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Climate change mitigation via afforestation, reforestation and deforestation avoidance: and what about adaptation to environmental change?

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Abstract Climate change is affecting the world's ecosystems and threatening the economic system, livelihoods and availability of natural resources. Forest ecosystems can be carbon sources or sinks and are therefore integrated in international climate policy. Forest-related carbon mitigation projects are threatened by climate change through altered environmental conditions and forest processes, as well as through synergistic effects of climate change impacts with already existing socioeconomic and environmental stressors. Data on risk management and adaptation strategies were collected by a survey of 28 current forest projects targeting climate change mitigation. Ten of these represent the officially implemented afforestation (A) and reforestation (R) activities under the UNFCCC and the Kyoto protocol. Additionally, the official methodologies for AR activities under the CDM (Scope 14) were examined for potential climate change adaptation requirements. As a result, the adaptation of forest mitigation projects to climate change is found to be insufficient. A systematic approach for the inclusion of climate change risk management and adaptation is developed and guidelines for the design of "climate-change-proof" afforestation, reforestation and deforestation avoidance projects are proposed. A broader mainstreaming of the issue is required and clear policy regulations are necessary, especially for the post-Kyoto process.

Keywords Climate change · Mitigation · Adaptation · Afforestation · Reforestation · Deforestation avoidance

Introduction

The recently published IPCC reports on climate change and numerous other scientific publications do not leave any doubts that anthropogenic greenhouse gas emissions contribute significantly to global climate change. There are already worldwide observed

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impacts such as the rise of the sea level or the increased frequency of extreme weather events (Solomon et al. 2007). Paleoecological data reveal that rapid climate change has already happened in the history of Earth (Birks and Ammann 2000). However, current changes, which occur within a relatively warm period, surpass, both in velocity and extent, any global environmental changes that mankind ever had to face (Bush et al. 2004; Overpeck et al. 2005). The climate change expected by the end of the century is threatening the economic system, livelihoods and the availability of natural resources in several regions of the world (Hansen et al. 2006), and adaptation to the unavoidable climate change becomes a crucial challenge.

Forest ecosystems engage a special position within the debate on adaptation to climate change, as they may act both as a carbon source or sink according to their age, management, environmental conditions and the disturbances that alter their composition (Watson et al. 2000; Rosenbaum et al. 2004; Dale et al. 2001). The deforestation of tropical forests alone currently contributes 1.5 Gt C year^{-1} to the global anthropogenic emission (vs. 8.4 Gt C year^{-1} from the use of fossil energy sources; Raupach et al. 2007; Canadell et al. 2007).

The United Nations framework convention on climate change (UNFCCC), 1992, and the Kyoto protocol (KP), 1997, provide the legal framework for the supranational strive against dangerous climate change. They define several mechanisms of climate change mitigation: the “activities implemented jointly (AIJ)” mechanism, “clean development mechanism (CDM)” and “joint implementation (JI)” mechanism. The overall scope of these actions are projects that somehow contribute to emission reduction or carbon sequestration all over the world and thus to climate change mitigation (Aukland et al. 2002; Stuart and Moura-Costa 1998; UNFCCC 2007).

According to the IPCC report on land use, land-use change, and forestry (LULUCF) (Watson et al. 2000), in the forestry sector, three types of mitigation projects are distinguished:

- Afforestation (A): conversion of long time non-forested land to forest with (relatively) free species selection, e.g., using non-native and fast-growing species.
- Reforestation (R): conversion of recently non-forested land to forest, often with a conservation or landscape protection background, generally, planting rather native species and focussing on restoration of “nature like” ecosystems.
- Deforestation avoidance (D): avoidance of conversion of carbon-rich forests to non-forest land, normally driven by land use change and illegal selective logging (Asner et al. 2005).

These actions can contribute to up to 25% of atmospheric CO_2 reduction by 2,050 by reducing emissions, increase CO_2 removals through sinks at low costs and have synergies with adaptation and sustainable development (Niles et al. 2002; Barker et al. 2007).

The potential success of these mitigation activities is facing two major challenges that have to be separated from each other, namely the unclear policy regulations and the project viability under changing climate with different directions and magnitude of change in various regions (Barker et al. 2007). A synopsis of all main impacts of climate change on forest ecosystems is presented in Table 1.

