in the developing world may seem strange since the CDM is set in the developing world. The collaboration which takes place in research does not dominate the literature, but it is present to some extent. If the literature is important for policy development then our analysis shows that the developed world sets the foundation for the research. This should not be forgotten when looking at the impact of the IPCC, which contributes expert knowledge and mainly uses peer-reviewed literature in

[5] Papua New Guinea, Costa Rica, Bolivia, the Central African Republic, Chile, Democratic Republic of the Congo, the Dominican Republic and Nicaragua.

its reports. The trend of a majority of authors involved in the production of IPCC reports being drawn from developed countries is clearly documented by Fogel (2005). Fogel also concludes that nearly all authors of the special report on LULUCF in 2000 were trained in the natural sciences; the same trend is seen in this study.

From this study it is evident that the linkages between peer-reviewed literature and policy agenda are mixed and non-linear. However, this does not mean that the policy agenda is completely separated from the science community. According to Lidskog and Sundqvist (2002), there is clear evidence of co-production between science and policy. Lidskog and Sundqvist conducted an analysis of the science-policy interactions in terms of long-range transboundary air pollution. It would be interesting to conduct a similar analysis of LULUCF within the CDM.

This study brings up several interesting issues to be dealt with in the future, such as (i) how and where the research community influences the negotiations and (ii) identifying the true author of the agenda for research and policy. One way of broadening the scope would be to include material produced by NGOs, various technical papers and material from lobby organisations. Another way would be to conduct qualitative or quantitative interviews with people involved in negotiations in order to analyse their sources and use of information. With a deeper analysis of each individual paper, including information about each author's agenda and means of communicating research results, the level of interaction on scientific policy would be more clearly understood.

6 Summary

A majority (65%) of the discussions in the articles showed support for the inclusion of LULUCF activities, particularly on a local level. The most widely discussed issue was that of sustainable development and general climate benefit. A majority (52%) of the articles had first authors who were trained in the natural sciences.

The authors of 15 out of 77 articles investigated works in a developing country. The results show that authors from developing countries tend to discuss fewer barriers than potential in comparison to authors from developed countries. For a mechanism built on cooperation between developing and developed countries it may seem strange that the share of research from the developing world is not larger than the results in this study show.

This literature assessment could not clearly illustrate interaction between peer-reviewed scientific research and COP decisions. This could be because (a) the process of publishing peer-reviewed literature is slow and is formally available to others only a considerable time after its production and (b) input to decision-makers may be found in scientific working papers and publications from NGO and lobby organisations; hence peer-review work can be regarded as more of an evaluation of policy decisions.

From the results it is evident that there is a clear difference between declarations and decisions and their relation to peer-reviewed articles. The results indicate that policy-makers set the research agenda by declaration with low levels of detail, which provides the focus for researchers, while researchers feed the decision-making process with highly detailed research up until the point at which a decision is made.

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Appendix 1 Reference list of articles included in the literature study

Mitigation and Adaptation Strategies for Global Change	(2000) 5: 9–24	Land use, land use change, forestry and agricultural activities in the clean development mechanism: estimates of greenhouse gas offset potential	Bloomfield J and Pearson H
	(2001) 6: 213–232	Mitigation potential for carbon sequestration through forestry activities in southern and eastern China	Deying X, Xiao-Quan Z and Zoumin S
	(2001) 6: 291–312	Forestry mitigation options for Mexico: finding synergies between national sustainable development priorities and global concerns	Masera OR Cerón AD and Ordónez A
	(2001) 6: 257–290	Economic assessment of mitigation options for enhancing and maintaining carbon sink capacity in Indonesia	Boer R
	(1997) 2: 113–155	Global climate change mitigation and sustainable forest management—the challenge of monitoring and verification	Makundi W
	(1997) 2: 101–115	Policies, measures and the monitoring needs of forest sector carbon mitigation	Sathaye J and Ravindranath NH
	(1999) 4: 43–60	The monitoring, evaluation, reporting and verification of climate change projects	Vine E and Sathaye J
	(2001) 6: 313–334	Climate change mitigation activities in the Philippine forestry sector: application of the COMAP model	Lasco R and Pulhin F
	(2001) 6: 185–211	Carbon mitigation potential and costs of forestry options in Brazil, China, India, Indonesia, Mexico, the Philippines and Tanzania	Sathaye JA, Makundi WR, Andrasko K, Boer R, Ravindranath NH, Sudha P, Rao S, Lasco R, Pulhin F, Masera O, Ceron A, Ordonez J, Deying X, Zhang X and Zuomin S
	(2000) 5: 81–97	Forest land use change in the Philippines and climate change mitigation	Lasco R and Pulhin F
	(2002) 7: 381–402	Fractions of permanence—squaring the cycle of sink carbon accounting	Dutschke M
	(2004) 9: 217–240	Forest conservation and the clean development mechanism: lessons from the Costa Rican protected areas project	Vöhringer F
	(2005) 10: 307–331	C-lock (patent pending): a system for estimating and certifying carbon emission reduction credits for the sequestration of soil carbon on agricultural lands	Zimmerman PR, Price M, Peng C, Capehart WJ, Updegraff K, Kozak P, Vierling L, Baker E, Kopp F, Duke G and Das C
	(2003) 8: 323–348	Estimating baseline carbon emission for the eastern Panama canal watershed	Dale VH, Brown S, Calderón MO, Montoya AS and Martínez RE
	(2003) 8: 261–280	Potentials of CO2 emission reduction by carbonizing biomass waste form industrial tree plantation in south Sumatra, Indonesia	Okimori Y, Ogawa M and Takahashi F

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Climatic Change	(2001) 51: 35–72	Potential of desertification control to sequester carbon and mitigate the greenhouse effect	Lal R
	(2004) 65: 333–346	Carbon sequestration and the restoration of land health – An example from Iceland	Arnalds A
	(2004) 63: 247–257	A decision matrix approach to evaluate the impacts of land-use activities undertaken to mitigate climate change	Kueppers LM, Baer P, Harte J, Haya B Koteen LE and Smith ME
	(2004) 65: 347–364	Assessment and measurement issues related to soil carbon sequestration and land-use, land-use change, and forestry (LULUCF) projects under the Kyoto Protocol	García-Olica F and Masera OR
	(2003) 58: 47–71	Can trees buy time? An assessment of the role of vegetation sinks as a part of the global carbon cycle	Kirschbaum MUF
	(2004) 65: 255–261	Carbon sequestration, soil conservation, and the Kyoto Protocol: summary of implications	Dumanski J
	(2004) 65: 365–387	International and national aspects of a legislative framework to manage soil carbon sequestration	Hannam I
	(2002) 55: 157–173	Changes in area and carbon in forest of the middle Zavolgie: a regional case study of Russian forest	Kurbanov EA and Post WM
	(2002) 54: 471–495	Soil carbon sequestration and the CDM: opportunities and challenges for Africa	Rignius L
	(2003) 61: 123–156	Forestry projects under the clean development mechanism?	Van Vliet OPR, Faaij APC and Dieperink C
Environmental Management	(2000) 26:3 283–297	Forest protection and reforestation in Costa Rica: evaluation of a clean development mechanism prototype	Subak S
	(2005) 33: s374-s387	Land-use change, carbon sequestration and poverty alleviation	Lipper L and Cavatassi R
Nutrient Cycling in Agroecosystems	(2004) 70: 103–116	Agricultural activities and the global carbon cycle	Lal R
Environment, Development and Sustainability	(2004) 6: 163–174	An Amazon perspective on the forest-climate connection: opportunity for climate mitigation, conservation and development?	Carvalho G, Moutinho P, Nepstad D, Mattos L and Santilli M
	(2004) 6 133–143	Estimation of soil carbon gains upon improved management within cropland and grasslands of Africa	Batje NH
	(2004) 6: 1–9	Mitigation greenhouse gas emissions from tropical agriculture. Scope and research priorities	Wassmann R and Vlek PLG
	(2004) 6: 183–211	The clean development mechanism: making it operational	Mendis M and Openshaw K
New Forest	(2003) 26: 101–136	Economics of wasteland afforestation in India, a review	Balooni K

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Energy Policy	(2000) 28: 935–946	Project-based greenhouse-gas accounting: guiding principles with a focus on baseline and additionality	Gustavsson L, Karjalainen T, Marland G, Savolainen I, Schlanadinger B and Apps M
	(2005) 33: 2385–2397	Transaction costs of unilateral CDM projects in India—results from an empirical survey	Krey M
	(2004) 32: 801–810	Biomass energy technologies for rural infrastructure and village—opportunities and challenges in the context of global climate change concerns	Kishore, VVN, Bhandari PM and Gupa P
	(2006) 34. 26–39	An economic assessment of the Kyoto Protocol application	Dagoumas AS, Papagiannis G K and Dokopoulos PS
	(2003) 31: 709–719	Carbon quota price and CDM after Marrakech	Chen W
	(2005) 33: 1157–1576	Near-term technology policies for long-term climate targets—economy wide versus technology specific approaches	Sandén BA and Azar C
	In press	Spatial boundaries and temporal periods for setting greenhouse gas performance standards	Murtishaw S, Sathaye J and LeFranc M
International Environmental Agreements	(2005) 5: 191–210	Biotic carbon sequestration and the Kyoto Protocol: the construction of global knowledge by the Intergovernmental panel on climate change	Fogel C
	(2005) 5: 25–46	Graduation and deepening: and ambitious post-2012 climate policy scenario	Michaelowa A, Butzegeigr S and Jung M
	(2005) 5: 105–124	Challenges and outcomes at the ninth session of the conference of the parties to the united nations framework convention on climate change	Dessai S, Schipper LF, Corbera E, Kjellen B, Gutierrez M and Haxeltine A
Biomass and Bioenergy	(2000) 18: 457–468	Uncertainty in land-use change and forestry sector mitigation options for global warming: plantation silviculture versus avoided deforestation	Fernside P
	(1999) 16: 171–189	Forests and global warming mitigation in the Brazilian forest sector for responses to global warming under the "clean development mechanism"	Fernside P
	(2005) 28: 107–117	Promoting bioenergy through the clean development mechanism	Silveris S
	(2003) 25: 197–207	Electricity from bargasse in Zimbabwe	Mbohwa C and Fukuda S
	(2004) 27: 41–55	Trees for carbon sequestration of fossil fuel substitution: the issue of cost vs. carbon benefit	Baral A and Guha GS

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Forest Ecology and Management	(2004) 202: 131–147	Carbon stock changes in successive rotations of Chinese fir (Cunninhamia lanceolata (lamb) hook) plantations	Zhang X-Q, Kirschbaum MUF, Hou Z and Guo Z
	(2005) 207: 245–262	An integrated decision support framework for the prediction and evaluation of efficiency, environmental impact and total social cost of domestic and international forestry projects and for greenhouse gas mitigation: description and case studies	Garcia-Quijano JF, Deckmyn G, Moons E, Proost S, Ceulemans R, Muys B
	(2003) 179: 321–331	Surface wildfires in central Amazonia: short-term impact on forest structure and carbon loss	Haugaasen T, Barlow J and Peres CA
	(2004) 191: 283–299	Appropriate measures for conservation of terrestrial carbon stocks – analysis of trends of forest management in Southeast Asia	Kim Phat N, Knorr W and Kim S
Environmental Science and Policy	(2000) 3: 99–113	Forestry projects for climate change mitigation: an overview of guidelines and issues for monitoring, evaluation, reporting, verification, and certification	Vine EL, Sathaye JA and Makundi WR
	(1999)2: 187–198	Concerns about climate change mitigation projects: summary of findings from case studies in Brazil, India, Mexico and South Africa	Sathaye JA, Andrasko K, Makundi W, Lebre La Revere E, Ravindranath NH, Melli A, Rangachari A, Imaz M, Cay C, Friedman R, Goldberg B, van Horen C, Simmonds G and Parker G
	(2001) 4: 269–292	The potential contribution of sinks to meeting Kyoto Protocol Commitments	Missfeldt F and Haites E
	(1999) 2: 199–206	Issues related to including forestry based offsets in a GHG emission trading system	LeBlanc A
	(1998) 1: 313–327	The Kyoto Protocol: provisions and unresolved issues relevant to land-use change and forestry	Schlamadinger B and Marland G
	(2005) 8: 87–104	The role of forestry projects in the clean development mechanism	Jung M
	(2003) 6: 441–455	A review of remote sensing technology in support of the Kyoto Protocol	Rosenqvist Å, Milne A, Lucas R, Imhoff M and Dobson C
	(2003) 6: 475–486	The role of scientific uncertainty in compliance with the Kyoto Protocol to the climate change convention	Gupta J, Olsthoorn X and Rotenberg E
	(2002) 5: 367–384	Global economic implications of alternative climate policy strategies	Kemfert C
	(2004) 7: 239–251	How costly are carbon offsets? A meta-analysis of carbon forest sinks	Van Kooten GC, Eagle AJ, Manley J and Smolak T
	(2002) 5: 429–441	The role of carbon sequestration and the tonne-year approach in fulfilling the objective of climate convention	Korhonen R, Pingoud K, Savolainen I and Matthews R

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Forest Policy and Economics	(2004) 6: 329–343	How "sustainable" is the "sustainable development objective" of CDM in developing countries like India	Haripriya G
	(2004) 6: 153–167	Could payments for forest carbon contribute to improved tropical forest management	Smith J and Applegate G
	In press	Site identification for carbon sequestration in Latin America: a grid-based economic approach	Benitez PC and Obersteiner M
Ecological Economics	(2001) 39: 167–184	Saving tropical forests as a global warming countermeasure: an issue that divides the environmental movement	Fernside P
	(2000) 35: 203–221	The Kyoto Protocol and payment for tropical forestry: an interdisciplinary method for estimating carbon-offset supply and increasing the feasibility of a carbon market under the CDM	Pfaff ASP, Kerr S, Hughes RF, Liu S, Sanchez-Azofeifa GA, Schimel D, Tosi J and Watson V
	In press	Temporary credits: a solution to the potential non-permanence of carbon sequestration in forest?	Marechal K and Hecq W
	(2005) 55 380–394	Secondary forest as a temporary carbon sink? The economic impact of accounting methods on reforestation projects in the tropics	Olschewski R and Benitez P C
	In press	Forest conservation in the Philippines: a cost-effective approach to mitigation climate change	Sheeran KA
	(2005) 52: 81–96	Carbon offsets as an economic alternative to large-scale logging: a case study in Guyana	Osborne T and Kiker C
	(2003) 46: 143–157	Conflicts between biodiversity and carbon sequestration programs: economic and legal implications	Caparrós A and Jacquemont F
Global Environmental Change	(2001) 11: 203–216	An overview of guidelines and issues for the monitoring, evaluation, reporting, verification, and certification of forestry projects for climate change mitigation	Vine E, Sathaye JA and Makundi W
	(2000) 10: 259–272	Community forest management in Mexico: carbon mitigation and biodiversity conservation through rural development	Klooster D and Masera O
	(2002) 12: 331–336	Implementing the Kyoto Protocol on climate change: environmental integrity, sinks and mechanism	Begg, KG
	In press	Geographic diversification of carbon risk—a methodology for assessing carbon investments using eddy correlations measurements	Hultman NE
	(2003) 13: 19–30	Making global initiatives local realities: carbon mitigation projects in Chiapas	Nelson KC and de Jong BHJ

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Climate Policy	(2001 1: 41–54)	The leaky sink: persistent obstacles to a forest carbon sequestration program based on individual projects	Richards K and Andersson K
	(2001) 1: 411–417	Carbon sinks and the CDM: could a bioenergy linkage offer a constructive compromise?	Schlamadinger B, Grubb M, Azar C, Bauen A and Berndes G
	(2002) 2: 35–49	Baseline, leakage and measurements issues: how do forestry and energy projects compare?	Chomitz KM
	(2002) 2: 379–385	LULUCF-based CDM: too much ado for... a small carbon market	Bernoux M, Eschenbrenner V, Cerri CC, Melillo JM and Feller C
	(2002) 2: 89–95	Precautionary climate policy and somewhat flawed Protocol: linking sinks to biofuel and he CDM to the convention	Read P
	(2002) 2: 129–144	Linkages between climate change and sustainable development	Beg N, Corfee Morlot J, Davidson O, Afrane-Okesse Y, Tyani L, Denton F, Sokona Y, Thomas JF, Lébre La Rovere E, Parikh JK, Parikh K and Rahman AA
	(2002) 2: 179–196	Estimating the CDM market under the Marrakech Accords	Jotzo F and Michaelowa A
	(2002) 2: 353–365	Future restrictions for sink in the CDM How about a cap on supply?	Forner C and Jotzo F
	(2003) 3: 107–122	Replacing carbon lost from forest: as assessment of insurance, reserves, and expiring credits	Subak S
	(2002) 2: 335–351	Forest certification eligibility as a screen for CDM sinks projects	Subak S
	(2004) 4: 193–204	Accounting methods for carbon credits: impacts on the minimum area of forestry projects under the clean development mechanism	Locatelli B and Pedroni L
	(2005) 5: 407–418	Carbon accounting for sinks in the CDM after CoP 9	Pedroni L
	(2005) 5: 109–125	Value and risks of expiring carbon credits from afforestation and reforestation projects under the CDM	Dutschke M, Schlamadinger B, Wong JLP, and Rumberg M
	(2005) 5: 199–208	Can the EU emission trading scheme support CDM forestry?	Schlamadinger B, Bosquet B, Streck C, Noble I, Dutschke M and Bird N
	(2005) 5: 433–443	Reducing carbon transaction cost in community-based forest management	Skutsch M
The Royal Society	(2002) 360: 1641–1652	The role of multilateral institutions	Kiss A, Casro G and Newcombe K
	(2002) 360: 1875–1888	Designing a carbon market that protects forest in developing countries	Niesten E, Frumhoff P, manion M and Hardner J
	(2002) 360: 1685–1703	Understanding and managing leakage in forest-based greenhouse-gas-mitigation projects	Schwarze R, Niles J and Olander J

