# Potential synergies between existing multilateral environmental agreements in the implementation of Land Use, Land Use Change and Forestry activities

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***Abstract***

There is potential for synergy between the global environmental conventions on climate change, biodiversity and desertification: changes in land management and land use undertaken to reduce net greenhouse gas emissions can simultaneously deliver positive outcomes for conservation of biodiversity, and mitigation of desertification and land degradation. However, while there can be complementarities between the three environmental goals, there are often tradeoffs. Thus, the challenge lies in developing land use policies that promote optimal environmental outcomes, and in implementing these locally to promote sustainable development. The paper considers synergies and tradeoffs in implementing land use measures to address the objectives of the three global environmental conventions, both from an environmental and economic perspective. The intention is to provide environmental scientists and policy makers with a broad overview of these considerations, and the benefits of addressing the conventions simultaneously.

***Keywords****:* Climate change, LULUCF, Biodiversity, Desertification, Sustainable development.

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# 1 Introduction

The United Nations Framework Convention on Climate Change (UNFCCC) recognizes that management of the terrestrial biosphere can contribute to mitigation of climate change. Within the context of climate change policy, emissions and removals of greenhouse gases resulting from direct human-induced impacts on the terrestrial biosphere are accounted within the sector known as land use, land use change and forestry (LULUCF)[1]. Besides their relevance to the UNFCCC objectives, measures undertaken in the LULUCF sector are relevant to several other multilateral environmental agreements that have entered into force during recent years, particularly the United Nations Convention to Combat Desertification (UNCCD, United Nations, 1994) and the Convention on Biological Diversity (CBD, United Nations, 1992).

This paper focuses on the implications of LULUCF measures[2] in relation to the objectives of the UNCCD, CBD and the UNFCCC. The potential synergies and possible trade-offs between the objectives of measures that may be promoted under the three

[1] National GHG inventories are currently prepared following the Revised 1996 IPCC Guidelines for national Greenhouse Gas Inventories and Common Reporting Formats, in which the Land Use Change and Forestry (LUCF) sector is reported separately from the Agriculture, Energy, Industrial Processes and Waste sectors (Houghton et al. 1997). The 2006 Guidelines combine reporting for the Agriculture and LUCF sectors under the title Agriculture, Forestry and Other Land Use (AFOLU) (IPCC 2006). In Kyoto Protocol accounting, carbon stock changes and non-CO2 emissions from afforestation, reforestation and deforestation, and, if elected, forest management, cropland management, grazing land management and revegetation are reported under "Land use, land use change and forestry" (LULUCF), except for non-$CO_2$ agricultural emissions, which are reported under Agriculture, and fuel use in agricultural and forestry operations which are reported in the Energy sector. The term "land use" is here used to include all emissions and removals associated with agricultural and forestry land uses.

[2] LULUCF measures are here defined as changes in land use and land management undertaken to reduce GHG emissions. Specific measures are discussed in Section 4 and Table 2.

environmental conventions are discussed, both from an environmental and economic perspective, and policy options for facilitating beneficial land management and land use changes are briefly outlined. The paper reflects the views and experience of the authors, and is intended to provide environmental scientists and policy makers, who commonly focus on one specific field, with a broad overview of these considerations, and the benefits of addressing the conventions simultaneously.