The species individually respond to climate-change-induced habitat changes at different velocities. This commonly might lead to the disassembling of current biotic communities and to the formation of new, unstable ones with altered ecosystem functions and increased risk of extinction (Parry et al. 2007). Forest ecosystems are affected at different rates and extent, but the risks of disturbances and synergistic effects of climate change, invasive species, pollution, and pressure from land-use change increase (Scholze et al. 2006;

Table 1 Synopsis of forest ecosystems, ARD projects (afforestation, reforestation, deforestation avoidance) and climate change impacts

Phenomenon and direction of trend	Likelihood of future trends based on projections for twenty-first century using SRES scenarios (a)	Impact on forest ecosystems	Project type most affected
Over most land areas, warmer and fewer cold days and nights, warmer and more frequent hot days and nights (a)	Virtually certain	Increased insect outbreaks (b), earlier phenological events (c, d; e)	ARD
Warm spells/heat waves, Frequency increases over most land areas (a) (f)	Very likely	Heat stress; fire danger increases (g, h)	ARD
Heavy precipitation events, Frequency increases over most areas (a)	Very likely	Soil erosion (g), damage to plants	AR
Area affected by drought increases (a)	Likely	Land degradation, lower yields, fire danger increases, (g, h) altered tree health, dying of trees; (i)	ARD
Intense storm and tropical cyclone activity increases (a)	Likely	Windthrow of trees (g)	AR
Changes of forest processes through elevated CO_2 concentrations (k)	Not assessed	Higher individual plant productivity (l) leads to altered forest composition (m) and increase of invasive species (n)	ARD
Changes in biome and species distribution (o)	Not assessed	Northward and poleward shift of current distributions (d), disruption of communities (d), increase of invasive species (p)	D
Disruption of societies, climate change refugees (q)	Not assessed	Land clearings for agriculture	D
Growing demand for agricultural land as a consequence of climate protection initiatives	Not assessed	Land clearings for agriculture	D

a = Solomon et al. (2007); b = Altenkirch et al. (2002); c = Dullinger et al. (2004); d = Parry et al. (2007); e = Root and Hughes (2005); f = Meehl and Tebaldi (2004); g = Dale et al. (2001); h = Hulme (2005); i = Slik (2004); k = Aber et al. (2001); l = Boisvenue and Running (2006); m = Yarie and Parton (2005); n = Drake et al. (2005); o = Hansen et al. (2001); p = Dukes and Mooney (1999); q = Davidson et al. (2003)

Hannah et al. 2005; Parry et al. 2007). For example, fragmented forest ecosystems that are more easily affected by invasive species and at the same time suffer from land-use changes may be more vulnerable to climate change and associated risks.

It is generally assumed that species ranges will shift along latitudinal and altitudinal gradients (Hughes 2000; Parry et al. 2007). As the world's ecosystems have always faced changes, this shifting process per se may be seen as a natural succession, but species migration speed is limited (Davis and Shaw 2001) and in many cases slower than the poleward movement of isotherms (Hansen et al. 2006). Moreover, anthropogenically fragmented habitats in combination with other stressors (Hannah et al. 2005) modify the reaction capacities of many species. Forest ecosystems already reveal phenological changes related to temperature regimes, such as trees' budburst, seed dispersal and flowering; mismatch and desynchronization of these events are emerging threats (Dullinger et al. 2004; Parry et al. 2007; Root and Hughes 2005). The conventional concept of the "potential natural vegetation" must be revised and take into account the transient process that forest ecosystems undergo today (Hannah et al. 2005; Ibisch 2006).

Other threats are climate-change-induced forest disturbances. A frightening aspect is the increase of climate variability going beyond the magnitude, which a linear relationship of temperature and temperature variability allows to assume (Schär et al. 2004). Thus, besides changing mean values and seasonal regimes of temperature and precipitation (Hulme 2005; Jenkins et al. 2005), especially extreme weather events like heat-waves, droughts and heavy precipitation are likely to increase.

Also, the health of insect populations, their reproduction success and the outbreak of large-scale calamities are closely related to climate patterns (Altenkirch et al. 2002). Climate change is also likely to foster the propagation of invasive species (Dukes and Mooney 1999), as well as changes of forest fire regimes and the forest susceptibility to fire (Westerling et al. 2006).

A non-climate-related impact of the increasing greenhouse gas concentrations in the atmosphere on forest ecosystems are changes in forest processes driven by the elevated CO_2 concentration stimulating net primary productivity of plants (Boisvenue and Running 2006). This alone can alter the forest composition as species respond individually to the new growth opportunities and constraints imposed by other lacking nutrients (Reich et al. 2006; Yarie and Parton 2005). Different forest types also respond differently to these changes; model calculations reveal negative responses from higher CO_2 concentrations in the Tropics and positive feedbacks in extratropical regions (Berthelot et al. 2002).