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Environmental Modeling & Software	(2005) 20: 1139–1148	Tree-crop interactions and their environmental and economic implications in the presence of carbon-sequestration payments	Wise R and Cacho O
Journal of Forest Economics	(2005) 11: 77–94	Hoe attractive are forest carbon sinks? Economic insights into supply and demand of certified emission reductions	Olschewski R, B, Oenitez P.C, de Koening G.H.J and Schlichter T
Journal of Environmental Management	(2003) 69: 25–37	Carbon dynamics and land-use choices. Building a regional-scale multidisciplinary model	Kerr S, Liu S, Pfaff ASP and Hughes F
Geoderma	(2004) 123: 51–68	Assessment of soil property special variation in an Amazon pasture: basis for selecting an agronomic experimental area	Cerri CEP, Bernoux M, Chaplot V, Volkoff B, Victoria RL, Melillo JM, Paustian K and Cerri CC
	(2004) 123:1–22	Soil carbon sequestration to mitigate climate change	Lal R
Journal of Arid Environments	(2004) 59: 583–604	Impacts of land use and climate change on carbon dynamics in south-central Senegal	Liu S, Karié M, Wood E, Diallo O and Tieszen LL
World Development	(2004) 32.1: 173–190	Deforestation and carbon emission at tropical frontiers: a case study from the Peruvian Amazon	Naughton-Treves L
CES Focus on Environmental Partnership	(1999) 6.1: 61–64	Protecting forests and addressing climate change	Coda M and Firstenberg EL
Agricultural Ecosystems & Environment	(2000) 82: 371–383	Linking climate change research with food security and poverty reduction in the tropics	Sanchez PA
The Science of the Total Environment	(1999) 240: 145–156	Maximizing financial support for biodiversity in the emerging Kyoto Protocol markets	Walsh MJ
Journal of Forestry	(2000) 38–47	Forest carbon and the Kyoto Protocol's clean development mechanism	Rotter J and Danish K
Environmental Conservation	(2000) 27: 300–311	Harnessing carbon markets for tropical forest conservation: towards a more realistic assessment	Smith J, Mulongoy K, Persson R and Sayer J
Land degradation and development	(2001) 12: 131–142	Options for increasing carbon sequestration in West African soils: an exploratory study with special focus on Senegal	Batjes, NH
Ambio	(2001) 30.6: 351–355	Carbon emissions and sequestration potential of Central African ecosystems	Zhang Q and Justice C
Environmental and Resource Economics	(2002) 21: 23–46	Economic value of the carbon sink services of tropical secondary forest and its management implications	Ramirez O, Caprio C, Ortiz R and Finnegan B
Science in China	(2002) 45: 65–74	Fire risk in forest carbon projects in Indonesia	Murdiyarso D, Widodo M and Suyamto D

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Agroforestry Systems	(2005) 64: 237–250	A bioeconomic analysis of carbon sequestration in farm forestry: a simulation study of Gliricidia Sepium	Wise R and Cacho O
IDS Bulletin	(2004) 35: 76–83	Carbonising forest landscapes? Linking climate change mitigation and rural livelihoods	Leach G and Leach M

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Paper III

Biofpr
Biofuels Bioproducts & Biorefining

Multifunctional biomass production systems – an overview with presentation of specific applications in India and Sweden

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Abstract: This perspective discusses multi-functional biomass production systems, which are located, designed, integrated and managed so as to provide specific environmental services, in addition to biomass supply. Besides discussing the general concept and outlining a range of different possible applications, we present in somewhat more detail specific applications of such systems for the cases of Sweden and India. The overall conclusion is that the environmental benefits from a large-scale establishment of multi-functional biomass production systems could be substantial. Given that suitable mechanisms to put a premium on the provided environmental services can be identified and implemented, additional revenues can be linked to biomass production systems and this could enhance the socioeconomic attractiveness and significantly improve the competitiveness of the produced biomass on the market. The provision of additional environmental services also contributes to local sustainable development, which is in many cases a prerequisite for local support for the production systems. © 2008 Society of Chemical Industry and John Wiley & Sons, Ltd

Keywords: biomass production; plantations; environment; socioeconomic effects

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Introduction

The complexity and interconnected nature of environmental and socio-economic problems implies that strategies based on a holistic perspective are needed: a too narrow focus on one problem at a time can, at worst, make another problem even more serious, or, at best, prevent taking advantage of potential synergy effects. The importance of a holistic perspective in development strategies is generally well established and concrete initiatives can, for example, be found in concepts of promoting synergy between the three 'Rio Conventions' on the environment (climate change, biodiversity and desertification).

Biomass production, to provide feedstocks for the production of various biofuels and bioproducts, is a good example of where a holistic perspective must be adopted. One primary aim with greater use of renewable feedstocks such as biomass is to reduce society's use of coal, oil and fossil gas, thereby reducing our influence on the climate. But the production of biomass can also yield significant additional (positive and negative) environmental effects in connection with changing how land is used in forestry and agriculture. Also, the central role of agriculture for livelihoods – especially in developing countries – implies that strategies for increasing biomass production need to consider socio-economic as well as environmental aspects.

It is essential to avoid, as far as possible, negative environmental and socio-economic effects of increased biomass production for biofuels and bioproducts. This can be done by setting up rules and guidelines concerning how biomass production should be carried out. There are presently several initiatives aimed at developing certification systems and criteria sets for sustainable biomass production. Selected examples are listed here.[1,2] However, complementary to the implementation of certification systems hedging against undesirable developments, promotion of *desirable* developments is an equally important task. Based upon general and local knowledge of possible feedbacks and integration between technical, social and ecological systems, it may be possible to find different ways of producing biomass while generating additional benefits.

This perpespective deals with so-called multifunctional biomass production systems. We discuss the general concept and briefly outline a number of possible applications . We describe selected applications in somewhat more detail for the cases of Sweden and India. We will concentrate on the environmental benefits that can be obtained from multifunctional biomass production, but emphasize that these are very much linked to the socio-economic systems and thus also contribute to socio-economic benefits and local sustainability. We end by discussing how the possibility of providing additional environmental benefits can improve the economic viability and local support for multifunctional biomass production systems. We also briefly account for various important factors that affect the future scope of multifunctional biomass production systems.

Multifunctional biomass production systems

Multifunctional biomass production systems can – through well-chosen localization, design, management and system integration – offer extra environmental services that, in turn, create added value for the systems.[3] The systems can be divided roughly into two categories. Some are exploited for directed environmental services, an example being when trees are established as a wind break to reduce wind erosion. Others are systems that provide environmental services of a more general nature, for instance soil carbon accumulation leading to improved soil fertility and enhanced climate benefit.

While the concept of multifunctional biomass production systems might appear a recent invention, the underlying idea – that certain plants can be cultivated in certain ways to provide various benefits in addition to the harvest – has probably always influenced land-use strategies. Specifically for lignocellulosic feedstocks, integration of different perennial grasses and short-rotation woody crops has been suggested as a way of remediating many environmental problems, including biodiversity loss. A brief survey of some specific applications is given below. More extensive information can be found in the growing number of publications in this field. Selected examples are listed here.[4–9]

Purification of different types of nutrient-bearing water

Plantations can be used as vegetation filters for the treatment (via irrigation) of nutrient-bearing water such as wastewater from households, collected run-off water from farmlands and leachate from landfills. Plantations can also be located in the landscape and managed as buffer strips for capturing the nutrients in passing run-off water. Sewage sludge from treatment plants can also be used as fertilizer in vegetation filters. These applications are described in somewhat more detail (for the case of willow cultivation in Sweden) later in this perspective.

Regulation of water flow

Plantations can be located and managed for reduction of water erosion and for flood prevention. Besides the onsite benefits of reduced soil losses, there are also offsite benefits, such as reduced sediment load in reservoirs and irrigation channels, as well as reduced deterioration in the quality of river water due to the suspended load that accompanies flood waters formed mostly by runoff.

Reduction of wind erosion

Plantations established as wind breaks can reduce wind erosion that cause soil-productivity losses and lower crop yields. Besides increasing crop yields and pasture production, plantations can provide wind shelter and shade for livestock on farms – and even provide supplementary fodder. There are also reductions of offsite impacts on the health of particulate pollution and less cost in the form of cleaning, maintenance and replacement expenditures.

Salinity management in waterlogged conditions

The replacement of forests with pastures or other vegetation types having lower evapotranspiration rates than the original forests can lead to productivity losses due to soil salinity induced by rising water tables. In such situations, vegetation with high water usage can be planted to intercept water moving through the soil and reduce ground-water recharge. There are different ways to combine this function with engineering strategies for lowering the water table in salt-affected areas. When planted up-slope of salt-prone areas, high-water-use crops contribute to preventing salinity by reducing the amount of water reaching the recharge zones. When planted within salt-prone areas, high-water-use (saline tolerant) crops can lower the water table and also reduce evaporation losses by proving ground cover.

Enhancement of soil carbon content

When multi-year biomass plantations replace annual plants, such as cereals, the working of the land decreases greatly and the supply of organic material to the soil increases. This leads to increases in the soil carbon content (until a new equilibrium is reached after some decades, where the supply and breakdown of organic material balance each other) and improved soil productivity. There is also an enhanced climate benefit since the soil carbon is fixed from the atmosphere. Also the average amount of standing biomass increases. The size of this carbon sink depends on the rotation time, since the time and the growth determine the average volume of the standing biomass. The use of plantations for enhancing soil carbon content is further discussed for the case of wasteland rehabilitation in India in a later section.

Removal of cadmium and other heavy metals from cropland soils

In addition to degradation processes leading to soil productivity losses, an increasing amount of agricultural land is contaminated by anthropogenic pollutants. Cadmium accumulation in arable soils is one specific example of soil degradation, which has received considerable attention due to possible direct environmental effects (risks for soil living organisms and thereby important soil functions, such as nitrogen fixation) and health risks associated with exposure of humans to cadmium through agricultural products (renal dysfunction and possible brittleness of the bones). Plantations of suitable species can be used to remove cadmium and other heavy metals from cropland soils. For example, certain Salix clones are very efficient at accumulating heavy metals – notably cadmium but also, to some degree, zinc – which are then removed from the field with the harvest. The cadmium uptake in Salix can be up to 40 times higher than in cereal crops.

Creation of ecological corridors and improvement of the game potential

In general, integration of specific biomass plantations in the agricultural landscape can contribute to a more varied landscape, increased biodiversity and more animal life. More specifically, plantations can be located in the agricultural landscape so as to provide ecological corridors that provide a route through which plants and animals can move between different spatially separated natural and semi-natural ecosystems. This way they can reduce the barrier

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effect of agricultural lands. For example, a larger component of willow in the cultivated landscape promotes more animal life in the area. This applies to cervids such as elk and roe deer, but also foxes, hares, and wild fowl like pheasants. The function has been exploited in England, for example, where willow is planted to raise the land's hunting value. The positive effect on opportunities for hunting is now also beginning to be noticed in Sweden: an investigation shows that about 40% of the Swedish cultivators would consider growing Salix partly or solely for the wild game's sake.

The case of waste water treatment in willow vegetation filters in Sweden[10]

Willow is a perennial crop with an extensive root system and a long growth season. It transpires much water, which makes it suitable for cultivation in vegetation filters to purify different types of nutrient-bearing water. Irrigation with nutrient-rich water also results in higher biomass harvests and less need to buy fertilizer, which means that the cultivator receives further advantages from growing willow in the form of irrigated vegetation filters. These forms of multifunctional biomass production systems receive increased attention and three such applications are described below.

In about ten facilities in Sweden, willow vegetation filters are today used for the *treatment of municipal wastewater* (Fig. 1). The municipal sewage treatment plants in Sweden have long concentrated on reducing the discharge of phosphorus and of oxygen-depleting substances. This purification, which uses a combination of biological and chemical methods, is effective: on average, both phosphorus and Biological Oxygen Demand (BOD) are reduced by over 90%. In contrast, the reduction of nitrogen discharges has been much lower (ca. 30%), and the willow vegetation filters are established primarily to reduce the nitrogen discharges.

Along with the growing attention to nitrogen discharges, especially in coastal regions, the coast-based treatment plants have been increasingly complemented with (mostly conventional) systems for greater nitrogen removal. Still, a substantial part of Sweden's population is not yet connected to facilities of the latter type, particularly in small and medium-sized communities inland. Compared with conventional nitrogen removal, willow vegetation filters are an economically attractive solution and this application can therefore be expected to become further established. Besides the economic benefit from reduced nitrogen treatment costs, the avoided cost of sewage sludge treatment could be almost equal to the reduced nutrient treatment costs.

A precondition, of course, is the availability of suitable arable land. One hectare of willow can receive sewage from about 30 people, so that a community of, for example, 10,000 requires just over 300 hectares of willow. However, the arable land does not need to lie very near the purification plant, as sewage can be transported for relatively long distances (around 5–10 km) at tolerable cost.

If all wastewater is to be treated in willow plantations, storage ponds are required that hold the winter half-year's volume until the growth season. A cheaper alternative is to treat only sewage that is produced during the summer half-year with the help of willow, and to utilize conventional purification (including phosphorus precipitation) during the winter. The nitrogen removal is then half as great, but so is the land area needed. Hence, this may be a solution if limited arable land is available.

Treatment of nitrogen-rich water in agriculture is another application for willow vegetation filters. Today, agriculture is estimated to be responsible for, on average, 45% of society's total output of nitrogen that reaches the sea through Swedish waterways. In strongly agricultural regions ground leakage from arable land can account for up to 75% of this nitrogen supply. Several measures for decreasing the nitrogen leakage are employed today – such as more efficient spreading of farmyard manure, creation of edge zones, and restoration of wetlands. Another possible measure is to establish willow vegetation filters in especially pollutant-sensitive regions.

If the arable land lacks a covered-drain system, willow can be planted in protective zones along open waterways, where nutrient-loaded surface and ground waters are purified. The efficiency of nitrogen retention depends on water-flow pathways controlling the transport of nutrients through the landscape, and the width of the buffer zone. About 70% of the water's nitrogen content is estimated to be removable in zones 25–50-m wide, provided that the willow plantation is harvested regularly to maintain the nutrient uptake. Thus, a 50-m wide willow buffer strip, where half of the width is harvested at a time, appears to be a design that could provide a continuous high uptake of nutrients.

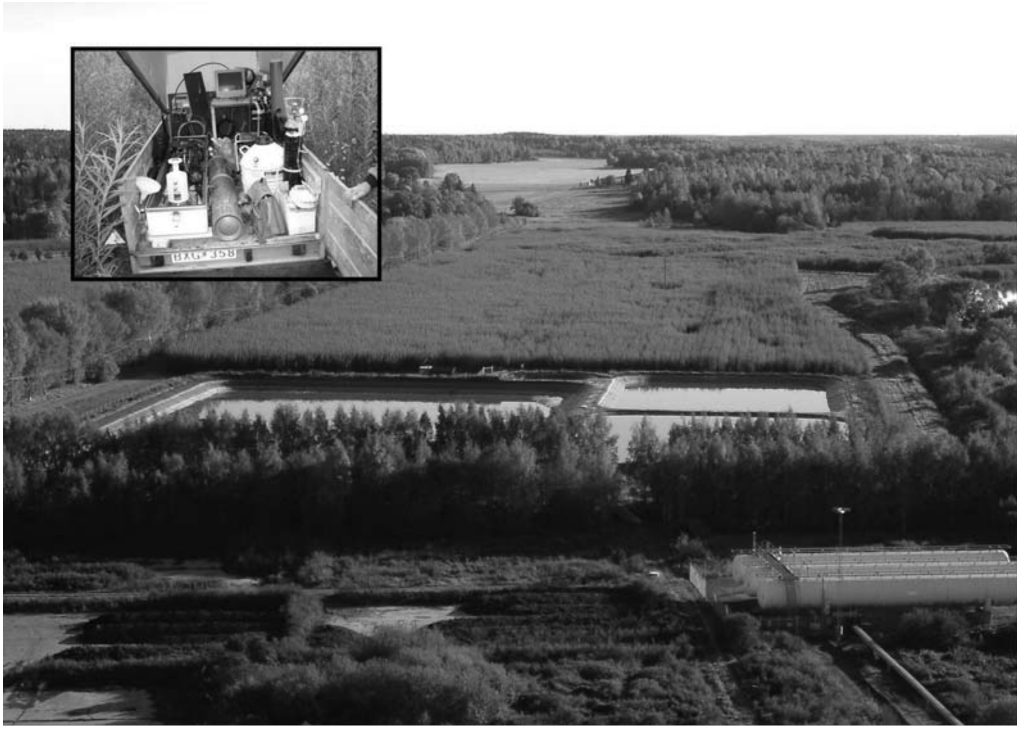

Figure 1. A Salix field irrigated with pretreated municipal sewage in Enköping, Sweden. The inset picture shows measurement equipment used to chart the nitrogen flows in the field. An important question is how much of the nitrogen input is transformed to nitrous oxide, a powerful greenhouse gas. The investigations until now indicate that the climatic impact of these discharges is small in relation to the climatic benefit of the produced biomass in replacing, for example, fossil fuels in municipal heating plants. Also important are the hygienic aspects of sewage-irrigated Salix production. Experiments show that the risk of spreading infection is low, but that unsuitable locations should be avoided, such as nearness to waterways. (Photo: Pär Aronsson, Swedish University of Agricultural Sciences).

If the arable land has a system of covered drains that makes it possible to collect the run-off water in storage ponds to be used for the irrigation, willow vegetation filters can be irrigated with run-off water in the same manner as when treating municipal wastewater. Run-off water has high nitrogen content in proportion to its phosphorus content, but sewage sludge has an opposite proportion and, if added to supplement the irrigation, thus balances the nutrient supply. Sludge fertilization of Salix plantations is an opportunity to increase the *recycling of sludge in agriculture*. The sludge can be spread with conventional techniques for spreading manure during establishment and after harvesting. Experience of using sludge shows that the growth is comparable to plantations using commercial fertilizer, that the leakage of metals and nutrients is negligible, and that the heavy-metal content in the topsoil remains almost unchanged.

The interest in local *treatment of leachate from landfills* has grown in Sweden during recent years and around 25 facilities presently treat landfill leachate in willow vegetation filters. One reason is that the majority of municipal sewage treatment plants are no longer willing to accept leachate for fear that the sewage sludge's quality will be worsened. Another reason is that the collection and purification of leachate are increasingly required. The main environmental problem for older landfills with household waste is usually the nitrogen leakage, since leachate has a low content of, for instance, heavy metals.

Besides the municipal landfills which operate today, older abandoned landfill sites may eventually need to establish systems for leachate management in order to deal with diffuse discharges, and this is an ever-more salient problem. The degradation in deposits can continue for up to a century or so, which means that leachate treatment may be required for a long time. For these types of landfills, willow vegetation filters can be a cost-effective alternative. In addition to capturing nitrogen, willow has a high transpiration rate that contributes to decreasing the amount of leachate.