# 2 Historical background

Human activity inevitably has impacts on the land. As expressed in the Stockholm Declaration (United Nations Conference on the Human Environment, 1972) "Man is both creature and moulder of his environment". The first major human-induced land use changes are associated with the burning practices of indigenous peoples, for example in Australia (Yibarbuk et al., 2001) beginning in the late Pleistocene and North America in the early Holocene (MacCleery, 1999): altered fire regimes, whereby aboriginal mosaic burning replaced infrequent intense lightning-induced fires, are considered responsible for displacement of forests by woodlands and grasslands, and thus a reduction in carbon stocks. Subsequently, the first agricultural revolution of the Neolithic (Mazoyer and Roudart, 1997) with extensive deforestation phenomena due to "slash and burn" technologies that dominated for thousands of years, substantially affected land use patterns in many parts of the world. The relationships between Neolithic land use, world-wide migration patterns, and technological evolution have been explored by Diamond (1999), and described mathematically by Wirtz and Lemmen (2003). Could it be that land use contributed to the change in climate during the mid-Holocene shift? Recent definitions of the Anthropocene place the start of the Anthropocene in the late eighteenth century (Crutzen, 2002), when analyses of air trapped in polar ice show the beginning of growing global concentrations of carbon dioxide and methane. Certainly Neolithic agriculture had a negligible impact on climate, but influence on early land degradation phenomena, like erosion and decline of organic matter content in soils, is apparent: most of the land degradation phenomena in the Mediterranean basin commenced in the Neolithic, subsequently reaching a peak during Roman times (Lowdermilk, 1953); extensive erosion by water in the Apennines of Central Italy that can be considered as early forms of desertification in the area. Soil salinisation caused by poor irrigation practices led to widespread land degradation in Mesopotamia in 2000 BC (Jacobsen and Adams, 1958).

From the perspective of global climate change, greenhouse gas emissions from human influence on the biosphere started well before the inception of the Anthropocene, as defined by Crutzen. Figure 1 represents in a simplified way the changes in the terrestrial organic carbon pool generated from the sequence of aboriginal burning, through agricultural revolutions, till today, and depicts the projected changes if positive LULUCF measures are implemented in the future. This historical time trend demonstrates that human activities have generally tended to reduce the terrestrial carbon pool over time. It also exemplifies the concept that the potential to restore the carbon pool is limited by resource constraints[3].

*Insert Figure 1 near here*

[3] The natural resource constraints at a site determine the natural carbon carrying capacity, however, human intervention can overcome natural resource constraints, and thereby raise the maximum potential carbon stock at a site.

The natural capacity of an environment should be a guide to the selection of appropriate LULUCF measures for a particular site. Paleovegetation maps, showing the distribution of the major vegetation types before the Anthropocene, give an indication of the natural carbon carrying capacity of different regions, based on local biophysical constraints (Crowley, 1995; Adams and Faure, 1997). The notion that LULUCF measures are site specific is of crucial importance and will be addressed in more detail in subsequent sections of this paper.

# 3 Policy instruments steering sustainable land management

Land use and land use change are driven by economic and social influences, but with the recognition of the concept of sustainable development, environmental and sustainability concerns have started to influence land use policy. The report of the World Commission on Environment and Development (WCED), *Our Common Future* (WCED, 1987), also known as the "Brundtland Commission Report", has significantly influenced sustainability policy in the western world (eg MacNeill, 1989, p11). The WCED report promoted sustainable development as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs'. Out of this framework the term "sustainable land management" was defined.

Numerous multilateral environmental agreements have been ratified in recent years addressing specific aspects of sustainable land management, environmental degradation and resource depletion; those that influence, or are influenced by, LULUCF actions are listed in Table 1. Three conventions emanating from Agenda 21 (United Nations, 1992c)., established at the UN Conference on Environment and Development (UNCED) in Rio de Janeiro in 1992, have particular relevance to LULUCF:

- Framework Convention on Climate Change (UNFCCC)
- Convention on Biological Diversity (CBD)
- Convention to Combat Desertification (UNCCD)

*Insert Table 1 near here*

### *3.1 LULUCF within UNFCCC*

The ultimate objective of the UNFCCC, adopted in 1992, is to stabilize greenhouse gas emissions "at a level that would prevent dangerous anthropogenic (human induced) interference with the climate system". Parties agreed to develop and implement policies and programs to reduce greenhouse gas emissions, to report annual inventories of emissions, and to provide support to developing countries. The commitments of parties were strengthened through the adoption, in 1997, of the Kyoto Protocol, under which industrialised countries committed to individual legally-binding targets.