Synergies are of vital importance: the multiple impact of different stressors in these natural or close-to-nature systems is greater than the simple sum of the individual effects and, thus, the danger of degradation of livelihoods, loss of biodiversity and feedbacks triggering further climate change is considerably high (Drake et al. 2005). Additionally, the socio-economic phenomenon of "climate refugees", referring to people who are forced to leave their homes because of severe climate-change influenced degradation of their livelihoods, in some regions, can further threaten the integrity of forest ecosystems (Davidson et al. 2003). Even climate protection initiatives themselves, based on the replacement of fossil fuels by biomass, have the potential of increasing the pressure on natural forests (Ibisch et al. 2007).

The need of adaptation to the imminent environmental changes directly or indirectly caused by climate change is obvious. Correspondingly, the main objectives of this study are to compile existing experiences regarding different adaptation strategies and to propose a systematic approach for the inclusion of climate change risk management in ARD projects. The overall goal of this study is to stimulate the inclusion of adaptation criteria in ARD mitigation activities in order to guarantee the projects' effectiveness.

Methods

Data on risk management and adaptation strategies were collected by a survey of current forest mitigation projects and an analysis of official methodologies used in the context of the design of AR activities.

The survey of already existing projects includes 17 organisations that conduct afforestation and reforestation (AR) activities. The 17 organisations represent 28 projects that aim at contributing to climate change mitigation by carbon sequestration. The online presence of the project descriptions and accessibility of basic information were the determining criteria for their selection. Nine of the projects are listed as AR activities under the AIJ mechanism and a single one as an AR activity under the CDM. These ten projects represent all projects that are accredited as official AR activities under the UNFCCC and the KP. The remaining projects are not eligible for any KP mechanism but funded by NGOs and other organisations (see Table 2).

The project homepages and the available documents on the project design were analysed regarding management strategies addressing the adaptation to climate change. All of the 17 organisations were then contacted via email (15) and mail (11 out of 15) or personally (2). A complete list of all the projects is shown in Table 2. During this expert survey, the following five questions concerning adaptation to climate change were asked to the project designers:

- Do you take climate change projections into account in your project design?
- Which climate change projections do you consider in your project design (models/scenarios)?
- AR—activities require adaptive management practices to prevent future damage eventually caused by climate change impacts. How precise are the preventive management practices (e.g. species selection, silvicultural methods…) included in your project design?
- Where are these strategies documented?
- Would you provide us these documents for further data collection?

Additionally, the official methodologies for AR activities under the CDM (Scope 14) were examined for potential climate change adaptation requirements.

Based on the results of the evaluation, a systematic approach for the inclusion of climate change risk management and adaptation in ARD activities was developed. General management principles that foster a project's climate change risk management and adaptation are regrouped as possible guidelines for project designers.

Results

General project survey

The examined activities are conducted on different continents and represent the prevailing management standards of such project types. A lot of projects are located in South and Central America (13) but no project is located in Africa. The issue of adaptation to climate change is not considered on any of the studied projects' homepages or in documents available online. Although responses to the request letters were sparse, some very useful information was collected, when the projects were contacted directly. Among 5 out of 17 organisations representing 6 out of 28 projects did answer our inquiries (see Table 2). Two out of the five organisations proposed concrete climate change adaptation methods (see following case study for one example). The three remaining organisations did not address this issue actively in their project design.

Table 2 List of analysed projects and consideration of adaptation to climate change

Project	Organisation	Country of implementation	Contact via	Answer	Adaptation to climate change	URL
Scolel Té-Climate change and rural livelihoods	ECCM	Mexico	Mail, email	No	No	http://www.eccm.uk.com/scolelte/netscape/index_netscape.html
Deschutes riparian reforestation	Climate Trust	USA	Mail, email	No	No	http://www.climatetrust.org/offset_deschutes.php
Ecuadorian rainforest restoration	Climate Trust	Ecuador	Mail, email	No	No	http://www.climatetrust.org/offset_rainforest.php
Preservation of a native Northwest forest	Climate Trust	USA	Mail, email	No	No	http://www.climatetrust.org/offset_native.php
Saratov reforestation	Oregon University	Russia	Mail, email	Yes	No	http://unfccc.int/kyoto_mechanisms/aij/activities_implemented_jointly/items/1792.php
Facilitating reforestation for Guangxi watershed Management in Pearl River basin	Xinghuan Forestry Development Company Ltd	China	Mail, email	No	No	http://cdm.unfccc.int/Projects/projsearch.html
SIF Carbon sequestration project	Sociedad Inversora Forestal S.A.	Chile	Mail, email	No	No	http://unfccc.int/kyoto_mechanisms/aij/activities_implemented_jointly/items/1891.php
Klinki forestry project	Reforest the Tropics Inc.	Costa Rica	Mail, email	Yes	Yes	http://unfccc.int/kyoto_mechanisms/aij/activities_implemented_jointly/items/1971.php
Costa Rica/Norway reforestation and forest conservation AIJ pilot project	National Power and Light Company	Costa Rica	Mail, email	No	No	http://unfccc.int/kyoto_mechanisms/aij/activities_implemented_jointly/items/1812.php
Reforestation in Vologda	Environment and Economic Consulting	Russia	Mail, email	No	No	http://unfccc.int/kyoto_mechanisms/aij/activities_implemented_jointly/items/1795.php