Leachate from industrial deposits often contains lower levels of nutrients, such as nitrogen, whereas the content of diverse organic and inorganic impurities may be higher. In such cases, willow vegetation filters can complement other treatment methods, and then primarily reduce the amount of leachate. When the polluted water contains heavy metals, such as cadmium and to some extent zinc, willow can be used to capture these metals.

The case of biomass plantation establishment on wasteland in India

Almost 20% of the total land area in India is classified as wasteland and includes grassland, degraded forest land, gullied, ravenous and bedrock-intruded land, land under shifting cultivation, degraded pasture and grazing land, degraded land under plantations and mining and industrial land.[11] Soil degradation processes on wastelands have severely reduced the soil organic carbon levels, primarily due to a combination of low biomass productivity and excessive crop-residue removals. On average, wastelands have an estimated biomass productivity of less than 20% of their overall potential.[12]

Biomass plantation establishment on wasteland can contribute in several ways to the reclamation of wastelands

Figure 2. The large photo illustrates a wasteland area in the state of Karnataka, India with its low vegetative cover and erosion-prone surface. The inset photo shows an attempt at water harvesting using gully check to increase the infiltration of rainwater in the district of Bidar, India.

into productive uses. Plantation projects can facilitate *soil rehabilitation* and enhance the soil carbon content: several experiments with selected trees and intensive management on severely degraded Indian wastelands (such as alkaline, sodic or salt-affected lands) showed increases of soil carbon, nitrogen and available phosphorous after 3 to 13 years.[13–15]

In arid and semi-arid regions, rainfall is limited and subject to high intra- and inter-seasonal variability. In addition, poor vegetative cover and shallow and crusting soils result in much of the rainwater being lost through surface runoff and evaporation. These factors provide a strong drive for strategies that make best use of the rainfall and runoff water. Plantation establishment on wasteland or degraded forest land leads to an *enhanced vegetation cover*: the infiltration of surface water increases and surface run-off (which can be very degrading for agriculture) decreases.

During heavy monsoon periods, the precipitation creates sheetwash on a bare soil and brings loose soil particles to lower elevation (e.g., valleys which very often are used for agriculture) where the fields become covered with unwanted sand. *Water harvesting* through plantations on wasteland can in this situation be planned and used (Fig. 2). Measures for water harvesting, such as gully check, terracing, trenching treatment of soil and selection of appropriate plants and crops can be implemented together with check dams that are constructed as part of water conservation and recharging of underground water aquifers.

Energy for domestic use is dominated by biomass energy and fuelwood is the dominant source of energy in rural India leading to high pressure on the forests (Fig. 3). Increased availability of fuel and wood products from plantations on wasteland can lead to a *reduced pressure on adjacent natural forests*. A study from Orissa[16] showed that with the introduction of village plantations biomass consumption increased (as a consequence of increased availability) but at the same time, the pressure on the

Figure 3. The large photo shows a wiped forest floor – a consequence of biomass need for household fuel. In the inset photo a man is collecting fuelwood in a mature plantation. Both photos are from Orissa, India.

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surrounding natural forests decreased. The effect of the plantation establishment was distant-dependent: in this case, a distance of two kilometers resulted in the highest reduction of the pressure on the natural forests. Plantations that were established too far away or too close to the natural forest did not reduce the pressure.

In addition to reduced pressure on the natural forest from plantation establishment, animal feed and grazing areas can also be shifted. Grazing animals are important capital for rural India and the *supply of fodder* can have a direct impact on the livelihoods. For example, villagers could harvest on average 7.5 t/ha of grass fodder for animal feed just a few years after plantation establishment in an experimental silvipastoral system.[15]

There are several examples of how careful planning and consideration of local conditions may improve the prospects for plantations – although these may not qualify as multifunctional plantations given the definition used in this perspective. For instance, the plantations can provide indirect services in the form of improved livelihoods in social and economical terms. Availability of *income-earning activities* is one such service that plantations can generate. Within afforestation programs in India, plantations in the rural areas have generated employment opportunities; an important poverty alleviation component and thus contribution to one central objective of these programs.[17]

Since rural India is depending on biomass for household energy, a large part of the labor (for the poorest) or money (for the more well-off) is spent on obtaining fuelwood. However, studies have indicated that households with access to village plantations could *reduce labor input for fuelwood collection* by several hours a week.[10] This was particularly obvious for women: well-managed plantations closer to the villages – and also easier to access than forests – clearly facilitated fuelwood collection.

Prospects for a large scale implementation

It is important to get an idea of what extent different multifunctional applications can attain, and also how they can be combined. The majority of environmental services are specific to a particular type of soil, localization in the landscape, or geographical region, and therefore often cannot be obtained simultaneously. It is also crucial to understand in which ways the farmers can benefit from establishing multifunctional biomass plantations, since it is these benefits that are the motivation for the land user. For some applications, the advantages are obvious: wind-break plantations, for example, reduce soil erosion and lead to higher yields of the protected crops. Here, the environmental function may even be the prime function. For other applications, the direct benefits for the farmer may be less obvious and the community may have to pay the farmer so as to create an incentive for providing the environmental service.

Studies in Sweden have assessed the scope for a wide range of multifunctional biomass production systems.[18,19] Besides the possible extent, the economic values of the provided environmental services have also been estimated (based on the substitution-cost method). Estimates for Sweden indicate a possibility to grow willow at a negative net production cost (i.e., the estimated economic value of the environmental services provided is higher than the willow cultivation cost) approaching 100,000 hectares, if diverse potential extra environmental services are fully utilised. For a further 200,000 hectares or more, willow cultivation can be done at a production cost half that of conventional cultivation. This may be compared with the ca. 15,000 hectares of farmland which are used today for growing willow.

Most willow vegetation filters applications appear attractive from an economic point of view; when willow is cultivated as vegetation filters for municipal wastewater treatment the estimated production cost is negative. The cost of treatment of drainage water in willow vegetation filters is sometimes lower and sometimes higher than the cost of wetland restoration. This depends on local conditions and the required size of the intermediate storage ponds, which strongly affect the costs of willow vegetation filters. Willow plantations that are established as buffer strips along open streams can provide biomass at approximately half the cost when the economic value of nitrogen retention is included.

Barriers

Barriers exist that hinder a large-scale implementation of multifunctional biomass production systems. Several factors other than the purely economic ones come into play. Barriers of technical/geographical and institutional kinds that hinder the new establishment of bioenergy plantations in general also hinder the establishment of multifunctional plantations. For example, investigations show that the willingness to cultivate willow in general can be influenced by structural factors such as the farm's geographical location, the farmer's age, the farm's size and the orientation of its production.

There may be barriers specific to certain types of multifunctional plantations, such as difficulties of allocating benefits between involved actors. There may also be a requirement to allocate risks between involved actors. For instance, when farmers establish willow vegetation filters for municipal wastewater treatment, they face the risk of long-term commitments with less flexible land use and may require payment of an additional risk premium. Policy design in the fields of energy, environment and agriculture also influences the prospects for multifunctional plantations (and biomass plantations in general), in many instances in negative ways, not least due to a lack of harmonization of policies in these different fields.

Similarly for the case on India: despite demonstrated environmental and economic benefits, the implementation of plantation projects on wasteland in India has been hampered by social, environmental and economical barriers (lack of funding and a long investment period). Attempts by the Indian Government to stimulate reforestation of these lands (e.g., through social forestry projects and joint forest-management programmes), have not resulted in an adequate afforestation rate, compared to what is required to cover the wastelands within a reasonable timeframe.[20] The low soil productivity is in itself a barrier for a large-scale establishment of these types of plantations, if the only driver is the need to rehabilitate the soil.[20,21] Additional drivers are required, such as the multiple benefits associated with plantations on wastelands described earlier.

Incentives

Coordination and clearer coupling between agricultural, environmental and energy policies could take concrete expression in the form of directed measures for stimulating multifunctional plantations. An example is long-term environmental and cultivation subsidy to farmers for willow cultivation in protective zones and vegetation filters for purification of drainage water. To facilitate the use of biomass that is produced in multifunctional plantations, subsidies may be also needed for other actors in the biofuel chain (such as incineration facilities that accept biomass with high cadmium content). These could take the form of an environmental bonus that benefits entrepreneurs and end-users of the biomass.

The creation of carbon sinks through establishment of plantations on unproductive lands has been suggested (and also heavily debated) as a possibility to mitigate climate change and one of the mechanisms of the Kyoto Protocol, the Clean Development Mechanism (CDM), is considered a possible way to increase the rate of wasteland rehabilitation by adding income from the generated carbon credits.[22] Afforestation and reforestation are both included in the CDM, but up to now (mid-2007) no plantation-based CDM project is registered in India and only one such CDM project has been registered globally. In recent years however, fossil fuel substitution with biomass from plantations on wasteland has gained increased attention. The increasing biomass demand and attempts to facilitate development and management of CDM projects – increasing the possibilities to link revenues to plantations – may improve the prospects for plantation establishment on wastelands in India.

Conclusion

The survey presented here has illustrated many of the opportunities that exist for meeting a growing biomass demand while at the same time promoting environmental protection and sustainable land management. The growing biomass use in the world has, in many places, caused concern about possible negative impacts. However, if guided in a sound direction, the expanding biomass production can, in fact, help address not only climate change concerns but also many other pressing environmental problems of today. One key issue will be to identify suitable mechanisms to put a premium on the environmental services that can be provided. In some cases, actors can be identified that are willing to pay for a specific environmental service. In other situations, information campaigns and innovative government measures that credit the biomass producer may be required. A challenge when implementing such measures lies in the coordination of different policies in the energy, environmental and agricultural fields.

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Paper IV

Barriers to plantation activities in different agro-ecological zones of Southern India

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Abstract

This paper analyses environmental and socio-economic barriers for plantation activities on local and regional level and investigates the potential for carbon finance to stimulate increased rates of forest plantation on wasteland, i.e., degraded lands, in southern India. Building on multidisciplinary field work and results from the model GCOMAP, the aim is to (i) identify and characterise the barriers to plantation activities in four agro-ecological zones in the state of Karnataka and (ii) investigate what would be required to overcome these barriers and enhance the plantation rate and productivity. The results show that a rehabilitation of the wasteland based on plantation activities is not only possible, but also anticipated by the local population and would lead to positive environmental and socio-economic effects at a local level. However, in many cases, the establishment of plantation activities is hindered by a lack of financial resources, low land productivity and water scarcity. Based on the model used and the results from the field work, it can be concluded that certified emission reductions such as carbon credits or other compensatory systems may help to overcome the financial barrier, however the price needs to be significantly increased if these measures are to have any large-scale impact.

Keywords: plantations, agro-ecological zones, carbon finance, CDM

1. Introduction

India contains vast tracts of land which are classified as wasteland; these total approximately 64 Mha (NRSA 2005). Wastelands are degraded land, with the degradation process defined as a decline in soil quality with an attendant reduction in biomass productivity and environment moderating capacity i.e. the ability of soil to perform specific functions of interest to humans (Lal 2004). It is estimated that the average Indian wasteland has a biomass productivity of less than 20% of their overall potential (Ramachandra and Kumar 2003). Despite attempts from the Indian government to reforest the lands through programmes such as the Social Forestry Projects and Joint Forest Management, the current rate of plantation is inadequate considering what is required to cover all wastelands within a reasonable timeframe (Ravindranath and Hall 1995).

According to Balooni (2003) the planting of India's wastelands is not only being considered for environmental reasons, but also for the anticipated benefits to the economy. The implementation of plantation projects on wasteland is hampered by social, environmental and economical constraints. Soil degradation processes on wastelands have severely reduced the soil's organic carbon, which is primarily induced by a combination of low biomass productivity and excessive crop residue removals. At the same time, low soil productivity, together with financial difficulties such as a lack of funding and long investment periods are themselves barriers to the implementation of plantation schemes (Ravindranath and Hall 1995; Balooni and Singh 2003). The causes of land abandonment are a complex mix of social, economic and ecological factors (Cramer et al 2007). Overgrazing and fallowing of land, as a result of inadequate rains, drive the land degradation and increase the wasteland areas in Karnataka as well as elsewhere in India.

Following the ideas of the general forest transition model (e.g Mather 1992), India has increased its forest cover from its all time low. This increase is according to the model a result of less dependence on forest resources driven by a more mature economic development. However, in the rural areas of India the dependence on natural resources in general is great, hence the national expansion of forest cover can compete over land that is in demand for other uses, or it can benefit two purposed. In India's submission to the United Nation Framework Convention on Climate Change regarding ways forward for reducing emission from deforestation and forest degradation (REDD), it is proposing a strong conservational component. Due to the national forest circumstances India has actively promoted the concept of 'Compensated Conservation'. As a mechanism, India has proposed that REDD should compensate for reducing deforestation as well as I) stabilizing forest cover and II) conserving and increasing forest cover (UNFCCC, 2007). With these circumstances in mind, India will need ecological restoration of less favorable lands to meet the need and ambition that the country has.

The introduction of certified emission reductions, or carbon credits under the Clean Development Mechanism (CDM), or other financial systems such as payment for environmental services or voluntary carbon offsets (Rosa et al. 2003; Taiyab 2005; World Bank 2008) create opportunities and may potentially provide incentives to re-vegetate the wastelands. The mitigation potentials of these financial systems, as well as the environmental and socio-economic factors that influence their realisation are not well known due to the short time span since the emergence of the systems. The carbon market has rapidly gained traction, the questions and the answers related to the implementation of projects and marketplaces have become increasingly important to investors, policymakers and environmentalists (Hamilton 2009). The definition and analysis of possibilities and constraints for plantation projects at both local and regional levels will help policy development by identifying areas where the plantation process may need to be altered or simplified. Albeit a simplification, the use of regional baselines (Sudha et al. 2006) may lead to more approved methodologies and additional registered forestry CDM projects.

Efforts in India to put together plantation projects for CDM, particularly by industries but with local farmer involvement have gained results.. The ITC, Bhadrachalam project that is now registered and a small scale project in Haryana involving farmer's lands is yet another forestry project that has been registered for CDM (UNFCCC 2009). There are few other projects at different stages of development wherein either abandoned agricultural lands or village commons and degraded forest lands are being considered for plantation activities under CDM.

To analyse the potential for plantations on wasteland, based on an agro-ecological zone approach for constraints and potentials of environmental characteristics and socio-economic data, is one method of improving the knowledge in this field, as exemplified by Ravindranath et al. (2007) and that will be adopted in this paper. The paper identify and analyse environmental and socio-economic constraints for plantation activities on both local and regional scales, with an emphasis on the plantation process and local sustainable development. The potential for wasteland development within the CDM or other financial systems was evaluated by looking at different land uses and various forestry options in four different agro-ecological zones. The land uses chosen are natural forest, plantation, agricultural land, grassland and degraded forestland.
The questions raised are:

- What are the barriers for forest plantations in four agro-ecological zones in Karnataka?
- What would be required to overcome these barriers and thus enhance the rate of plantation and productivity?
- Could the CDM or other financial systems become an instrument for promoting plantation in Karnataka?

2. Study area

This study was conducted in the state of Karnataka in southwest India. The geographical area of Karnataka is about 19.05 Mha, of which roughly 3.06 Mha (i.e., 16%) is covered with forest. India has a diverse pattern of temperature, rainfall, soil, vegetation type and socio-economic conditions and has adopted the principles of agro-ecological zoning (FAO 1981; FAO 1996). This study uses the FAO agro-ecological zone classification, which is based on the length of growing period concept. This, in turn, is derived from climate, soil and topography data and evaluated using a water balance model and knowledge about crop requirements. The agro-ecological zone (hereafter referred to as the zone) approach has been globally adopted for assessing the growth potential of crops and can also be extended to the growth of forest or plantation biomass. The use of zone classification for this assessment is logical due to the geographical differences that greatly influence the potential of any plantation activity. India has categorised its entire geographic area into 20 zones, four of which will be included in this study (Figure 1): zones 3, 6, 8, and 19 (Table 1).

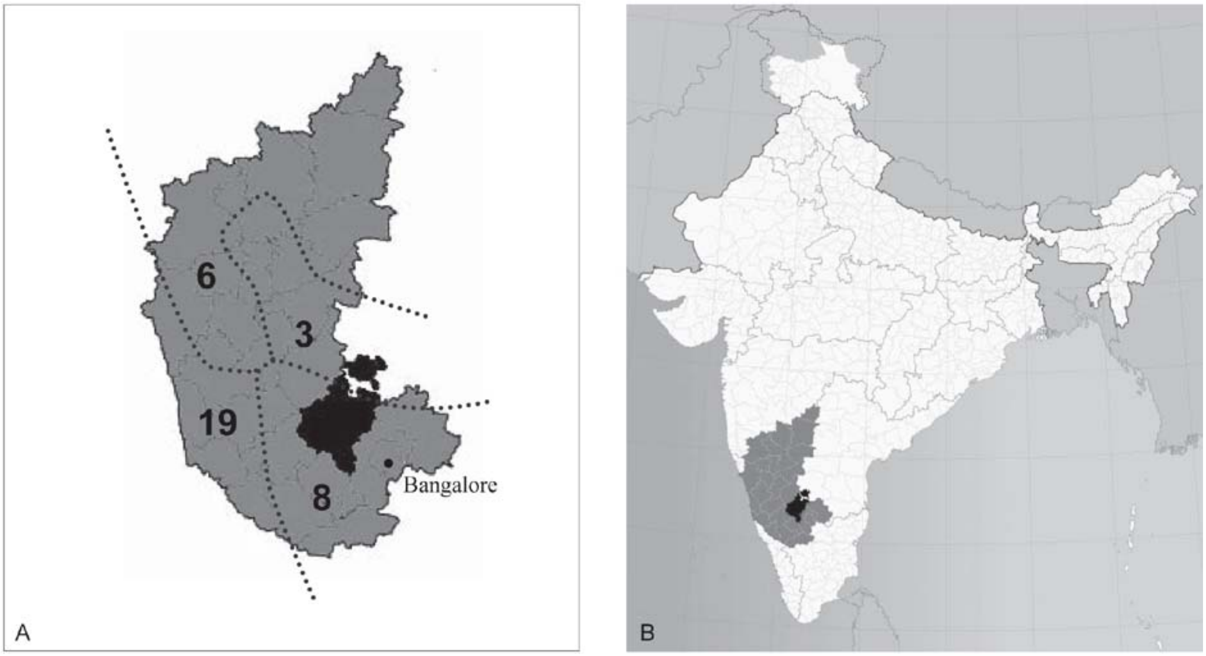

Figure 1. Figure 1 (A) Map of Karnataka state with Tumkur district highlighted. Agro-ecological zones of Karnataka area marked in the map. (B) The map shows India and the location of Karnataka state and Tumkur district.