Recognising the contribution of the terrestrial biosphere to emissions and removals of greenhouse gases, net change in carbon stocks in biomass, litter and soil are included in inventory reporting. The basic premise is that through LULUCF measures the terrestrial carbon pool can be increased, by increasing the above and below ground biomass and consequently the soil organic matter pool. Thus, the Kyoto Protocol allows parties to offset emissions from other sectors against removals generated through specific LULUCF activities: under Article 3.3 of the Protocol, removals due to afforestation and reforestation since 1990 are accounted towards commitments. Emissions resulting from deforestation must also be included. Under Article 3.4 parties can elect to include additional LULUCF activities, viz. forest management, cropland management, grazing land management and revegetation.

Article 12 of the Kyoto Protocol defines a Clean Development Mechanism whereby developed countries (the "Annex 1" countries that have an emissions target under the Protocol) earn "certified emissions reductions" through projects implemented in developing countries. This mechanism is intended to promote projects that contribute to sustainable development in the host country. Afforestation and reforestation projects are eligible, though other LULUCF measures are not. In order to demonstrate contribution towards the goals of sustainable development, project proponents are required to assess the environmental and socio-economic impacts of the proposed project, and to seek input from local stakeholders.

## *3.2 LULUCF within CBD*

The goals of the Convention on Biological Diversity (CBD) are "the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources" (CBD, 1992). The provisions in the convention require parties to, inter alia, implement measures to protect biodiversity, and particularly to protect and promote recovery of threatened species. Measures include establishment of a system of protected areas, and promotion of "environmentally sound and sustainable development" adjacent to protected areas. The provisions of the CBD are general in nature, and do not involve binding targets. They include financial contribution towards biodiversity protection in developing countries, scientific and technical co-operation between parties, access to genetic resources, and the transfer of environmentally-sound technologies.

In 2002, recognising that the rate of loss of biodiversity was continuing to increase, the parties to the convention agreed to a strategic plan intended to halt the loss of biodiversity. Parties committed to the "2010 Biodiversity target", that is "to achieve by 2010 a significant reduction of the current rate of biodiversity loss at the global, regional and national level as a contribution to poverty alleviation and to the benefit of all life on earth". Outcome-oriented targets, on a global basis, have been agreed, and include a target of "at least 30 per cent of production lands managed consistent with the conservation of plant diversity". Actions to be taken include conserving production species, protecting other species in the landscape, and introducing management practices that minimise adverse impacts on surrounding ecosystems, such as by reducing export of agri-chemicals and preventing soil erosion.

The strategic plan includes the goal to reduce pressures from habitat loss, land use change and degradation, and unsustainable water use, and to enhance resilience to climate change. Parties are to implement national polices and programs targeted toward these goals.

### *3.3 LULUCF within UNCCD*

The United Nations Convention To Combat Desertification (UNCCD, 1994), the third of the Rio Conventions, is often called the "convention of the poor". Its main focus has been to combat desertification and mitigate the effects of drought in developing countries, particularly sub-Saharan Africa. Desertification, defined as land degradation in dryland areas, is as much a social and economic issue as an environmental concern. Therefore, as its main target the UNCCD aims to fight poverty and promote sustainable development and is consequently mostly oriented towards development aid measures rather than environmental protection.

Land degradation is estimated to affect 10 to 20% of the world's drylands (Millennium Ecosystem Assessment, 2005a). Desertification is caused by climate variability and unsustainable human activities, such as overcultivation, overgrazing, deforestation, and poor irrigation practices. These practices lead to erosion of topsoil, loss of soil organic matter, and soil salinisation, which in turn cause loss of biological and economic productivity and diversity in croplands, pastures, and woodlands. Deforestation in dryland regions of Australia, North America, South Africa, Iran, Afghanistan, Thailand and India has led to development of dryland salinity. Under the convention, parties agreed to implement national, sub-regional, and regional action programmes, and to seek to address causes of land degradation, such as international trade patterns and unsustainable land management.

## *3.4 Synergies between the conventions*

Each of the three global environmental conventions deals with the interrelationships between humans, animals, plants, soil, air and water. The environmental issues are themselves intertwined: climate change is a major threat to conservation of biodiversity and is likely to exacerbate desertification and drought in some regions; deforestation reduces biodiversity, reduces carbon stocks in biomass and soil thereby exacerbating climate change, and can lead to desertification; desertification further contributes to climate change through increase in land-surface albedo; dryland salinity, a symptom of desertification, threatens biodiversity. An in-depth analysis of the negative feedback loops linking desertification, climate change and biodiversity loss has been recently published (Gisladottir and Stocking, 2005). The relationships between desertification and LULUCF have been extensively reviewed in the Millennium Ecosystem Assessment (2005b).