Table 2 continued

Project	Organisation	Country of implementation	Contact via	Answer	Adaptation to climate change	URL
Commercial reforestration in the Chiriquí province	Center for Clean Air Policy	Panama	Mail, email	No	No	http://unfccc.int/kyoto_mechanisms/aij/activities_implemented_jointly/items/1791.php
Increasing carbon sequestration through use of genetically improved planting stock	CSIRO Forestry and Forest Products	Vietnam	Mail, email	Yes	No/yes	http://unfccc.int/kyoto_mechanisms/aij/activities_implemented_jointly/items/1961.php
Profafor	Face Foundation	Ecuador	Mail, email	Yes	No	http://www.stichtingface.nl
Infapro	Face Foundation	Malaysia	Mail, email	Yes	No	http://www.stichtingface.nl/
Trees restoring the economy and environment	Winrock	USA	Email	No	No	http://www.winrock.org/fact/facts.asp?CC=5390&bu=9086
Reforesting a vital ecosystem in Honduras	Winrock	Honduras	Email	No	No	http://www.winrock.org/fact/facts.asp?CC=5607&bu=9086
Advancing the science of carbon sequestration	Winrock	Brazil	Email	No	No	http://www.winrock.org/fact/facts.asp?CC=5385&bu=9086
Stimulating environmental restoration and economic development in Arkansas	Winrock	USA	Email	No	No	http://www.winrock.org/fact/facts.asp?CC=5468&bu=9086
Using Indonesian forests to fight global warming	Winrock	Indonesia	Email	No	No	http://www.winrock.org/fact/facts.asp?CC=5529&bu=9086
Reforestation and sustainable land management in Belize	World Land Trust	Belize	Email	No	No	http://www.carbonbalanced.org/
Restoration of cloud forest from pasture land in Ecuador	World Land Trust	Ecuador	Email	No	No	http://www.carbonbalanced.org/
Carbon sequestration and coastal protection through mangrove planting in southern India	World Land Trust	India	Email	No	No	http://www.carbonbalanced.org/

Table 2 continued

Project	Organisation	Country of implementation	Contact via	Answer	Adaptation to climate change	URL
Climate Action Project: Bayou Pierre Floodplain, Louisiana	TNC	USA	Email	No	No	http://www.nature.org/initiatives/climatechange/work/art19665.html
Climate action project: Midwest forest restoration, United States	TNC	USA	Email	No	No	http://www.nature.org/initiatives/climatechange/work/art4964.html
Climate action project: guaraqueçaba environmental protection area, Brazil	TNC	Brazil	Email	No	No	http://www.nature.org/initiatives/climatechange/work/art4254.html
Afforestation Precious Woods Nicaragua	Precious Woods	Nicaragua	Email	No	No	http://www.preciouswoods.com/index.php?option=com_content&task=view&id=87&Itemid=148&lang=en
Several projects	Prima Klima	Germany	Personal	Yes	No	http://www.prima-klima-weltweit.de/
Several projects	Future Camp	Germany	Personal	No	No	http://www.future-camp.de/deutsch/subwebs/2klima/20_emission.html

Case study: reforest the tropics (USA/Costa Rica)

The Klinki—Reforest the tropics programme focuses on the reforestation of areas that formerly were deforested for pastureland. It is approved by the US and Costa Rican government and listed as an AIJ by the UNFCCC. There are already more than 100 ha reforested and the project generates both carbon credits and wood for the local farmers.

The projects aims to install multifunctional plantations with ecological and economical benefits like fruits and shelter for wildlife, income generation for local farmers and capacity building through the training of the farmers. The project managers identified the following risks to the project: inappropriate farm management, lack of long-term funding and political adjustments as *general risks*, and fire, storms, diseases and pest outbreaks as *climate-change-induced risks*. The general risks are addressed with the help of training and a high economical viability of the project. For climate change adaptation and climate-change-induced risks several forest management principles are implemented. Twelve tree species are used in the reforestation in 26 mixtures combining native and non-native, slow and fast growing, as well as hardwood and softwood species in order to detect the most efficient forest. For example, *Eucalyptus deglupta* Blume hybrids are planted at very wide spacing (20 m × 20 m) applying a 10-year rotation cycle system. These are to provide short term income without dominating the forest. The structure of the stands also varies from even-aged stands with every age-class represented on a small area to all-aged forests. The species composition may be adjusted by under- and replanting if ever a species is sensitive to arising climatic conditions or susceptible to insect attacks. The risk of fire (although today of minor importance) and storm is reduced through intensive management with 5 year thinning periods to minimize the accumulation of fuelwood at the same time as producing healthy individual trees. The overall lifetime of a contract is 25 years and reduced impact logging techniques are used. The planting is also done very carefully with double density, deep-hole planting with mycorrhiza addition, root pruning, fertilization and pest control in order to allow the development of stable trees.