The state of Karnataka is diversified, not only when it comes to the physical geography but also with respect to its climate characteristics. The four zones differ in both precipitation and available water capacity. The diverse rainfall pattern is not only dependent on the season – the area receives 80% of its rainfall during the southwest monsoon period – there are also geographical differences, with the costal zone (19) receiving more than 1700 mm/year, while zone 3 on the central plateau receives only 1200 mm/year.

Table 1. Climate, soil, length of growing period (LGP) and available water holding capacity (AWC) characteristics of the four agro-ecological zones (AEZ) for the state of Karnataka, India.

Characteristics	AEZ 3	AEZ 6	AEZ 8	AEZ 19
Climate	Hot arid	Hot dry semi-arid and hot dry sub humid	Hot moist semi-arid	Hot perhumid*
Soils (FAO)	Vertisols and Lexisol	Vertisols	Lexisol	Nitosols
LGP (days)	60-90	90-120 150-180	120-150	240-270
AWC	Low to medium	Medium to high	Low	Low

* Moisture index over 100, i.e., available water exceeds the potential levels of evapotranspiration (Thornthwaite 1948).

3. Approach and methodology

3.1 Collection and processing of land-use data

District wasteland data for the years 1994 and 2001 were collected from the National Remote Sensing Agency (NRSA 1998; NRSA 2005) to obtain the total extent of wasteland in Karnataka. The collected data was later compared with historical data to analyse the current wasteland development. The plantation rate was estimated based on the annual area planted under different species as reported by Karnataka Forest Department annual reports (KFD 2003). The carbon uptake rates of above ground biomass and increases in soil organic carbon were compiled from a survey of the available literature for the given zones as well as for different plantation management systems, in this case long and short rotation plantations (Ravindranath et al. 2000; Ravindranath et al. 2006). Biomass growth rates and soil carbon uptake rates for different zones and different plantation management options (short rotation, 7 years and long rotation, 40 years) were compiled from the literature (Prasad et al. 1987; Ravindranath et al. 1992; Ravindranath et al. 2000).

3.2 Assessment of wasteland quality

3.2.1 Interviews

The semi-informal interviews with key informants were conducted to assess the socio-economic factors affecting the usage of the wastelands (Mikkelsen 1998). One key informant from each village was participating in the study, eight in total. The key informant was either the chairman of the village forest committee or a person in a leading position in the village. The aim of the interviews was also to assess the availability of land for plantation purposes from a local perspective, to receive information regarding the usage of the existing forest from the people directly influenced by a plantation project and finally, to estimate the potential for the villagers to play an active role in such a project. The interviews consisted of a set on fixed question and possibilities to informal conversation. Amongst all the interviews provided information about how the villages viewed the plantation projects and their willingness to be involved in further development projects. Potential areas for plantation projects were also selected. The land quality in selected areas varied from rather good to bad within the wasteland categories. A total of 17 wasteland areas[1] were assessed, together with nine plantations[2] and two areas consisting of natural forest land and agricultural land. The plantations were further sub-divided into old and new plantations

3.2.2. Soil

Soil samples were collected and United States Department for Agriculture (USDA) vegetation and erosion assessments (USDA 1993) were conducted during field work to determine the environmental features of the wasteland. The soil samples were collected from a total of 56 plots, identified by the key informants measuring 50x50 m, with up to four plots in each land-use. A total of five different land-use systems were investigated, giving 336 individual soil samples altogether. Three pits, 30 cm in depth, were dug to collect 200 g samples at two depths in each pit, one at 0-15 cm and one at 15-30 cm, giving six samples from each plot. The samples were aggregated to composite samples, one for each depth and each land-use, resulting in 48 samples. They were analysed for carbon content using

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[1] Grassland (some partly cultivated), degraded natural forest and degraded plantations.

[2] Cashew, Eucalyptus, Mango, Indian Gooseberry.

the Walkely-Black method, nitrogen (N) using the Kjeldahl method, phosphorous (P) using the Olsen method, cation exchange capacity[3] and particle size (Landon 1991). The particle size distributions were measured and expressed in the form of the sand:silt:clay ratio (Table 2 defined according to the USDA soil texture classes (USDA 2002), The soil texture can be used to determine the relationship between land use and the available water capacity (AWC) (NMSU 1996).

Table 2. Following data were collected at zone level.

Area data	**Biomass and soil carbon data**	**Cost for carbon stock monitoring**
Annual land area planted (short rotation and long rotation) Total available land Land area available for mitigation activities.	Standing vegetation and mean annual increment of biomass Wood density and rotation period Initial soil carbon stock and soil carbon accumulation rate Litter as % of mean annual increment Decomposition period % mean annual increment as timber Harvest categories and % timber Wood waste Fuel wood and harvest residue.	Yearly monitoring cost per ha: US$1*.

* The cost of 1 US$ per ha for yearly monitoring reflect the actual operational cost as experienced in the field in Indian conditions (Ravindranath et al 2007).

3.2.3. The USDA vegetation and erosion assessment

The USDA vegetation and erosion assessment is a visual interpretation and assessment, conducted to gain knowledge about the quality of the land including existing vegetation, erosion and physical characteristics such as soil cover and measures to preserve the soil. The assessment was categorised into six classes, 0, 0-24, 25-49, 50-74, 75-99 and 100% where the parameters evaluated was: erosion, ground vegetation, shrub vegetation, crown cover and soil cover (USDA 1993). The plots were mapped, i.e. measured, systematically drawn on a scale of 1:500 and photographed. The different classes were used to compare different land-use systems in terms of the percentage of erosion, ground vegetation, shrub vegetation, crown cover and soil cover.

3.3 Assessment of financial incentives using GCOMAP

To estimate the future investment necessary for plantation implementation and the effect of those investments on the plantation rate, the Generalized Comprehensive Mitigation Assessment Process (GCOMAP) model was used (Sathaye 2005). Sathaye (2005) describe the model as a dynamic partial equilibrium model built to simulate the response of the forestry sector to changes in future carbon prices. The general equilibrium models mostly rely on a few global data sets. A major goal of GCOMAP is to make use of detailed country-specific activity, demand, and cost data available to the authors on mitigation options and land use change by region. The model establishes a baseline scenario which has no financial revenues from carbon (US$0 per tC) and represents the current plantation rate in different zones upon which the future development is based. Using this as a starting

[3] Cation exchange capacity (CEC) can be used as a measure of the fertility of the soil. A high CEC is considered favourable as it contributes to the capacity of the soil to retain plant nutrient cations (Landon 1991).

point, areas under plantation for carbon mitigation, the overall mitigation activity and the potential for the period 2005-2100 was assessed. GCOMAP simulates the response of uses of forest and wasteland to changes in the carbon price at different plantation rates and estimates the amount of additional land brought under the mitigation activity above the baseline level.

Three additional carbon price cases (US$5, 50 and 100 per tC) were considered in this assessment. The carbon price used in the baseline scenario represents a present-day approximate carbon price from voluntary projects, where voluntary forest credits range from 6.3 – 7.7 US$/t CO_2 equivalents, including projects of afforestation/reforestation plantations, afforestation/reforestation conservation, forest management and avoided deforestation (Hamilton et al. 2009). The other two price scenarios are higher and more in line with the European Union emission trading level which have varied between 10-15 US$ for 2009 (ECX 2009). The carbon monitoring cost was set to US$1/ha/year and applied to all the carbon pricing scenarios except for the baseline, where no carbon monitoring was required.

4. Result

4.1. Land-use pattern in the agro-ecological zones

Approximately 1.4 Mha of the total area in the state of Karnataka has been identified as land which is potentially available for plantation projects, representing 7.1% of the total wasteland (NRSA 2005). This area was included in the model as potential land for plantation projects, with distribution among the four zones based on their percentage of the total area (Table 3).

Table 3 The development of different wasteland areas during the period 1998 to 2001 in different agro-ecological zones (AEZ). The areas are presented in hectares.

Characteristics	Year	Grassland	Degraded forestland	Other*	Total
AEZ 3	1998	66 228	137 048	1 431	**204 707**
	2001	66 907	135 731	8 717	**211 355**
% change		1	- 1	609	**3**
AEZ 6	1998	276 077	238 739	9 743	**524 559**
	2001	180 010	139 431	21 707	**341 148**
% change		- 35	- 42	223	**- 35**
AEZ 8	1998	424 302	315 914	43 366	**783 582**
	2001	180 330	219 911	21 285	**421 526**
% change		- 58	- 30	- 51	**- 46**
AEZ 19	1998	142 161	138 240	3 615	**284 016**
	2001	55 616	104 858	6 416	**166 590**
% change		- 61	- 24	177	**- 41**

*Other land-uses include gullied and ravinous land, shifting cultivation, degraded pasture and grazing land, degraded land under plantation and mining or industrial land. These lands together make up less than 10% of the total area and are therefore not described in more detail (NRSA 2005)

Based on Karnataka Forest Department annual reports it is estimated that 1.6 Mha of land was planted in the state of Karnataka up to 2004. Of this, approximately 12% of the plantations fell under long rotation management, while 88% was planted under short rotation management. The same proportion of available potential land was allocated to different options in different zones under the assumption that this trend will continue.

Compiled literature data from across Karnataka suggests that plantations established on wasteland have considerably lower biomass growth rates than natural forests or plantations on private land. For instance, in zone 8, the biomass productivity in plantations on wasteland varied from 1.4 to 1.7 t/ha/yr with a mean of 1.55 t/ha/yr, while they were considerably higher in plantations on farm land i.e., in agro-forestry, where the productivity varied from 4 -11.1 t/ha/yr with a mean of 7.55 t/ha/yr. The natural forest in zone 19 had a mean productivity of 4.85 t/ha/yr according to our references (Prasad et al. (1987), Ravindranath et al. (1992) and Ravindranath et al. (2000)).

4.2 Wasteland quality

4.2.1. Environmental and socioeconomic barriers and incentives

During the interviews, the eight key informants identified several barriers to, and merits for the establishment of plantation activities on their land. The issues discussed were not ranked, however pointed out several times. The villagers identified lack of water and soil quality concerns, meaning that the plantations would use too much of the already scarce water resources in the villages as well as extract nutrients from the soil needed for other crops. However, the erosion rate would decreases after the establishment of a plantation, the infiltration capacity increases and the plantations contribute to better local climates which are clear incentives for a potential implementation of a plantation project. The villagers point out that plantation projects on privately-owned plantations on wasteland are welcomed by the villagers whilst the experience shows that plantations introduced by the government are occupying too vast an area of the village. The results also indicate that the plantations already established in the villages do not have the same soil quality as the natural forest.

When the key informants were asked for their opinion and experience regarding plantations projects and their possible involvement in such a project their response was more or less similar regardless of the geographical location. Many of the villages have had negative experiences of governmental plantations, where neither the revenues nor the harvest have benefited the locals. However, previous plantation activities have increased the rate of employment in the villages. Even though the villagers do not manage these plantations themselves the accessibility of forest products increases with the establishment of plantation activities. The villagers state that they are interested in, and have the capacity to invest their time and devote land to an eventual plantation project, as they see a plantation on the wasteland as an investment for future needs. The villagers would prefer a mixed plantation with natural species and would like to receive an income, as well as pulp and fruit yield from a potential plantation on the wasteland. Such a project would ideally be locally rooted and managed by the villagers. However, financial resources are scarce in the villages and the funding needed for the establishment plantation projects are not locally available.

4.2.2. Soil

The results of the soil analysis (Table 4) show the differences in soil organic carbon, nitrogen, phosphorous and cation exchange capacity and clay content between the different land-use systems. All the investigated parameters have lower values in wastelands than in the natural forests. The plantations have a higher soil organic carbon value, cation exchange capacity and clay content than the wastelands.

Table 4. The results from the soil analysis divided into different land-use systems in different agro-ecological zones (AEZ) in Karnataka. The wasteland category includes grassland and degraded forestland.

Parameter / Land-use	Organic C%	Nitrogen %	Phosphorus ppm	CEC	Particle size % sand	silt	clay	Soil texture*	AWC mm/m
AEZ mean									
Natural forest	1.1	0.27	38	9.2	37	30	32	CL	188
Wasteland	0.37	0.13	28	8.4	61	15	24	SCL	154
Plantation	0.42	0.12	24	9,5	62	12	25	SCL	154
- *Old***	*0,49*	*0,14*	*20*	*9,6*	*48*	*20*	*32*	SC	171
- *New***	*0,37*	*0,10*	*26*	*9,4*	*57*	*15*	*28*	SCL	154
AEZ 3									
Wasteland	0.45	0.11	23	13.2	47	29	24	L	169
Plantation	0.17	0.08	14	7.9	68	13	19	SL	118
AEZ 6									
Wasteland	0.39	0.14	27	8.9	63	11	26	SCL	154
Plantation	0.44	0.11	25	10.0	50	16	33	SC	171
AEZ 8									
Wasteland	0.25	0.07	35	5.5	75	9	16	SL	118
Plantation	0.51	0.15	25	9.4	53	21	26	SCL	154
AEZ 19									
Natural Forest	1.1	0.27	38	9.2	37	30	32	CL	188
Wasteland	0.55	0.19	32	9.1	51	17	33	SC	171
									154

* CL: Clay Loam, SC: Sandy Clay, L: Loam, SCL: Sandy Clay Loam, SL: Sandy Loam

CEC,: AWC: AWC source (NMSU 1996)

** Old plantation implies plantations older than 10 years and new plantation implies plantations younger than 10 years

The carbon content, cation exchange capacity and clay content are higher in the plantations than in the wastelands of zones 6 and 8. In contrast, all parameters in zone 3 are lower in the plantations in comparison to those in the wasteland. The results show that the old plantations have higher values for all parameters than the newly established plantations, with the exception of phosphorus. The old plantations also exceed the values of wasteland for all parameters except phosphorous. When the newly-established plantations are compared to wasteland, only the cation exchange capacity and the clay content are higher in the plantations. This illustrates the poor quality of the land where plantations are established.

Given the sand:silt:clay ratio the wasteland and plantations are classified as sandy clay loam and the natural forest as clay loam. The soil texture can be used to determine the relationship between land use and the available water capacity for the different sampled areas in this study. The soil texture analysis shows that the wasteland and plantation categories have an average available water capacity of 154 mm/m soil (Table 3), while the natural forest category has an average available water capacity of 188 mm/m soil.

4.2.3. USDA

The USDA analysis divides the wasteland category into grassland and degraded forest land and compares the result with those for plantations and agricultural land (Table 4). It also gives an assessment of the environmental barriers and potential for plantation activities. The grasslands and the degraded forests show a high degree of erosion and have less soil cover than other land-use systems. The degraded forests hold some tree cover, but not enough to be defined as a forest under the rules and regulations of the CDM. The grassland has a small amount tree or shrub cover. This makes the grassland ideal for plantation establishment, since no vegetation needs to be cleared prior to the plantation. The impact of erosion on the land is low or non-existent where some kind of land management has taken place, such as plantation or agriculture. The USDA analysis shows that the wastelands with largest areas of erosion are located in zones 6 and 19, which have a total of 10% erosion in each zone (Figure 2).

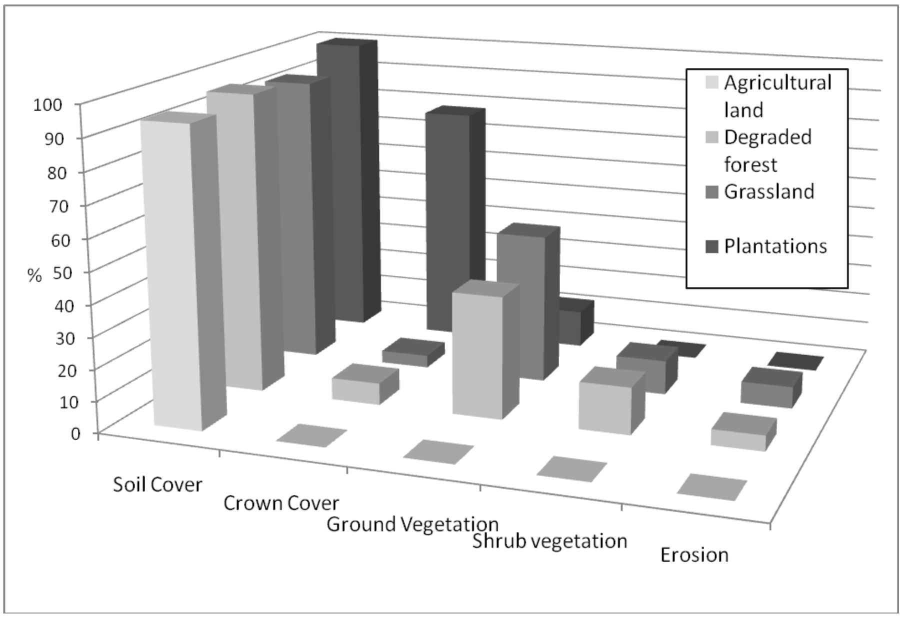

Figure 2. Results from the USDA vegetation and erosion assessment. The results of the USDA analyses are expressed in percentage. The overview was categorised into six ground cover classes, 0, 0-24, 25-49, 50-74, 75-99 and 100% (USDA 1993). These were converted into means (0, 12, 37, 62, 87, 100) which were later used to calculate the percentage of each characteristic.

4.2.4. Climate

The climate data, mean temperature and total precipitation, compiled from the National Centers for Environmental Prediction Reanalysis data base (NCEP 2006), show an increasing trend in the mean air temperature, about 0.5 – 1°C over a period of approximately 60 years, from 1946 – 2005 (Figure 3). The change is largest in the two districts with the lowest mean annual temperature: zone 8 on the inland plateau and zone 19, the coastal area. The two zones with the highest mean annual temperature have experienced a smaller increase over these years. The precipitation pattern over the same period shows a decreasing trend in all four zones, most noticeably in zone 19 with a decrease of 500 mm and around 160 -170 mm over this period in the other zones. Zones 6 and 8, however, showed increased precipitation in a later part of the period. This data does not indicate minimum and maximum values, i.e., the variability which may have a direct bearing on vegetation.