The impacts on biodiversity and land degradation of LULUCF measures undertaken for mitigation of climate change are further explored in Section 4. There are many opportunities to build synergy among the activities undertaken in support of these various commitments. These linkages mean that it is vital for the measures implemented under these conventions to be integrated. There are multiple benefits from seeking synergy in implementation of the conventions: strengthening the effectiveness of actions undertaken in support of the conventions and ensuring efficient use of human and financial resources in planning, implementing, monitoring and reporting. The need for monitoring, prediction, mitigation and adaptation are common to all three conventions; besides efficiencies from linking these activities, such as through sharing data and tools, development of policy mechanisms and approaches will benefit from sharing collective wisdom on successful approaches. The economic benefits of joint regulation are further explored in Section 5.

The CBD's ad hoc technical expert group on Biological Diversity and Climate Change identified opportunities for mitigating climate change, and for adapting to climate change, while enhancing the conservation of biodiversity (CBD, 2003).

The United Nations Forum on Forests' Collaborative Partnership on Forests (CPF) program aims to foster cooperation and coordination among international organizations that promote Sustainable Forest Management. Activities of the CPF include work on harmonising terms and definitions used in forest management, and facilitation of streamlining of reporting on forest issues to the UNFCCC, CBD and UNCCD. (UNFF, undated)

The parties to the conventions have acknowledged the convergence of objectives of the three Rio conventions, accepted the necessity to integrate actions to ensure optimal environmental outcomes, recognised the benefits of exploiting the synergies, and therefore called for enhanced collaboration among the conventions (UNFCCC, 2004).

Efforts to integrate the conventions are led at the international level by the Joint Liaison Group (JLG) of the UNFCCC, CBD and UNCCD, established in 2001. The JLG facilitates collaboration between the secretariats of the three Conventions and promotes integration through sharing of information, coordination of activities, and identification of measures that simultaneously address all three issues (CBD, undated; UNFCCC, 2004). Actions include a workshop on synergies between the three conventions with respect to forests and forest ecosystems (UNCCD, 2004). At its fifth meeting (FCCC/SBSTA/2004/INF.9), the JLG discussed the potential for the Global Environmental Facility (GEF), which provides support for capacity building and technology transfer, to support synergies by promoting implementation of projects in a coordinated and cooperative manner.

By definition, the UNCCD applies only in dryland regions, that is, the arid, semi-arid and dry sub-humid. Thus, integration of the three conventions is not universally applicable. However, issues of land degradation occur globally. Just as it is desirable to seek synergy in implementation of the UNFCCC, CBD and UNCCD in dryland regions, it is appropriate to look for mutually beneficial actions that meet the objectives of climate change mitigation, biodiversity protection and protection against relevant forms of land degradation in those regions not covered by the UNCCD.

# 4 LULUCF activities and their influence on climate change, biodiversity and desertification

LULUCF measures implemented to mitigate greenhouse gas emissions may also affect, positively or negatively, desertification and conservation of biodiversity. The influences of broad categories of LULUCF actions are discussed below, and impacts of specific actions are listed in Table 2. Before considering these impacts, we will firstly outline the measures by which impacts on each of the three environmental attributes are quantified.

INSERT TABLE 2 NEAR HERE

## *4.1 Quantifying impacts of LULUCF measures*

### 4.1.1 Climate change impacts

The carbon sequestration impact of change in land use or land management on an area of land is determined from the difference in average carbon stock between the new system and the previous land use. Quantifying impacts of LULUCF measures requires estimation of biomass growth and change in soil carbon, using measurements (eg MacDicken, 1997; Janik et al., 1998; Brown et al., 2006), empirical or process based models (eg Masera, 2003; Richards and Evans, 2004; Kurz and Apps, 2006), or look-up tables (such as "Tier 1" methods for reporting national greenhouse gas inventories (IPCC, 2006)). In addition to emissions and removals estimated from C stock change, emissions of non-$CO_2$ GHGs (particularly $N_2O$ and $CH_4$) should be included in assessing climate change impact.