Survey of official project methodologies

In a second step, the official and approved UNFCCC Scope 14 methodologies for the implementation of AR activities (CDM AR-AM0001, CDM AR-AM0002, CDM AR-AM0003, CDM AR-AM0004, CDM AR-AM0005, CDM AR-AM0006, CDM AR-AM0007 and CDM AR-AMS0001) were examined for any recommendation addressing adaptation to climate change (UNFCCC 2006a, b, c, d, e, f, g, h). The result is that there is neither any formulation referring to the impacts of climate change on the project's viability nor any direct measures related to climate change adaptation.

Discussion and conclusions

Significance of assessing and managing climate change risks in ARD projects

The project survey and the revision of the Scope 14 methodology provide strong evidence for an insufficient inclusion of climate change adaptation in ARD activities as information and documents are lacking.

Climate change is not affecting all of the Earth's regions at the same extent, and the adaptation potential of a region also varies mainly according to the socioeconomic development. The combination of these two factors results in a high vulnerability to climate change especially in developing countries, where, unfortunately, adaptation is hardest and most ARD projects are located (Salinger et al. 2005).

Hence, incorporating climate change in the design of mitigation projects must be a logical consequence of every serious risk assessment and management of forestry activities to make sure the project design guarantees the long-term viability of the project and is not only focussing on short-term carbon sequestration (Stock 2003; Maciver and Wheaton 2005). The best knowledge available and as precise as possible descriptions of trends and risks may be applied. This basic information leads to practical and systematic activities that should be used as guidelines for adapting projects to climate change and that should also provide a basis for further discussions of climate change adaptation strategies. Once, the coherency of the climate change adaptation effort and the carbon sequestration aim acquired, projects are more likely to fulfil their aim of mitigating climate change and contributing to sustainable development.

Proposal of guidelines for the inclusion of climate change risk management and adaptation in ARD activities

A successful risk assessment and management tackles all relevant risks arising from climate change at all stages of a project, respectively. Both the present and the potential future conditions must be considered. These future conditions may be influenced by directly and indirectly climate-change-induced forest disturbances, altered forest processes, as well as socioeconomic consequences of climate change and synergistic effects with other stressors, such as land use change and demographical pressure. The perception of climate change scenarios and adequate adaptation strategies will change but this does not mean that it is too early for action. Thus, a dynamic and "mistake-friendly" (Pietersen 2002) approach following the principles of adaptive management with a focus on "learning by doing" and continually updating of management strategies, goals and measures, is definitely the most intelligent option (Peterson et al. 1997). The consequent monitoring of climate change impacts and the success of adaptation methods allows project designers to act coherently regarding the continuous changes.

Downscaling the general risks, which are known from national and regional assessments [see Carter and Kankaanpää (2003) for Finland and Warren et al. (2004) for Canada], to a project level or even a stand level is a difficult task for project designers not trained in this topic. However, a systematic plan of climate change risk assessment and management, and the corresponding adaptation of the project design is a powerful tool to mainstream the issue. The following six checkpoints resume all risks that may occur to ARD projects from climate change:

1. Insufficient knowledge of regional climate change patterns.
2. Local climate-change induced land-use change.
3. Disrupted socioeconomic situation by climate change.
4. Directly and indirectly climate-change-induced risks and other broader climate change related risk (e.g. seed dispersal, forest processes).
5. Unknown quality, quantity and spatio-temporal pattern of risk occurrence.
6. Lack of clear adaptation possibilities.