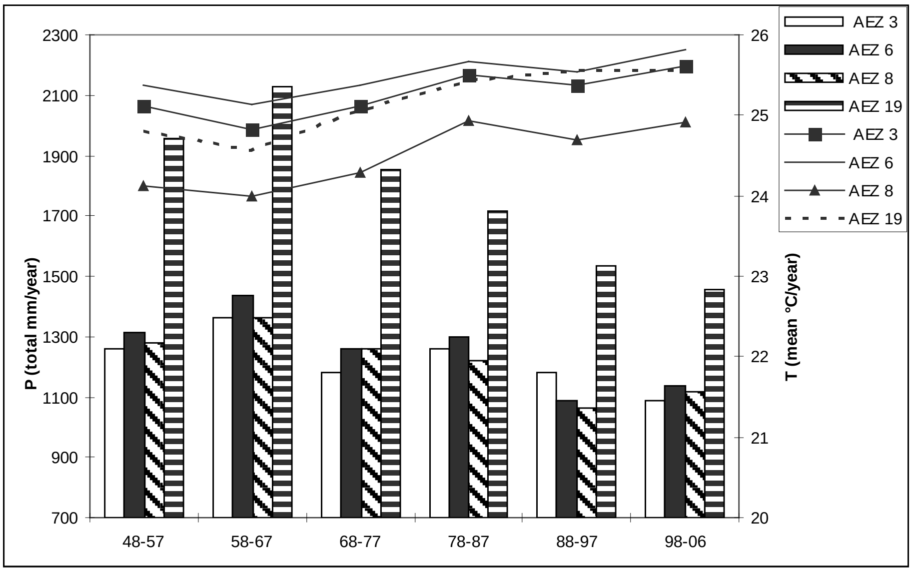

Figure 3. Total precipitation and mean temperature in agro-ecological zones 3, 6, 8 and 19 in Karnataka in 10-year periods between 1948 and 2006 (except between 1998 and 2006, which is only nine years). Source data NCEP 2006.

4.3 Assessment of carbon price incentives

Figure 4 shows the rate of plantation activities with different carbon price scenario model runs according to the GCOMAP model. An increase in the carbon price from 0 in the baseline to 5, 50 or US$100 per t/C sequestered would, as expected, increase the plantation rate. For all the zones, the rate of plantation activities would be higher for a short rotation management period than for a long rotation management period, regardless of the carbon price. The increase is larger in zones 6 and 8 than in zones 3 and 19 for the entire period. The difference in the planted area between zones 6 and 8 is more than twice the planted area in zone 3. For the short rotation option in zone 8, a maximum planted area of 0.3 Mha is reached by the year 2100 (carbon price level US$100/tC). The results show that with US$100/tC all the wasteland will be under plantation prior to the year 2100.

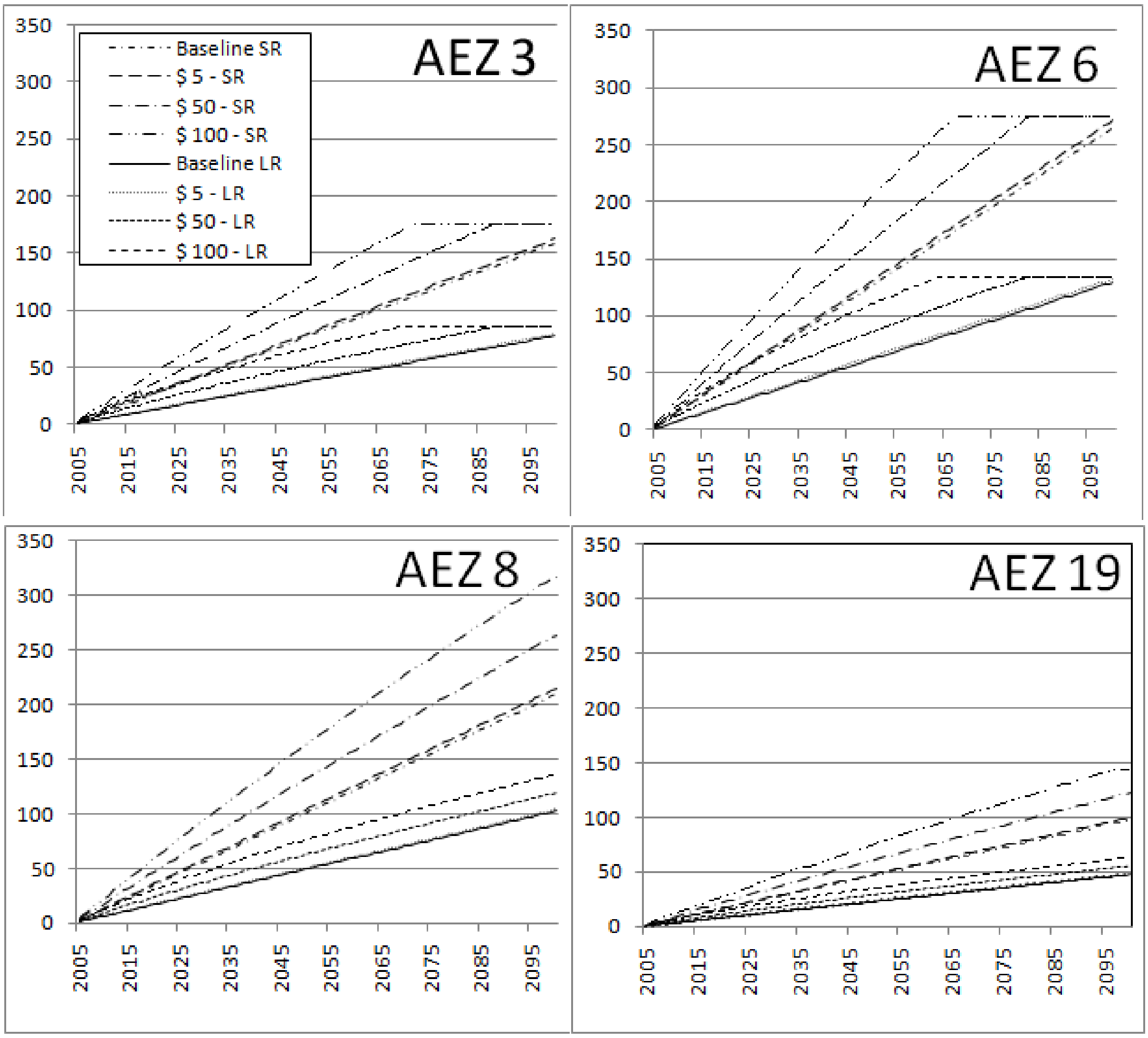

Figure 4

The amount of land area brought under plantation activities under short rotation and long rotation in agro-ecological zones 3, 6, 8 and 19 under different carbon price scenarios with GCOMAP modeling. SR - short rotation and LR - long rotation.

Increases in the carbon price from 0 to US$5/tC would only create marginal increases in land area planted. The largest increase in land under plantation activities by the year 2100 was obtained at this price for the short rotation option in zone 6, where the increase from the baseline scenario is 6740 ha. The smallest increase (2500 ha) was obtained for the short rotation option in zone 19.

4.4 Illustrative recommendation for a possible CDM strategy

The illustrative results of this study make it is possible to give recommendations for a potential CDM strategy (or other financial systems) in the state of Karnataka. The current carbon price situation seems to be insufficient as an incentive for the establishment of plantation projects. Higher prices or additional incentives are required. The zone approach can be useful in feasibility studies and evaluations of plantation activities. The four zones considered in this study show several similarities when it comes to both climate and socio-economical factors. The interviews show that plantation activities are welcome and needed in all four zones. A future increased temperature, lack of financial resources and limited water availability are the main barriers to the establishment of plantation projects. The wasteland availability, USDA, GCOMAP, soil quality and available water capacity local socio-economy and finally local barriers analyses reveal were incorporated in a comparative table to resent recommendations regarding future plantation projects.. Depending on the requirements for a plantation project, different zones will be more or less suitable. For example, the results from the USDA analysis show that zone 6 is most affected by erosion in comparison to zone 8, where erosion is a minor problem. The results from the analysis regarding, USDA, GCOMAP, soil quality, AWC, for plantation

Plantation activities can either aim at wasteland rehabilitation, preferably targeting areas in zone 6, or aim at maximising productivity, which would mean targeting areas in zone 8. When the available water capacity is taken into account, zone 19 appears to be the most favourable and zone 8 the least favourable. An evaluation of soil quality, including the carbon content, cation exchange capacity and clay content would point to zones 6 and 8 both having a significant potential for improvement. According to the GCOMAP results, zones 6 and 8 seem most favourable since an increased carbon price would result in the highest increase in the plantation rate. A synthesis of the results of the different analyses point to zone 6 as the preferable zone for plantation activities, followed by zones 8 (Table 5) and 19, with zone 3 being the least suitable.

Table 5. A comparison of wasteland potential, in different agro-ecological zones (AEZ), for plantation activities based on field work cases.

AEZ	Climate trend	Wasteland Availability (in ha)	USDA (% land erosion)*	GCOMAP	Soil quality	AWC mm/m	Local socio-economy	Local barriers for A/R establishment
3	Precipitation: decrease Temperature: increase	211355	3	Least favourable	Low potential	167	Available land: Y Interest: Y	Partly financial and lack of water**
6	Precipitation: decrease (an increase the last 20 yrs) Temperature: increase	341148	10	Most favourable	Most suitable	154	Available private: Y Interest: Y	Financial and lack of water
8	Precipitation: decrease (an increase the last 20 yrs) Temperature: increase	421526	2	Most favourable	Most Suitable	118	Available land: N*** Interest: Y	Financial and lack of water
19	Precipitation: decrease Temperature: increase	166590	10	Least favourable	Good quality of land	171	Available land: Y Interest: Y	Financial

* To obtain the actual characteristics of the five land types included, the mean of each USDA class was divided by the number of plots investigated in each land type.

** The interview response to local barriers was not unanimous in zone 3.

*** Only if there are financial means and the rate of return is higher from the A/R activities than from the present land-use.

Y = yes N = no

The analyses carried out in this study confirm the degraded state of wastelands, with low productivity and hence low incentive for usage. Overcoming the environmental barriers will require large investments. In addition to the financial barrier at the local level, water shortages and low land productivity are also important factors which limit plantation activities.

5. Discussion

According to the NRSA (NRSA 2005), the availability of wastelands in this area is substantial; however poor land quality and low water availability are one of the greatest environmental barriers to plantation projects in the area, as indicated by the results. Plantation projects can facilitate soil rehabilitation and enhance the soil carbon content show several experiments with well selected trees and intensive management on severely degraded Indian wastelands (Sing 1990, Mishra et al. 2003, Pal and Sharma 2001). When the plantations in this thesis are being compared to the wasteland there is a clear indication that soil quality improves with time arguing for long term plantation projects. This indicates that plantations on wastelands would indeed increase the productivity of the lands and improve the general environmental status. However, even a slight increase in vegetation cover from the baseline can be beneficial for restoration the wasteland in terms of erosion control and an increasing of the organic matter. The modeling conducted in this study is based on eucalyptus and acacia plantations which are very often not the preferred alternatives of the local communities. Depending on the local need, a mixed plantation or agro-forestry is the preferred options, even if exotic species such as acacia may be highly valued for certain purposes. The plantations analyzed in this study are a mixture of fruit species and fast-growing species.

Water is currently scarce in Karnataka, particularly in the eastern parts. The climate in the recent past shows an increase in temperature and a decrease in rainfall. If the increasing trend in temperature and the partly decreasing trend in precipitation continue in the future, the implications are a drier and warmer climate in the entire state. The lack of water is already a problem when establishing new plantations. In a country such as India, which is dependent on season-regulated monsoons, there is an even higher pressure on land management schemes aimed at an increasing infiltration and decreasing surface run-off. If an increase in the productivity of the wasteland is to be achieved then improved land management is necessary, with water conservation as the main goal. All possible practices, such as increasing soil organic matter, clay content and cation exchange capacity are necessary for a sustainable water resource management. One option to increase the infiltration rate and reduce runoff is to increase the vegetation cover or implement soil management practices such as ditching and countering of gully formation. However, to increase the productivity on wastelands further, initial supplement of nutrients and organic matter may be necessary (Ravindranath and Hall 1995; Olsson and Ardö 2002).

One of the major socio-economic barriers to current and future plantation activities is the lack of financial resources. The same barriers can be shown from projects worldwide (Zhou et al. 2007). Lack of funding is one major constraint. The investments required for wasteland rehabilitation may be too large for small scale farmers. Joshi (1997) shows that many farmers consider a rotation period of 7-10 years too long in relation to their revenue needs and are therefore unwilling to invest. The modalities of the forestry CDM where the carbon credits can be issued for temporary credits may be one way of getting around this problem. Involving a larger group of farmers may be another way forward, where the risk could be spread and common resources shared during the years where no revenue was obtained from the plantations.

The GCOMAP analysis shows that forestry CDM or other compensatory systems could be one way of overcoming some of the financial constraints illustrated in the results. Thus, a higher carbon price incentive is necessary to bring larger areas under plantation in the near future. Other options for financing plantation activities could be found in voluntary carbon projects with carbon credits presented to the voluntary market (World Bank 2008; Taiyab 2005; Hamilton 2009) or payment for environmental services (PES). The concept of PES is based on compensation to land holders for the protection or production of environmental services. These services could include an option to ensure climate change mitigation at the lowest cost, an option to ensure environmental services of local or regional interest such as the regulation or filtration of water flows and a possibility to strengthen rural livelihoods and revalue rural landscapes, their diversity of practices and ecosystems (Rosa et al. 2003).

It should be observed that the GCOMAP model only returns general/regional results; it cannot be reduced to a local/district scale without carefully examining the potential at the local level. As seen in the interviews, some of the key informants highlight several environmental barriers for plantation implementation. Local conditions must always be taken seriously since they are determining the failure or success of plantation implementations. Generally, it can be concluded that the villagers are not satisfied with the outcome of the government-introduced plantations, which only led to a small amount of employment and poor revenues. At the same time, several key informants describe multiple co-benefits that would follow the establishment of new plantations under a private regime. Perez et al. (2007) conclude that the introduction of a financial system for carbon trading should never be forced on local communities by regional, national or global institutions. The importance of local farmers' participation in plantation management and species selection is illustrated in a paper by Blay et al. (2008). By consulting the participants, the local people's needs were identified. This minimized the differences in interest and encouraged greater participation.

Since the reforestation of wasteland generates benefits for the public good from local to global level, it could be argued that some of the costs should be covered by national means or international aid (FAO 2006). To some extent, this is already happening in India, with its large reforestation program. A market mechanism was selected in this study as a complement to the national efforts. Using a market mechanism as an incentive to establish plantations on wasteland requires strong and well-developed institutions to ensure a flow of financial benefits to the locals involved. The well-established Joint Forest Management programme has developed institutions that empower and enable local communities to participate effectively in forest management to some extent. These institutions could be adjusted to suit a financial flow based on a market mechanism (Ravindranath et al. 2003). Prevoiusly, institutions such as the JFM have failed on certain occasions due to the fact that the returns from these plantations were very low and communities in some cases lost access to grass and fuelwood when plantations were introduced and its closure during the initial years. However with a carbon incentive, communities have a stake in the maintenance of these plantations and therefore the local institutions would take active interest in maintaining sinks. Given that the wastelands in question support very low biomass for use as fuelwood or fodder, raising of plantations that would provide incentives will motivate the local communities to maintain the sinks created, provided they are made aware of the benefits of maintaining sinks.

The wastelands in this study are in most cases unsuitable for agricultural purposes and would instead be better suited to plantation purposes; however, this does not mean that this is still the only option for land-less farmers to generate an income. To obtain a comprehensive picture of the different alternatives, several analyses need to be carried out, for example a cost-benefit analysis, a land suitability investigation and an eligibility analysis for different financial options. The rising concerns over land-use competition, food vs. fuel or mitigation, should not be taken lightly (Tenenbaum 2008, Runge and Senauer, 2008, Naylor et al., 2007, Pingali et al. 2008). However, while Runge and Seanuer (2008), and Naylor et al. (2007) both recognize that the right policies could curb this risk. The land competition issue will play a major role in determining the availability of land for plantations in the future (Ravindranath et al. 2009).

6. Conclusion

The results of this study led to the following conclusions:

- Water is currently scarce in Karnataka. The climate in the recent past shows an increase in temperature and a decrease in rainfall, which implies that less water will be available in the future. If an increase in the productivity of the wasteland is to be achieved then improved land management is necessary, with water conservation as the main goal.

- The major socio-economic constraint for establishing plantation activities on wasteland is the lack of financial resources, despite a wealth of interest and experience. In many cases, high investment costs and long rotation periods obstruct the establishment of financially beneficial plantation activities.

- Financial opportunities such as the CDM or other compensatory systems could possibly help to overcome financial constraints. At a carbon price of US$5/tC, the area planted would be marginal; hence the price has to increase to bring about an improvement on present plantation rate.

- The parameters addressed in this assessment is not exhausted, i.e. do not cover every aspect of relevance, which is primarily due to the complexity of the situation regarding land use in this environment, including both environmental hardship, climate variability, poverty aspects and development parameters. However, the method highlights several components of each of these parameters but acknowledge that other input data can be used.

- Area-specific results such as the ones presented here can be used as guidance in feasibility studies for plantation projects.

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Paper V

Land suitability analysis and land-use options on wasteland in Tumkur district, India

Working paper

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Abstract

This working paper describes the potential multifunctional biomass production systems on wastelands. These systems can, through well-chosen design, management and system integration – offer multiple benefits such as meeting energy demands, supplying timber, sequestering carbon, biodiversity conservation and environmental benefits such as decreased pressure on natural forest systems. Building on GIS modeling and a literature review, the aim of this working paper is to assess the potential of land rehabilitation through different land-use options in Tumkur district, India. More specifically the aim is to (i) describe land-use options for wasteland development with potential to produce environmental and socio-economic co-benefits (ii); assess the suitability of the wasteland to host the different land-use options.

The land-use options chosen for this paper are; (i) long rotational plantations for carbon sequestration (Teak) (ii) short rotational plantations for either carbon sequestration, production of biomass for energy or the production of ethanol from woody biomass (Eucalyptus and Acacia) (iii) biofuel plantations of Jatropha and Pongamia and finally iv) biofuel cereal crop (Sweet sorghum). The result describes under which circumstances the well suited multifunctional production systems can take place on wastelands in India. Best suited for plantation in Tumkur according to the land suitability analysis, is Jatropha, which has the potential to cover nearly 70% of the wasteland. Least favorable is Sweet sorghum which is only fit to cover 15% of the wasteland. Barriers for successful implementation are also described. The study presents in both qualitative and quantitative information regarding the relationship between biomass production and environmental services together with an incentive to develop degraded lands further.