Common adaptation strategies

All the projects have specific aims and settings and thus require different adaptation strategies but still some general common principles may be defined. They require adaptive and far-seeing management to ensure the resilience of the forest ecosystems and their maintenance as carbon sinks. This includes:

- Best knowledge of scenarios of regional climate change (use and development of regional circulation models and regional downscaled climate projections) to foster selection of species that are adapted to future climate variations and definition of adaptation management priorities.
- Development of scenarios of climate change-induced local and regional land-use changes potentially threatening the project's implementation (increase demand of agricultural land, dislocation of production, socioeconomic pressure and climate change refugees).
- Socioeconomic viability of the project (income to the local population, develop resistance against dramatic climatic events).
- Integration of the project into large scale, integrative development/conservation projects in order to secure the acceptance of the project and facilitate more general adaptation measures and achieve synergies with other sectors (e.g., mix of forested areas for sustainable wood production, carbon sequestration and conservation, and a combination of management efforts and fund raising).
- Use of species mixtures taking into account specific site characteristics (microclimate niches along altitudinal gradients and micro topography) if possible (Bush and Hooghiemstra 2005).
- Cautious translocation of site-adapted trees that have their climatic optimum under current as well as under future conditions by anticipative planting (see Fig. 1).
- Selection of plants according to ecological aspects and from neighbouring biogeographical regions anticipating probable natural immigration (avoiding the introduction of potentially invasive taxa, and assure best-possible ecological integration in existing communities).
- Alleviate the current pressure on forest ecosystems by minimizing other stresses such as forest fragmentation by road construction.

Specific adaptation strategies

Some project types face clear restrictions regarding an adequate adaptation to climate-change-related risks, such as single-tree species plantations. Yet, facing this problem, it is still possible to adapt the stands by differentiating the intensities and practices of management (type of intervention, fire regulations, weed management etc.). Therefore, a fair knowledge of the directly and indirectly climate change-induced risks, and the subsequentially altered forest processes like nutrient cycling is desirable. Their intensity, magnitude, spatial location and temporal patterns shall be identified. After classification in risk classes—as combinations of probability and potential severity-this information may be transcribed in silvicultural or other management practices and priorities. Subsequently, the corresponding adaptation profile for every project can be developed.

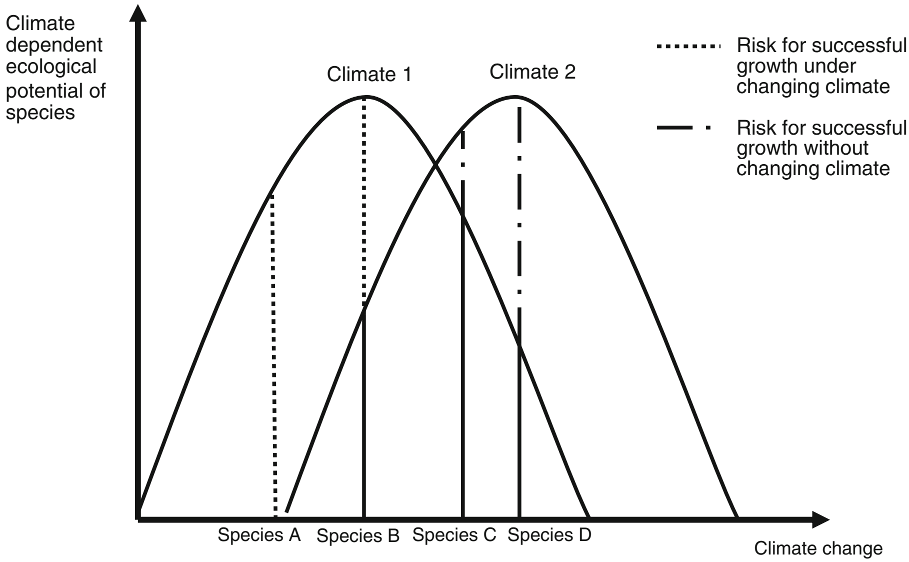

Fig. 1 Risk analysis of anticipative planting; under current (climate 1) conditions species B is at its optimum; under a climate change scenario (climate 2) species D is at its optimum. Once ecological conditions shift to climate 2 (maybe within one rotation cycle) species C and D are favoured whereas, species A and B loose competitiveness (A to such a dramatic degree, that it is not site-adapted anymore). According to the risk analysis, species C currently represents the best option because it grows acceptably under current and future conditions whereas, planting species D is still too risky nowadays (e.g. limiting late frosts)

Adaptation of afforestation projects

Afforestation projects are the most management-intensive and "artificial" forestry projects to sequester carbon. They usually represent a great potential for carbon sequestration and economic benefit when not disturbing natural carbon-rich ecosystems such as peatlands. Often, non-native species, hybrids or clones of rapid growth are used to install mono-specific, even-aged and less diverse stands that are often far from being site-adapted. Hence, they may be less resilient and resistant to pest outbreaks, fire, storms and other disturbances. Adaptation measures should foster stability and diversity. Specific adaptation measures are presented in Table 3.

Adaptation of reforestation projects

Reforestation projects face similar challenges as afforestation projects, but the reconversion to forest is less artificial and might imitate or accelerate natural succession. In some cases remnants of a primary or secondary forest remain, and usually some forest is located close to the site, providing seed input for natural regeneration. Beside these potentially favourable conditions the driving forces which caused the deforestation (e.g., collection of fire wood) may still persist.

The adaptation procedures regarding species selection, genetics, planting, rotation length, stand stability and fire management are the same than for afforestation projects (see Table 3). Increased stand resilience profiting from remaining natural dynamics is the key to successful adaptation.

Table 3 Guidelines for adaptation of AR projects

Field of adaptation	Adaptation measures for afforestation/reforestation
Genetics	Special breeding to increase the resistance and tolerance towards pests and other climate change-related stressors such as frequent and severe droughts
Regeneration/installation	Re-evaluation of seed orchards location and use of wild stand seeds to get strong individuals during the critical planting period (Spittlehouse and Stewart 2004)
Regeneration/installation	Use of seedlings from different provenances at the limit of the ecological distribution range of a species to increase the genetic diversity
Regeneration/installation	Species mix with native species and introduction of species that are site adapted under current and future conditions (future growth potential, diversification of risks; ideally species are introduced/translocated from neighbouring biogeographic regions)
Regeneration/installation	High-quality planting using small plants without cutting the root (Müller 2004)
Silvicultural management	Install forest conditions by planting pioneer species and wait for natural succession to get more valuable tree species that at the same time are proved to be site adapted (connectivity to other forest ecosystems required)
Silvicultural management	Short rotation cycles (but beware of soil nutrient loss and increased invasion by alien species; Noss 2001)
Silvicultural management	Adaptation of short rotation plantations after every cutting by replanting species best adapted to the climate projected for next rotation period
Silvicultural management	Stability of individual trees (largely developed crown and root system, no long phases of compressions of the stand)
Silvicultural management	Avoiding big openings in the canopy layer, vertically structured forest boundaries with shrubs and smaller trees and cutting orientated against the main wind direction
Silvicultural management	Regular cutting and thinning (even pre-commercial thinning) enhancing light, water and nutrient availability for the remaining trees (however, the water status may be altered by increasing ground vegetation and/or by a higher transpiration of the remaining trees)
Fire Management	Appropriate fertilization improving the humus consistency, weed management, higher air humidity (mixed and structured stands), underplanting with fire resistant tree species, improved detection and fighting of fire, rising public awareness for fire prevention and predescribed burning to decrease fire risk (Müller 2004; Spittlehouse and Stewart 2004)
Landscape management	Improving hydrological conditions whenever possible and adequate, e.g. reverting drainage
Socioeconomic management	Creating awareness and providing information to stakeholders; reducing or eliminating conventional anthropogenic stressors, e.g. by supporting livelihoods

Adaptation of deforestation avoidance projects

The intensity of forest management is decreasing from afforestation to reforestation and is definitely lowest in deforestation avoidance projects; this does not mean that adaptation measurements cannot be applied. The scientific literature has already defined consistent climate-change integrated conservation strategies focussing on:

- The maintenance and restoration of native ecosystems with habitat and community diversity representing various functional groups on large areas.
- The conservation and enhancement of ecosystem functions (e.g. related to hydroclimatic processes), among others, through the conservation of sufficiently large blocks of forests.

- Protected areas maintaining representative forest types along environmental gradients.
- Improving connectivity to minimise habitat fragmentation and loss of gene-flow.
- Rare species management and the control and prevention of invasive alien species.
- Socioeconomic integration of the project using e.g. agroforestry.
- Management, monitoring and coordination on a regional—not on a local—climate scale (Hannah et al. 2005; Watson 2005; Noss 2001).

Actually, there is much more concern about the adaptation of forest ecosystems in general, than about those that are part of deforestation avoidance/conservation projects as the maintenance of natural dynamics is the essence of adaptation to climate change. The multiple pressures and stresses natural forests are suffering from are enhanced by climate change impacts. The need for a comprehensive, sustainable management of deforestation avoidance projects is considered to be the most effective adaptation. Definitely, in contrast to forestation activities the avoidance of deforestation can provide an immediate contribution to climate protection having positive secondary effects in terms of biodiversity conservation (Ibisch et al. 2007).

Feasibility of adaptation measures

Some of the guidelines represent a true change from current management practices and a climate change adapted project design might conflict with today's conception of ARD projects (e.g. the shortening of rotation length that can foster adaptation but also leads to less carbon storage), but as climate change adaptation has to be considered as a new dimension of risk management, compromises have to be made. The high costs of developing local climate change models and other challenges at the personnel and institutional level are another problem. Especially in developing countries this is a major barrier to the downscaling of climate change projections (Jones 2005; Jones et al. 2005). An intelligent choice would be the adoption of several feasible adaptation strategies that promise a successful adaptation without jeopardizing the overall management goal of the project.