Key words: biomass; bioenergy; multifunctional plantations; soil; wasteland; water resources; carbon sequestration; rural development

Introduction

India, with its large and still growing population, need to maintain the delicate balance between the interrelated factors of food, water and energy security in a way that is sustainable for the future. Water demand for industries, human needs and environmental services are increasing at the same time as an increase in food production claims higher energy use in terms of irrigation and fertilizer. While the fertile agricultural land is limited and the demand for a sustainable energy production is increasing the expansion into the degraded lands, the wasteland, with sustainable water conservation strategies open a range of possibilities. 64 Mha, almost 20% of the total land area in India is classified as wasteland (NRSA 2005). Soil degradation processes on wastelands have severely reduced the soil organic carbon, primarily due to a combination of low biomass productivity and excessive crop residue removals which have left wasteland lying almost barren for decades. On average, wastelands have an estimated biomass productivity of less than 20% of their overall potential (Ramachandra and Kumar 2003). For environmental and socio-economical reasons the land needs to be rehabilitated through different land management options.

Biofuel is going to play an extremely important role in meeting India's energy needs by supplying clean, environmentally-friendly fuel (Gonsalves 2006). The country's energy demand is expected to grow at an annual rate of 4.8% over the next couple of decades. Most of the energy requirements are currently satisfied by fossil fuels – coal, petroleum-based products and natural gas. Domestic production of crude oil can only fulfill 25-30% of national consumption (Gonsalves 2006). The concept of substituting bio-diesel produced from plantations on eroded soils for conventional diesel fuel has gained widespread attention in India. In recent years, the Indian central Government as well as some State Governments has expressed their support for bringing marginal lands, which cannot be used for food production, under cultivation for this purpose Kishwan et al. 2009). In 2003, the Indian Government announced the National Mission on Biofuel which anticipated that 4 Mha of wasteland across the country would be transformed into bioenergy crops such as Jatropha (*Jatropha curcas L*) and Sweet sorghum (*Sorghum bicolor*) plantations by 2008-09. However, in 2008 the program was aborted (The Economic Times 2008) due to a fear of large land-grabbing by big energy companies. Even though the mission was supposed to target wasteland the Finance Minister P Chidambaram has raised the issue of how biofuel production increasingly uses farm land leading to a shortfall in grain production.

India is the largest producer of fuel wood with 306 million cubic meters (Mm^3) produced in 2005.This can be compared to the global industrial round wood production of about 1.7 billion m^3 in 2005 (FAO 2008). India is also one of the few developing countries that have made a net addition to its forest cover and tree cover over the last two decades which mean that Indian forest serve as a major sink of

CO_2. This is partly due to the forest conservation act where the conversion of forest land for non-forest land is banned (Ravindranath et al. 2009) and large scale reforestation programs. From 1995-2005 the carbon stored in India forest and trees have increased from 6 245 Mt to 6 662 Mt, with an annual increment of 38 Mt of carbon or 132 CO_2eqvivalents (eq) (Kishwan et al. 2009).

Land-use is partly limited by environmental factors such as soil characteristics, climate, topography, and vegetation. Land-use activities have direct impact on environmental resources, while these resources greatly influence the choice of land-use activities. An increased understanding of the interaction between land-use/land cover and environmental resources is needed. In an area with scarce water resources such as Tumkur, the relationship between land-use options and implications on water is very important.

The aim of this working paper is to conduct a land suitability analysis of different multifunctional land-use options for wasteland rehabilitation in Tumkur district, India. Primary goals were land rehabilitation and the production of environmental services such as the production of bioenergy, carbon sequestration and decreased soil erosion.

Wasteland rehabilitation

An increase in tree cover will have positive environmental effects on a degraded land area; an increase of soil organic matter will enhance the fertility of the soil, and, with the exception of monocultures, there will also be an increased biodiversity (IPCC 2000), the increase in tree cover will also decrease the erosion rate and decrease the loss of fertile clay minerals. Forest cover would also protect the land from further degradation (Sathaye et al. 2007, Ravindranath and Sathaye 2002, IPCC 2000). Unmanaged wastelands in India are vulnerable and suffer from the high intensity rain during the monsoon season and usually suffer from topsoil erosion. Due to low soil organic matter status and loss of silt and clay, the water (moisture) holding capacity is low (Palm et al. 2009). Measures to reduce soil erosion rates and enhance moisture retention are important in areas that are dependent on monsoon precipitation and where irrigation opportunities are limited due to low water availability, undulating topography, and high costs (Ravindranath and Hall 1995). An increase in the vegetation cover or implement soil management practices would increase the infiltration rate and reduce runoff and thereby protect the land from further degradation (IPCC 2000, Ravindranath and Sathaye 2002, Sathaye et al. 2007). Well managed crops can regulate water flows and reduce the risks of floods and droughts, particularly so for perennial crops with non-annual harvesting schemes (Gehua et al. 2006). The climate trends in the Tumkur area imply a decrease in precipitation and a temperature increase which only will result in a more problematic water situation (Palm et al. 2009).

According to the National Remote Sensing Agency (NRSA 2005), the availability of wastelands in Tumkur district is 997 km^2 or 9.4% of total area, consisting mainly of land with shrub and underutilized/degraded notified forest land. Compared to natural forest land or already established plantations the quality of the wasteland is in many cases lower than its potential, which is one environmental argument for increasing the rate of plantation. A previous study (Palm et al. 2009) show that plantations over time (in this case 10 years) have a favorable impact on the soil quality on wasteland in the state, including parameters such as organic carbon, nitrogen, cation exchange capacity, clay content and available water holding capacity (AWC). The same study also point out that the region where Tumkur is located is favorable for plantation establishments due to the large availability of land, low impact of erosion on the wasteland, a soil quality suitable for plantation establishment and large interest in developing the wasteland amongst the local people.

The rising concerns over land-use competition, food vs. fuel or sinks, should not be taken lightly. This issue will play a major role in the availability of land for plantations in the future. As long as bioenergy production only uses crop residue, excess agricultural production or surplus land and water, there will be little impact on food production (Smith et al. 2007). The wastelands in this study are in most cases unsuitable for agricultural purposes and would instead be better suited for plantation purposes; however, this does not mean that these options are the only option for land-less farmers to generate an income.

Implementing plantation projects for an increased vegetation cover to rehabilitate wasteland in south Karnataka are facing financial barriers. The environmental services provided by such a plantation project could generate financial revenues and function as an incentive for such a project. The most established a financial mechanism available for environmental services in developing countries is the Clean Development Mechanism (CDM) (UNFCCC 1998). This is one of the flexible mechanisms under the Kyoto Protocol aiming for carbon sequestration or emission reduction and sustainable development. This mechanism includes both bioenergy and sinks projects where bioenergy is responsible for the larger part. Other mechanisms are the voluntary carbon market, which includes similar sectors and Payment for Environmental Services (PES) where stakeholders paying for the protection or production of environmental services (Wunder 2008). These services could include a range of options to ensure environmental services of local or regional interest such as the regulation or filtration of water flows and a possibility to strengthen rural livelihoods and revalue rural landscapes, their diversity of practices and ecosystems (Rosa et al. 2003).

Sinks vs. bioenergy

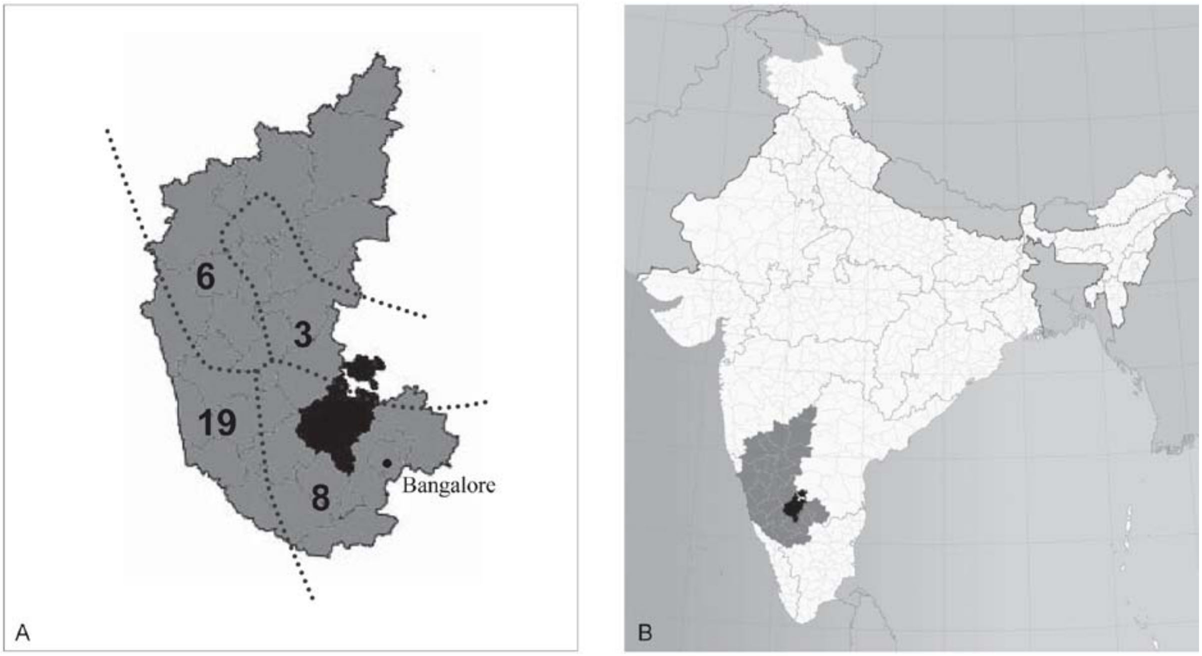
Climate and soil protection, social development, equity and finally secure and economically viable energy supply are three concepts that can be extracted from the United Nations Framework Convention on Climate Change (UNFCCC 1992) document prepared in Rio 1992.

Keeping these concepts in mind, a re-vegetation of eroded soils and wasteland are necessary actions in line with policy implementation. Actions to re-vegetate wasteland could either aim for the production of bioenergy, where vegetable matter are utilized for energy (Overend 2007) or for carbon sequestration where standing biomass function as a sink. The production of bioenergy and sinks can often offer synergies, Matthews and Robertson (2005) amongst others, suggests rotation schemes where constant carbon stocks function as a sink while the harvest is being utilized for bioenergy. The introduction of plantation schemes on degraded land will likely accumulate carbon both above and below ground while ensure the feedstock for bioenergy purposes. Marland and Schlamadinger (1997) showed that the carbon balance between restoring forests and producing biofuel is site-specific and depends on biomass productivity, the efficiency with which harvested material is used, the initial state of the surface vegetation, and the fossil fuel to be displaced. Technology such as liquid biofuels represents low efficiency conversion of harvest to energy, but direct combustion or gasification is more efficient at displacing carbon from fossil fuels. Righelato and Spracklen (2007) show that forestation of an equivalent area over 30 years would sequester two to nine times as much compared with the cumulative avoided emission per hectare from bioenergy. However, for a stringent global carbon target, it would be cost effective to use the land for short-rotational forest compared to short-rotational forest, given that the land are well suited for the purpose (Hedenus and Azar 2009)

Study area

The study was conducted in the state of Karnataka in southwest of India. The geographical area of Karnataka is about 19.05 Mha, of which roughly 3.06 Mha (i.e., 16%) is covered with forest. In the dryer districts, the wastelands of Karnataka comprise the following: 0.47 Mha of land with or without shrub (referred to in this paper as grassland), 0.06 Mha of degraded forestland and 0.06 Mha of other wasteland categories.

Figure 1. Map of (A) Karnataka state with the district of Tumkur and (B) India.

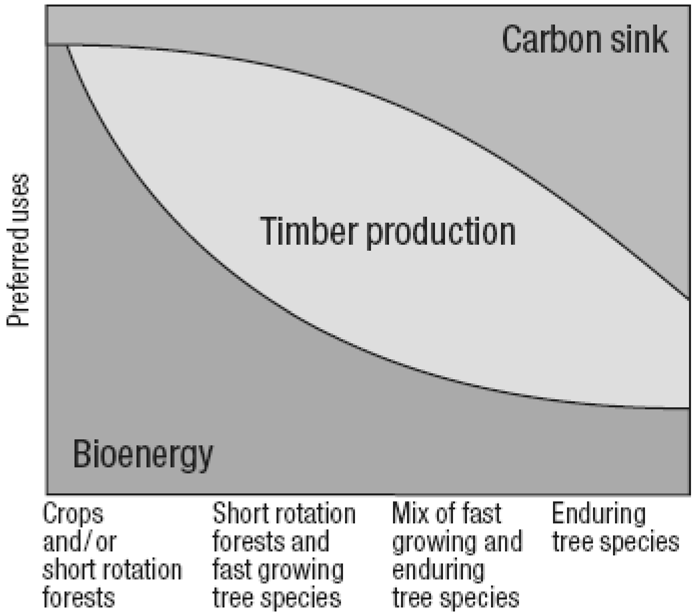


This study focuses on Tumkur district, located in the south east of Karnataka. Tumkur is situated on the Central Karnataka Plateau with semi-arid conditions, and an average rainfall of 688 mm/year (CST 2006). The Tumkur district border the Bangalore district, a city of geographical and population expansion, and is subject to an increased pressure on the land. The climate conditions in the district are challenging for the people and with projected decreases in precipitation and increase in temperature (Palm et al. 2009), the conditions will worsen. These factors motivate an assessment of the best utilization of wasteland.

Options for wasteland development

The options chosen for this study are developed based on field assessment and recent trends in the official governmental bioenergy mission. The assessment of the most appropriate land-use option for re-vegetation of the wasteland is dependent on the objectives for the plantations as well as of environmental, economic and social factors (Figure 2) (Mathews and Robertson 2005). If the aim is to maximize the energy outcome, crops and/or short rotation forest would be the given choice. On the other hand, if carbon sequestration in sinks is the main goal long term plantations or natural regeneration would be feasible options.

Figure 2. The land-use options can be chosen to generate bioenergy, timber production and carbon sinks. Adopted from Matthews and Robertson 2005.



The management choices for this study focus on both bioenergy production as well as carbon sequestration. All the options will take place on wasteland which requires resilient species with some kind of wasteland rehabilitation quality. Considering the local opinion have proven crucial the future success of a plantation project (Palm et al. 2008). According to farmers in Karnataka, plantations with mixed species are preferred or plantations generating employment and increase their livelihood (Palm et al. 2009).

Long rotation plantation

Long rotational perennial crops with the focus of carbon sequestration are one option for rehabilitation wastelands, with the aim to replant the land after harvest. The plantations could either be established as monocultures with valued species or as an integrated agroforestry system with trees planted along the fields or roads. Monocultures would generate more biomass per hectare whilst an integrated system might have socio-economic or environmental co-benefits that may add the possibility, to generate extra revenues from different schemes of payment for environmental services (Berndes et al .2008, Palm et al. 2009). The options for carbon revenues for such plantations would likely be either afforestation and reforestation (A/R) CDM or voluntary carbon credits.

Short rotation option

Even short rotation plantations can be managed to sequester carbon on wasteland. The carbon would be captured both in the biomass and in the soils. The plantation can be introduced under different management options where it can be harvested under different rotation schemes. The different options can, just as the long rotation plantations, generate revenues from additional sources such as carbon credits or payment for environmental services.

Short rotation options can include bioenergy production systems from fast growing species that are already present in the district today, mainly eucalyptus, but could be developed further with more locals involved (Swaminath 2007). The biomass can after harvest be used to produce heat (such as hot water or steam) through combustion or to produce electricity or both in a combined heat and power facility. Forest residue, fuelwood and wood waste can be converted into convenient solid, liquid or gaseous fuels to provide energy for industrial, commercial or domestic use. Different management schemes could be applied with agroforestry and produce several co-benefits for a project; however monocultures are a more common management strategy of today (Gowda 2003).

Cellulosic biomass such as wood, tall grasses, forestry and crop residue is expected to expand the quantities and types of biomass feedstock available for second-generation biofuel production in a near future (FAO 2008, WWI 2007). Using fast growing perennial energy crops with a short rotation have the possibility to cover wastelands where the remaining root system will help preventing erosion and increase carbon storage in the soil. Energy crops can often be grown on soils of poor quality, however a high biomass yield will more likely to occur on land of better quality. The technology for commercially competitive conversion of cellulose to liquid biofuel is expected to be available within ten to fifteen years (WWI 2007).

Energy agriculture

Liquid biofuels are used in many countries and regions such as Brazil, EU and The US to replace fossil fuel in the transportation sector (Mathews and Roberts 2005) and with high oil prices the interest of alternative fuels increases. Ethanol or biodiesel produced from Jatropha, Pongamia and sweet sorghum are considered “first generation” biofuel which are derived from food-crops and include sugar- and starch based bioethanol and oilseed based biodiesel (FAO 2008).

Other options

All the options for wasteland rehabilitation presented in this study can be combined with agroforestry where annual crops are combined with perennial crops. Agroforestry systems can store significant carbon in long-lived biomass, the amount depending on species type and cultivar, density, growth rates, and harvesting and pruning practices (IPCC 2006). Agroforestry systems can either be considered a cropland or a forest land depending on the countries definition of forest and have proven to generate multiple benefits and increase the sustainable development for the local communities (Smith et al. 2007). Co-production of energy and non-energy crops as agroforestry has the benefit of providing farmers with revenue between harvests of energy crops, since they typically require several years of growth before the first harvest. Using agroforestry helps to meet other environmental and socio-economic criteria for land-use (IEA 2009).

Methods and approaches

Land suitability analysis

Based on previous studies (Palm et al. 2009), the main constraints for wasteland rehabilitation in Karnataka are lack of financial means and water availability. Different options for rehabilitation of the wasteland will have different environmental demands, and are therefore better or worse suited for the wasteland. This can be demonstrated in a land suitability analysis. The species chosen for the land-use options were based on personal communication and literature and presented in Table 1. Assessed in a boleean GIS analysis, the suitability of the wasteland is based on environmental limitations for each of the land-use suggested, i.e., the thresholds. The thresholds are in turn based on physical requirements of the different land-use options and gathered from literature. The different layers will include these parameters:

- Soil depth,
- slope,
- temperature,
- precipitation and
- available water holding capacity (AWC) and
- soil quality.