Projects that take into account all the presented guidelines and incorporate them into their project design are more likely to have a successful adaptation. Therefore an integration of adaptation to climate change should be part of the official project methodology (e.g. Scope 14) as well as adaptive management principles keeping the projects flexible and adjustable.

Already existing projects that do not already take climate change adaptation into account are somehow less flexible, as investments and actions have already been implemented. Still, some of the adaptation objectives may easily be obtained without a great management effort (e.g. leaving some invaluable trees from the natural succession in the forest to increase biodiversity). Changing the whole project design step-by-step is required, when the climate change related risks overwhelm the adaptation capacity of the current design. Spittlehouse and Stewart (2004) propose to speed up rotation to foster species changes towards a more adapted stand with a different species composition than the initial project design prescribed.

Future of forestry mitigation activities: limits and problems of ARD activities

Successful adaptation to climate change is sustainable forest management with a climate change focus and serious risk assessment. Well-planned landscapes and an inclusion of climate variables in growth and yield models are not only important tools to minimize the impacts of climate change induced disturbances, calculating carbon sequestration and economic benefits, but they also allow the development of climate change adapted management strategies (Spittlehouse and Stewart 2004; Noss 2001). Some of the presented management recommendations are also consistent with the voluntary management guidelines for planted forests from the FAO (2006) and important general principles for forest management and forest conservation under climate change (Bolte and Ibisch 2007).

Hence, there is potential for project designers to adapt their projects, but other important issues have to be discussed within the context of mitigation: firstly, a consideration of the project benefits that justify the project implementation regarding the valorisation (e.g. high carbon storage potential, high socioeconomic benefits), and sustainable land utilisation without a possible alteration of soil productivity, water balance and site conditions occurring during, e.g. grassland afforestation. (Farley et al. 2005; Jackson et al. 2005; Jobbágy and Jackson 2004; Nosetto et al. 2005, 2006; Laclau et al. 2005).

Secondly, climate change mitigation projects in the forestry sector are far from being as developed as, e.g. projects of the energy sector, because of unclear political regulations and contradictions with conservation and development issues (FAO 2007; Capoor and Ambrosi 2006). Whereas, supporters emphasize on the low-costs and socioeconomic benefits, opponents often stress the high risks of leakage, the sensitivity of forests in general, the only temporal storage (Brown et al. 2002) and negative feedbacks on biodiversity (IUCN 2004; Totten et al. 2003).

Biodiversity is an essential element of forest ecosystem adaptation to climate change. Although land-use change is today still the biggest threat to biodiversity, climate change will become more and more important (van Vuuren et al. 2006). Linking biodiversity conservation and climate policy may thus benefit both and lead to properly designed mitigation projects (Mahrenholz and Georgi 2005; Ibisch et al. 2007; Barker et al. 2007). Adding synergisms of these two elements with development activities like employment creation, income generation, renewable energy supply and poverty alleviation can furthermore reduce the vulnerability of ARD projects to climate change while promoting sustainable development and secure livelihoods (Barker et al. 2007; Parry et al. 2007; Hammill et al. 2005). It is important to establish win–win situations where mitigation activities are combined with efforts to enhance the adaptation capacity. If this not achieved the impacts of climate change are likely to limit the mitigation success (Forner 2005; Murdiyarso et al. 2005).

Linking biodiversity conservation, sustainable development and climate protection is thus necessary to succeed in each of the three sectors. The climate, community and biodiversity alliance (CCBA) is an incentive trying to establish such combinations and networks and thus, in a broader sense, a very valuable climate change adaptation tool (Dutschke 2005; CCBA 2005, 2007).

The political continuity behind all these actions must also be guaranteed by clarifying the political framework for ARD activities. During the period 1970–1990 the CO_2 emissions from land-use change increased by 40%, mainly through tropical deforestation and consequently it is obvious that deforestation avoidance has the biggest mitigation potential from all types of ARD projects (Carvalho et al. 2004; Barker et al. 2007). A clear scientific, political and legal framework how to include deforestation avoidance in international climate policy must be developed (Kerr et al. 2004; Schlamadinger et al. 2005; Santilli et al. 2005). The development of a post-Kyoto process including deforestation avoidance activities has to be started and should no longer be hindered by national interests of individual countries (Ibisch et al. 2007). The recent adhesion of the USA to such a post-Kyoto process at the G8 summit (G8 2007) in Germany and the creation of the "forest carbon partnership" is a positive signal (Jellinek and Townshend 2007).

Spittlehouse and Stewart (2004) even propose to include climate change adaptation planning in forest certification and policy approaches to implement adaptation actions are developed (Wellstead et al. 2006). ARD projects may evolve with these developments and provide experiences and good examples so that their acceptance and importance gets broader attention during a second commitment period.

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