Suggested species

Tabel 1. Land-use options and species suggested for the land suitability analysis.

Land-use options		Suggested species	Common name
Long rotation	Carbon sequestration	*Tectona grandis*	Teak
Short rotation	Carbon sequestration	*Eucalyptus tereticornis* *Acacia auriculiformis*	Eucalyptus Acacia
	Biomass for energy	*Eucalyptus tereticornis*	Eucalyptus
	Ethanol from woody biomass	*Eucalyptus tereticornis*	Eucalyptus
Energy agriculture	Biodiesel (oilseed crop)	*Jatropha curcas L* *Pongamia pinnata*	Jatropha Pongamia
	Ethanol (sugar crop)	*Sorghum bicolor*	Sweet sorghum

Teak *(Tectona grandis*) is a large, deciduous tree reaching over 30 meters in height in favorable conditions (ICRAF 2009). It grows natural in India and is valued for is superior physical and mechanical properties making teak excellent for timber production. Teak can be intercropped with a variety of crops where soy beans are common. In Tumkur district teak is highly valuable tree species and would function as one possible option for long term plantations.

In this study, **Eucalyptus** (*Ecualyptus tereticornis*) plantations are one option for all the short rotation alternatives. Eucalyptus is a fast growing species, that coppice vigorously, which is well suited both for the production of bioenergy from woody biomass and for ethanol production (Keffera et al. 2009, Sudha et al 2003). Originating from Australia and Papua Guinea, Eucalyptus is widely used in plantation projects and there are several historic records of Eucalyptus plantations within the district. It's the most important usage in India is pulp and paper, timber and fuel (ICRAF 2009).

The other option for short rotational species is **Acacia** (*Acacia auriculiformis*), a tree native in India with open canopy that grows up to 30 meters. The tree is traditionally used for fuel, timber; the leaves are used for fodder, and Acacia is also used for paper pulp and for tanning (ICRAF 2009).

Jatropha (*Jatropha curcas L)* is a small tree that grows to be between 3-5 meters in height; under good conditions it can grow up to 10 meters in height. The tree produces oil rich seeds that contain 30-40% of their mass in oil (Sarin et al. 2007). Jatropha oil can be turned into a viable bio-diesel that can be used in conventional diesel engines (Achten et al. 2008).

Pongamia (*Pongamia pinnata*) is a native perennial deciduous tree that grows to about 15-25 meters in height. Pongamia is currently used for green leaf much or in manure and grows seeds with a high non-edible oil which can be processed for biodiesel. Pongamia is truly a multifunctional purpose tree where it, in arid regions such as Tumkur, is valued for the leaves used for fodder at the same time the flowers are being considered a good source for pollen for honeybees. The wood is used for timber, fuel and paper pulp (ICRAF 2009).

Sweet sorghum (*Sorghum bicolor*) grows well in drier and warmer climates and is drought tolerant and therefore represents one potential land-use option for the wasteland (WWI 2007). Sweet sorghum is a well functioning ethanol alternative to sugarcane, which is a more common crop for ethanol production in India, however limited by water constraints in Tumkur. Sweet sorghum accumulate high levels of sugar in the stalk of the plant which can be utilized for ethanol production using a methodology similar to the one used for sugarcane (Roony et al. 2007).

Thresholds

The thresholds have been collected from the literature and through personal communication (ICRAF 2009, Guiying et al. 2009, Gowda 2009, Prasanna 2009, Param 2009) and are presented in Table 2.

Soil depth: The species suggested in this study vary from deep rooted to shallow rooted. The data layer regarding the soil depth has the following layer data: 0, 15, 30, 60 and 120 cm. Species described as shallow rooted were given >15 cm as thresholds while the species described as deep rooted were given threshold >30 cm. (Murthy 2009)

Slope: Perennial trees and energy crops have the advantage over agricultural crops since they can be grown on sloped lands where traditional crops should be avoided due to erosion concerns (WWI 2007). Sweet sorghum is, although perennial, harvested every year and only with careful management can the soil be protected from erosion. Morgan (1995) suggests that crops cultivation on lands risks increased erosion when trees, bushes and grasses are removed. Reducing the cultivation to lands with a slope on no more than 0-3° will prevent and increased erosion and increase soil conservation. (Lobo et al. 2005) show that when sweet sorghum is planted on slopes already around 8° erosion risk index was very high. Since the rehabilitation of the wasteland is central in this study, the slope threshold for sweet sorghum were set to a maximum of 3°, as recommended by Morgan (1995).

Temperature: The average temperature in the district ranges from 20°C to 28°C while the maximum recorded temperature is 39°C and the minimum is 11°C. This means that the threshold for all the species suggested range within these numbers. The same is true for the precipitation in the district which ranges between 560-850 mm/y which mean that precipitation was not a limiting factor.

The description of **soil quality** data set include drainage, soil depth and AWC (see Appendix 1). The drainage ranges from poorly drained to excessively drained. All species chosen for this study prefers well drained soils and were therefore given the same thresholds ranging from moderately well drained, well drained to somewhat excessively well drained soils (Scott 2000).

Table 2. Thresholds used for GIS analysis of the suggested species in the land suitability analysis. The soil suitability was derived from ICRAF (2009). Precipitation and temperature are not limiting factors for any of the species suggested in this study

Species		Soil depth	Slope	Soil quality*
Teak	Requirements	Deep rooted	Perennial tree	Deep and well drained soils
	Thresholds	>30 cm	<35°	Very deep -moderately deep Moderately well - somewhat excessively drained
Eucalyptus	Requirements	Deep rooted	Perennial tree	Deep and well drained soils
	Thresholds	>30 cm	<35°	Very deep -moderately deep Moderately well - somewhat excessively drained
Acacia	Requirements	Accept shallow soils	Perennial tree	Shallow and well drained soils
	Thresholds	>15 cm	<35°	Very deep -moderately deep Moderately well - somewhat excessively drained
Jatropha	Requirements	Accept shallow soils	Perennial tree	Shallow rooted and well-drained soils
	Thresholds	>15 cm	<35°	>Very shallow
Pongamia	Requirements	Deep rooted	Perennial tree	Deep and well drained soils
	Thresholds	>30 cm	<35°	Very deep -moderately deep Moderately well - somewhat excessively drained
Sweet sorghum	Requirements	Deep rooted	Perennial crop	Deep and well drained soils
	Thresholds	>15 cm	<3°	Very deep -moderately deep Moderately well - somewhat excessively drained

GIS analysis

The GIS analysis is based on datasets derived from Karnataka Remote Sensing Agency (Sudha et al. 2006) and has been evaluated in ArcMap 9.2. The evaluations used the data sets to identify relevant vector layers and attributes to continue classify the land-use layers and the parameters;

soil type, soil depth, total water holding capacity, slope and precipitation. A raster layer of temperature was developed. The classification resulted in one map showing the total amount of wasteland available for plantations and one map each for each parameter. A column for the boleean analysis was created in each attribute tables and the information in the tables was classified boleean according to the threshold values. The boleean vector layers were transformed into seven raster layers which were later combined using a geoprocessing-model. From the combined layers the area was calculated and transformed from meters into hectare.

Results

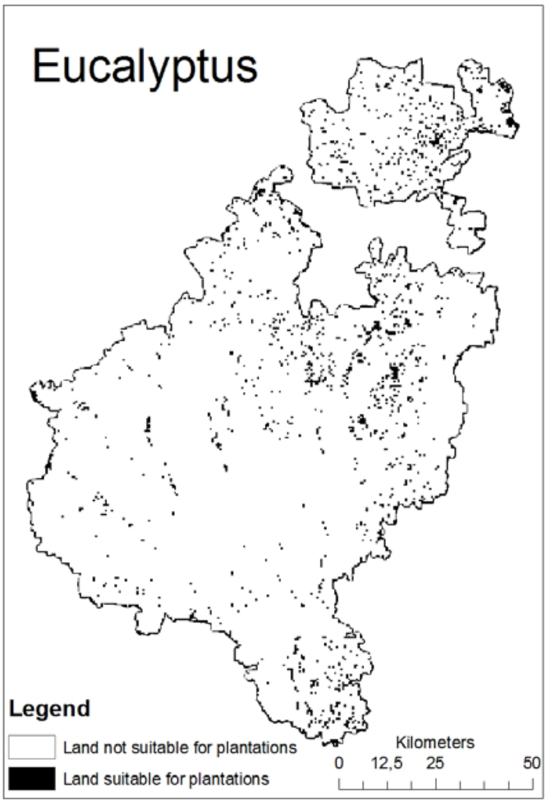
Land suitability analysis

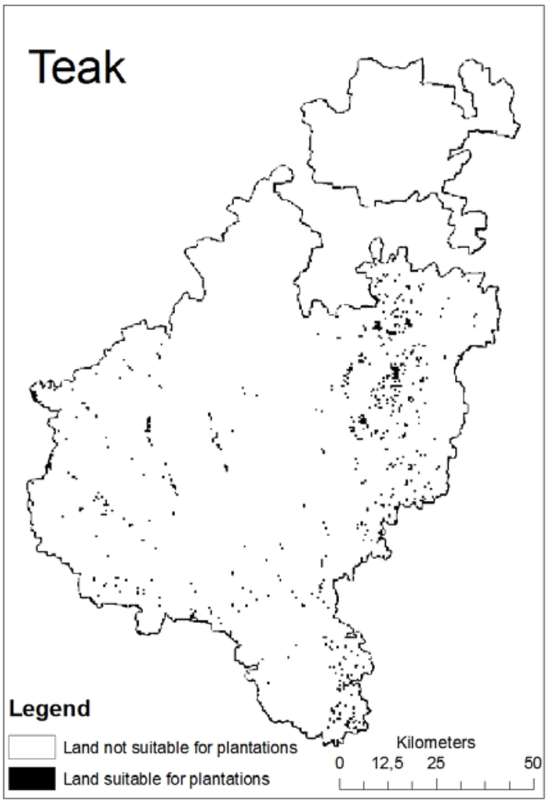
The GIS analysis reports a total district area of 1, 06 Mha out of which the wasteland available for plantation cover 73 300 ha. The land suitability analysis show that the land-use that could potentially cover the largest area is Jatropha plantations, covering 51 500 ha, due to its hardy nature and shallow root system. Acacia, Eucalyptus and Pongamia could cover substantial areas, while Teak only cover about 19 000 ha due to the both the water requirements and the deep root system. Sweet sorghum could cover the least area, only app. 11 000 ha. Sweet sorghum is though a perennial crop more sensitive to gradient compared to the tree species which limits its suitability.

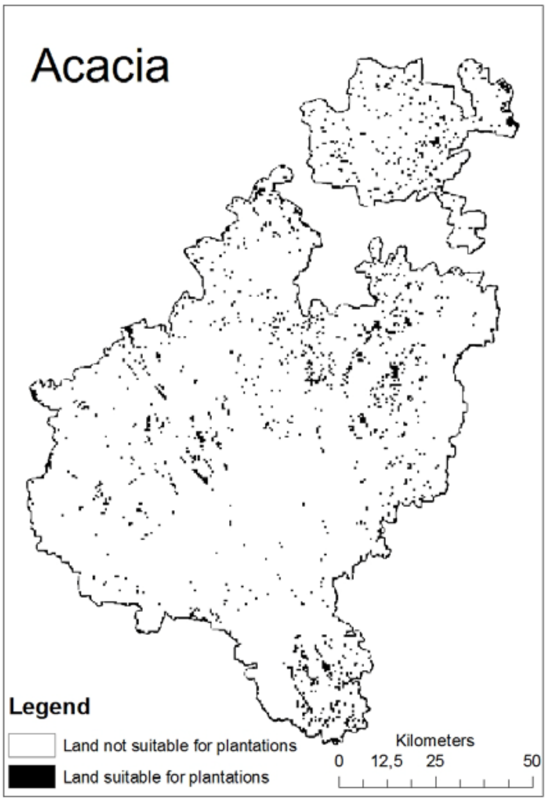
The land suitability analysis based on the GIS analysis resulted in six layers each representing one land-use suggested for wasteland rehabilitation. The layer results show the distribution of the potential land-use which also corresponds to the table 3 where areas are presented. The seventh layer shows the total amount of wasteland as a comparison (Figure 3). From the data layers it becomes clear that jatropha covers the largest wasteland area while sweet sorghum is only responsible for one fifth of the same area. Figure 4 exemplifies the number of species, suggested for wasteland rehabilitation, that are environmentally acceptable in each pixel. Zero represents either all the land that is not classified as wasteland or the land classified as wasteland but not fulfilling any of the (criteria) thresholds limits for any of the land-use options. Darker pixels symbolize the number of potential species environmentally acceptable in each area. The wasteland areas suitable for planting one or more species are 52 600 Ha which can be compared to the total amount of wasteland of 73 300. The area available for planting four or five species is dominating with slightly less than 20 000 Ha each. The area suitable for one and six species potentially only can cover approximately 4000 Ha each while the area where only one species out of six can be suitable for plantation are just over 700 Ha.

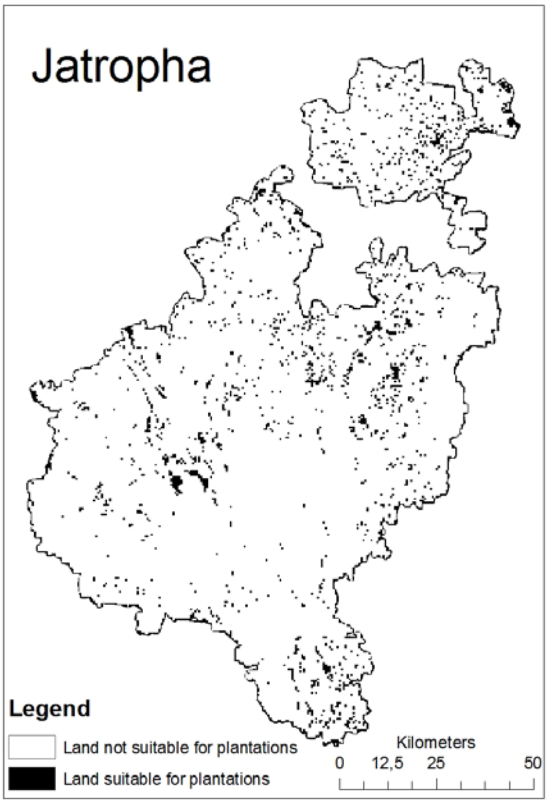
Available land	Available wasteland (ha)	% of total wasteland
Teak	18 900	25.8
Eucalyptus	42 500	58.0
Acacia	45 700	62.3
Jatropha	51 500	70.3
Pongamia	42 500	58.0
Sweet Sorghum	10 900	14.9

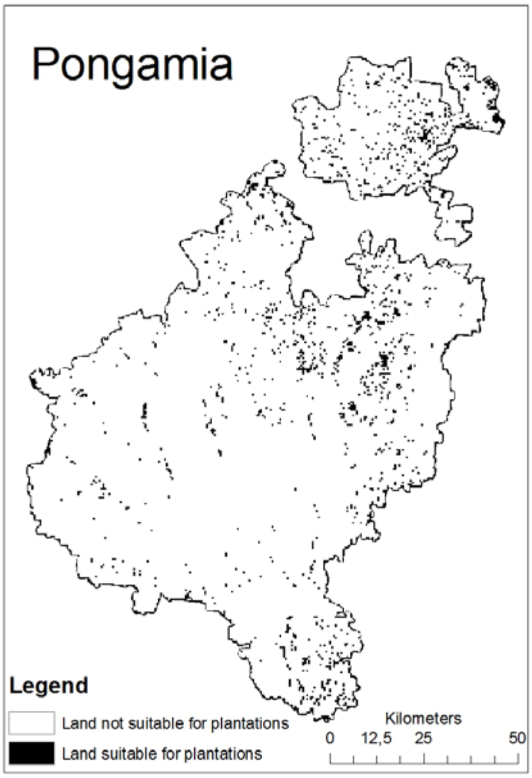
Table 3. The amount available wasteland.


Eucalyptus
Legend
Land not suitable for plantations
Land suitable for plantations
Kilometers
0 12,5 25 50


Teak
Legend
Land not suitable for plantations
Land suitable for plantations
Kilometers
0 12,5 25 50


Acacia
Legend
Land not suitable for plantations
Land suitable for plantations
Kilometers
0 12,5 25 50


Jatropha
Legend
Land not suitable for plantations
Land suitable for plantations
Kilometers
0 12,5 25 50



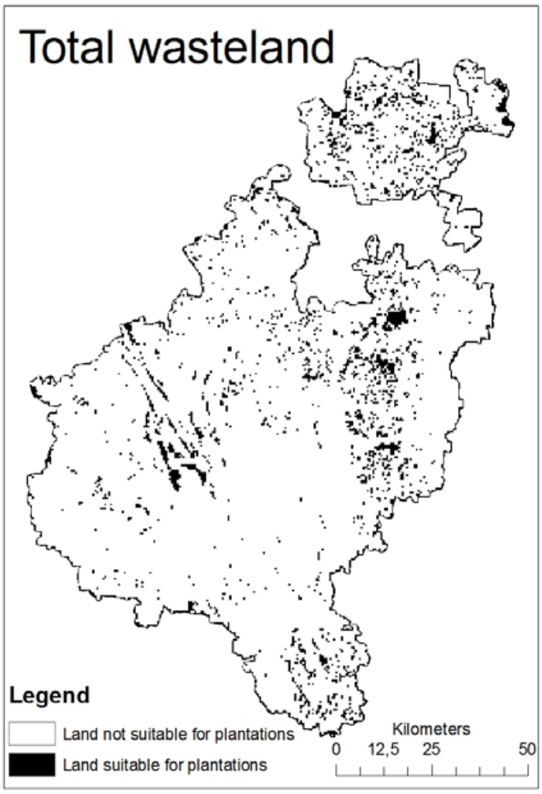
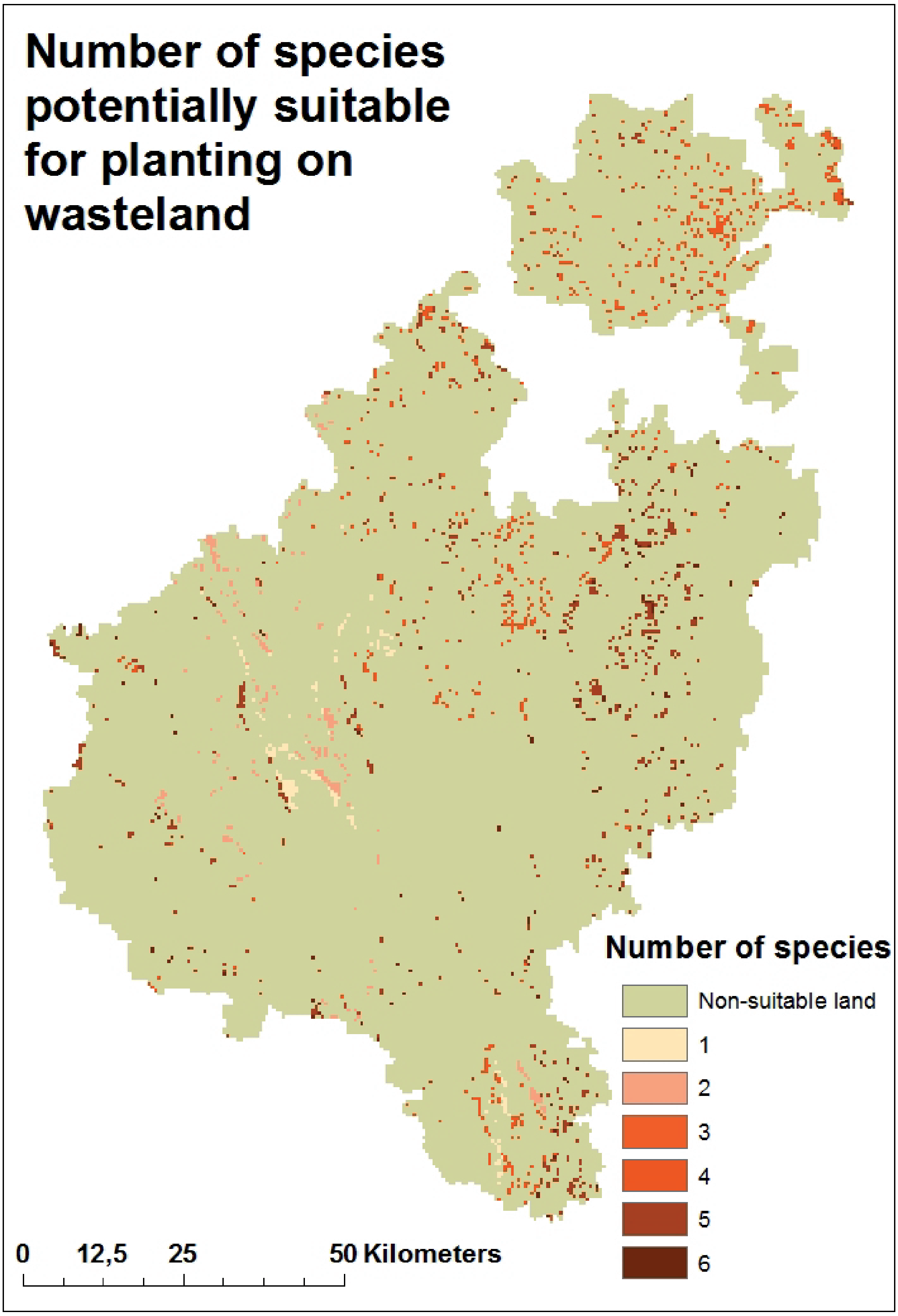


Figure 3. The maps show the potential for planting each of the suggested species on wasteland, including one map of the total amount of available wasteland. Included in the land, not suitable for planting for each of the specie, is the total land area not classified as wasteland together with wasteland not fulfilling the threshold criteria.

Figure 4. The map presents the Tumkur district with the number of species suggested for wasteland rehabilitation in each pixel. The largest area show the land either not suitable for the plantations species suggested in this study or land not classified as wasteland. The legend shows the number of species that potentially could be planted in each pixel. Darker colors represents larger number of species.



Discussion

This working paper results so far in a land suitability analysis where potential land-use options together with suitable species are suggested. It also investigates the amount of wasteland available for the suggested species and present potential implications with these options. The results will be further developed.

What are the potential land-use options for wasteland development?

Long rotational plantations have the option to provide carbon sequestration in several carbon pools, above ground biomass, below ground biomass, dead wood and litter as well as the soil. Due to low disturbance of the soils, the long rotational scheme is beneficial for the enrichment in soil carbon soli. Teak was included in the land suitability analysis as the only long rotational option due to its high value amongst the local population in Tumkur district.

Acacia, as a short rotational species, have several qualities making the species a good choice. It is widely used for erosion control due to its good soil-binding capacity (ICRAF 2009). It is also popular for the rehabilitation of seasonally dry, eroded and degraded soils where its ability to grow on dry, sandy, stony and shallow soils makes it a useful species for afforestation of difficult sites. Further, acacia is a nitrogen fixing species with a potential to thrive in nitrogen-deficient soils. Plantations of A. auriculiformis improve soil physio-chemical properties such as water-holding capacity, organic carbon, nitrogen and potassium through litter fall. Its phyllodes provide a good, long-lasting mulch.

Eucalyptus for plantings in a short rotational scheme will benefit from the fact that eucalyptus coppice rigorously which will result in less disturbance of the soil carbon. The literature show that planting eucalyptus is controversial (Jagger and Pender 2003), however, to plant the exotic eucalyptus for energy and timber in south India is well established (Tumkur 2003). Palm et al. (2009) shows that short term plantation introduced by the Indian Governmental, containing eucalyptus and acacia species, are rarely the preferred alternatives of the local communities. Depending on the local need, a mixed plantation or agro-forestry is the locally preferred options.

A common critique of eucalyptus plantations are the excessive root system and the ability to reach low lying water tables and thereby out compete crops for water, creating a decrease in yield (Malik and Sharma 1990, Saxena 1991, Calder et al. 1993). However, the ability of the tree to tap low water tables can be crucial for poor farmers in wasteland reclamation (Jagger and Pender 2003). In a study from north India Grewal et al. (1992) suggest that planting eucalyptus may reduce the rate of wasteland formation. Findings also show that compared to wasteland the system was superior and both resulted in greater waster retention and reduce topsoil losses. With respect to the soil water dynamics and with respect to the water balance of the watersheds, Eucalypts behave very similar to other tree plantation or natural forest cover. Thus, eucalypt plantations (as any other managed vegetation) can have both positive and negative effects on the water quality and quantity (El Bassam 1998). If these effects are positive or negative depend on the management practices. Monocultures rarely offer an increase in biodiversity however, while perennial crops planted on degraded areas or replace annual crops can favor biodiversity (Smith et al. 2007) compared to an intensification of agriculture and large scale of bioenergy crops.

Agricultural crops

Jatropha, Pongamia and Sweet sorghum are suggested as agricultural biofuel crops, all well designed to for the challenging environment on wasteland. Jatropha has demonstrated the ability to grow on poor soils while it also helps to remediate these soils, offering long-term ecological benefits. In a study conducted by Ogunwole et al. (2008), jatropha grown on marginal soils in India improved soil aggregation, helping to decrease soil erosion. The study also found that jatropha has the potential to increase carbon sequestration in soils, increasing the soils nutrient content (Ogunwole et al. 2008). It should be noted that Jatropha is not a nitrogen fixing species. This means that jatropha is best combined with some kind of nutrient fixing species if the wasteland shall increase in nutrients and rehabilitate (Openshaw 2000). Pongamia on the other hand is one of the few nitrogen-fixing trees that also produce oil (ICRAF 2009). Pongamia is especially attractive because it grows naturally through much of arid India, having very deep roots to reach water, and is one of the few crops well-suited to commercialization by India's large population of rural poor. Pongamia is a preferred species for controlled soil erosion and binding sand dunes because of its extensive network of lateral roots. Due to its tolerance moderate levels of salinity, Pongamia is an ideal candidate for recovering a variety of wastelands such as saline soil reclamation.

Both Jatropha and Pongamia are hardy plant/trees that can withstand long-periods of drought and can survive on marginal soils (Kumar and Sharma 2008, ICRAF 2009). A study by Abdrabbo et al. (2008) concludes that jatropha can survive and produce full yield with high quality seeds on otherwise unproductive agricultural land and under minimum water requirements without any significant effect of the oil composition. Foidl (1996) however means that Jatropha is a wild species that doesn't need irrigation to grow. While the remains of the seeds from jatropha are toxic the remains of the seeds from Pongamia are highly nutrient rich oilcake which can be used as an organic fertilizer; they are especially rich in nitrogen and sulphur. Experiments with soybean and maize with the application of Pongamia oilcakes resulted in a 41-47 % increased income when being compared with traditional farmers practices (Wani and Sreedevi 2007).

Sweet sorghum didn't prove its suitability to be implemented on wasteland in this paper being the least suitable of the chosen species. However, it still showed potential to be planted on low gradients. Sweet sorghum does provide multiple uses where the husks can be harvested as a food crop while the sugar in the stalk can be refined as ethanol, the fiber (cellulose) both as mulch or animal feed and, with second generation technologies, even for fuel (IFAD 2007). The multifunctional uses of a crop are very important for farmer in fragile agro-economic condition and are particularly useful in countries such as India where land availability can be a problem.

How large area of wasteland can be targeted?

In this working paper the results point out that even if the wasteland is degraded, that with a carefully assessed land suitability analysis more than two thirds of the wastelands could be covered with vegetation aiming for land rehabilitation. Both Jatropha and Pongamia have shown large potential in this area. Even plantations with a short rotation management, both eucalyptus and acacia plantations would be well suited in wasteland development. The development of a large scale biodiesel from Jatropha is advancing at the moment, especially in India where the government promotes a large scale development in this area. The demand for diesel is five times higher than the demand for petrol in India. But while the ethanol industry is mature, the biodiesel industry is still in its infancy (Gonsalves 2006).

There is also a need to realize the limitation of future techniques where a over belief of the benefits a future technique can provide. Techniques for utilization of 2nd generation biofuel i.e. ethanol from woody biomass, is still immature but is projected to be available in a near future, as stated above (WWI 2007). However, ethanol produced from starch rich crops, in this case sweet sorghum, has the technologies and market in place internationally. Sweet sorghum on the other hand is much less suited to be used in the wasteland development; less area is available for the implementation of this crop.

The land suitability in this paper shows the area available for implementing various land-use options and species for wasteland rehabilitation. It doesn't present a ranking of the land-use options and species choice nor does it weight the implication of such a plantation. The assessment has the advantage of an unbiased analysis, as far as possible, not favoring any specific end-use or implication. This view, however, is not granted the local land owner who need to make trade-offs with parameters such as investment cost, land rehabilitation, financial revenues and end products. It is likely that the land owner's options are limited by constraints of environmental parameters, financial means and time. One must further decide the aim for the plantation. Will it function as rehabilitation of the land, fuel production or food production? If the aim would change, due to fluctuations in the market and/or climate change, how flexible is the system to change and what would that cost. The systems suggested also need to be weighted on a time scale whether they can be implemented in a short or long timeframe and based on this discussion should the options be divided in present options and future options or should they be treated equally?

The results show that the area one or more species option could be implemented is 52 600 Ha, about 71% of the total wasteland in the district. This implicates an advantage for the land owner of that specific land and function as a great stimulus for sustainable development, the possible choice of actions. Limited options on local level are one driver on many environmental damaging activities. Drivers of deforestation on a local level are often an expression of an attempt to increase the livelihood on a community. If, in addition, the financial constraints can be overcome using financial mechanisms like CDM, voluntary carbon market or PES the options have a realistic possibility to be implemented (Palm et al. 2009). Many barriers, on the other hand, still limit the development of these lands where institutional constraint together with lack on water. Previous studies show that if constraints such as lack of water and poor soil quality on the wastelands together with financial constraints, the farmers are willing to develop and maintain the wastelands (Palm et al. 2009).

What are the implications for introducing these options?

The land suitability analysis for different land-uses for wasteland rehabilitation in Tumkur can of course only deliver theoretical co-benefits both for the environment and the socio- economic development. However, re-vegetating the wastelands has proven advantage compared to lack of development (IPCC 2000, Ravindranath and Sathaye 2002, Sathaye et al. 2007). More uncertain are the socio-economic implications when a plantation project is being implemented (Boyd et al. 2007). Boyd concludes that if depending on the project design a plantation project, implemented with local involvement, can produce local socio-economic development. The presents of institutional capacity together with an available market for products are crucial in the success of a project. Land tenure and legal rights are also issues need to be carefully investigated. One should be aware that the low quality of the wasteland can result is a lower yield than expected and a higher investment cost due to, for example, much needed irrigation. It should also be noted that the availability of water for irrigation of plantations is limited in this district (Ravindranath and Hall 1995).

All options suggested in this paper are affected by institutional capacity and the development of the market. For example, carbon sequestration to gain revenues from carbon credits or production of bioenergy can be done in a short timeframe, with a small time lag for the growth. Several options for carbon financing and PES are theoretically available; on the other hand, the administrative input in a carbon credit project is substantial and requires a huge in-house knowledge and capacity if the costs should be kept at a minimum. Producing bioenergy for the energy market can generate direct payment to the farmer in question, again with the time lag for growth. If the institutions are in place and the market is well developed the energy produced can be treated as any commodity and sold directly at the market. The production of biomass for energy is a technique already used in the district, both for local use and for production of electricity for the grid.

Since investment in bio-fuel plants is already taking place, time is of the essence due to the importance for the poor to take advantage of this emerging opportunity. Partnerships between the poor, the private sector, research Institutions, and the governments are especially important in achieving poverty alleviation and the research agenda should address the issues from a broad spectrum of perspectives, with priority to those crops that are ready for adoption (IFAD 2007).

Acknowledgement

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Appendix A

The Table below present soil types descriptions used in the assessment of thresholds of Tumkur district

Soil types description
Deep, Moderately welldrained, clayey soils of valleys with problems of drainage and slight salinity in particals; associated with: Deep, imperfectly drained, clayey over sandy soils.
Deep, Somewhat excessively drained, gravelly clay soils on rolling lands, with moderate erosion; associated with: Deep, somewhat excessively drained, clayey soils.
Deep, moderately welldrained, cracking clay soils on gently sloping interfluves, with moderate erosion; associated with: Very deep, moderately welldrained, calcareous, cracking clay soil.
Deep, moderately welldrained, cracking clay soils on gently sloping interfluves, with severe erosion; associated with: Deep, moderately welldrained, calcareous, cracking clay soils.
Deep, somewhat excessively drained, gravelly clay soils on gently sloping interfluves, with moderate erosion; associated with: Deep, somewhat excessively drained, clayey soils.
Deep, welldrained gravelly clay soils with low AWC on undulating interfluves, with Shallow, somewhat excessively drained, gravelly clay soil with very low AWC.
Deep, welldrained, clayey soils on undulating interfluves, with moderate erosion; associated with: Deep, welldrained clayey soils
Deep, welldrained, clayey soils with crusting on summits of plateau, with severe erosion; associated with: Very deep, welldrained gravelly soils
Moderately deep, welldrained, clayey soils on undulating interfluves, with moderate erosion; associated with: Moderately deep, welldrained, gravelly clay soils, moderately eroded.
Moderately deep, welldrained, clayey soils with medium AWC on undulating interfluves, with moderate erosion; associated with: Moderately deep, somewhat excessively drained, gravelly clay soils, strongly gravelly in the subsoil.
Moderately shallow, welldrained, gravelly clay soils with low AWC, strongly gravelly in the subsoil on gently sloping interfluves, with moderate erosion; associated with: Shallow, somewhat excessively drained, clayey soils with low AWC
Moderately shallow, welldrained, gravelly clay soils with very low AWC on undulating interfluves, with moderate erosion; associated with: Moderately deep, welldrained, gravelly clay soil with very low AWC
Rocky outcrops.
Rocky outcrops; associated with: Shallow, some
Shallow, somewhat excessively drained, gravelly loam soils with very low AWC on undulating interfluves, with severe erosion; associated with: Moderately shallow, welldrained, gravelly clay soils with very low AWC, moderately eroded.
Shallow, welldrained, gravelly clay soils with very low AWC, strongly gravelly in the subsoil on undulated interfluves; associated with: very deep, moderately well drained, calcareous, cracking clay soils, moderately eroded
Very deep, welldrained, clayey soils on undulating interfluves, with slight erosion; associated with: Shallow, somewhat excessively drained, gravelly clay soils, moderately eroded
Very deep, excessively drained, clayey soils on ridges with steep slopes, high runoff and moderate erosion; associated with: Very shallow, somewhat excessively drained, gravelly loam soils with very low AWC, severely eroded
Very deep, moderately welldrained, clayey soils of valleys, with problems of drainage and slight salinity in patches;

associated with: Moderately deep, welldrained, loamy soils

Very deep, moderately welldrained, cracking clay soils of valleys, with moderate erosion; associated with: Shallow, welldrained, clayey soils with low AWC.

Very deep, welldrained, clayey soils on undulating interfluves, with slight erosion; associated with: Deep, welldrained, gravelly clay soils with low AWC, moderately eroded.

Very deep, welldrained, gravelly loam soils, strongly gravelly in the subsoil on rolling lands with moderate erosion; associated with: Shallow somewhat excessive drained, gravelly clay soils with very low AWC.

Very shallow, excessively drained, gravelly loamy soils on ridges with severe erosion; associated with: Shallow, somewhat excessively drained. Gravelly clay soils with very low AWC, moderately eroded.

Very shallow, welldrained, loamy soils with stoniness on ridges with severe erosion; associated with: Moderately shallow, welldrained, clayey soils with very low AWC.

associated with: Moderately deep, welldrained, loamy soils
Very deep, moderately welldrained, cracking clay soils of valleys, with moderate erosion; associated with: Shallow, welldrained, clayey soils with low AWC.
Very deep, welldrained, clayey soils on undulating interfluves, with slight erosion; associated with: Deep, welldrained, gravelly clay soils with low AWC, moderately eroded.
Very deep, welldrained, gravelly loam soils, strongly gravelly in the subsoil on rolling lands with moderate erosion; associated with: Shallow somewhat excessive drained, gravelly clay soils with very low AWC.
Very shallow, excessively drained, gravelly loamy soils on ridges with severe erosion; associated with: Shallow, somewhat excessively drained. Gravelly clay soils with very low AWC, moderately eroded.
Very shallow, welldrained, loamy soils with stoniness on ridges with severe erosion; associated with: Moderately shallow, welldrained, clayey soils with very low AWC.