Internationally agreed methodology for estimating emissions and removals from LULUCF activities is given in publications of the IPCC (Houghton, 1997; Penman, 2003, IPCC, 2006).

Forest biomass can be used for bioenergy or for products that can substitute for more greenhouse-intensive products, displacing fossil fuel emissions. The mitigation benefits of these downstream activities should be included in the assessment of the impact of LULUCF activities.

### 4.1.2 Biodiversity impacts

While greenhouse gas mitigation potential is readily estimated by internationally agreed methodologies, estimating biodiversity value is very much more challenging. Predicting impacts of change in land use or land management often involves a degree of subjectivity and reliance on surrogates, and may include measures of taxonomic diversity, conservation status, patch size and shape, and connectedness. Many indices for quantifying and predicting biodiversity value of proposed land use changes have been developed (eg Freudenberger and Harvey 2003; Oliver and Parkes, 2003; Gibbons et al., 2005).

### 4.1.3 Desertification impacts

Like biodiversity, the impact of land use and land use change on desertification is difficult to quantify. Major causes of desertification are deforestation, overgrazing, cultivation of unsuitable sites, and poor irrigation practices, that lead to wind and water erosion, dryland and irrigation-induced salinity. Because the symptoms of desertification are diverse, quantifying potential benefits is challenging. Measures include stream turbidity and salinity, sediment and salt loads in waterways, water table depth, incidence of dust storms. Predicting impacts of LULUCF activities on these attributes requires complex spatial process-based modelling utilising data on local soil type, geology, elevation, and climate. Assessment of land use practice with respect to land capability can provide an indicator of risk of land degradation (Emery, 1985).

### 4.1.4 Integrated measures

Integrated measures seek to evaluate the combined impact of land use activities on the target environmental objectives. However, these measures are difficult to establish because environmental qualities are estimated in different physical units. Frequently proposed remedies involve the computation of environmental indexes or money equivalents for environmental goods. Environmental benefits indices are calculated from normalised measures of each biophysical attribute, weighted and aggregated to give a single score that integrates all environmental attributes of interest (eg index applied in the Conservation Reserves Program in the USA (USDA, 1999, 2003)). Arnalds' (2005) Sustainability Index Model considers social impacts in addition to assessing the impact of the proposed land use on land condition, including long term impact on the resource base. Measures of "inclusive wealth" (Arrow et al., 2003) value natural and human capital, as a metric for assessment of sustainability.

## *4.2 Afforestation and reforestation*

The impact of afforestation/reforestation on net GHG emissions, biodiversity and desertification is dependent on the features of the forest system established and the land use that it replaces.

The maximum potential carbon stock at a site, that is, its carbon carrying capacity (Gupta and Rao, 1994), is determined by climatic and edaphic factors that determine the net ecosystem productivity, and the influence of disturbances, such as fire, that together determine the net biome productivity[4]. The carbon stock of a managed forest is a function of site productivity and silvicultural management (stocking rate, species, pruning, thinning). The carbon sequestration benefit of a change in land use or management is determined by the increase in carbon stock of biomass and soil between the original and new land uses. Practices that maximise carbon sequestration in forest biomass are those that enhance forest growth: matching species to site, good site preparation, managing weed competition, and applying fertiliser to correct nutrient deficiencies and maintain fertility. Usually, practices that enhance forest growth will also build soil carbon stocks, through increased organic matter addition. However, where soil carbon stocks are high, and mineralisation is limited by nutrient deficiency, fertilisation can cause loss of soil carbon (Cleveland and Townsend, 2006). In forest systems managed for sawlog production, there will be a trade-off between management that maximises forest carbon stocks and returns from wood products, because silviculture to maximise value of stems (i.e. thinning and pruning) will reduce the total stand biomass and thus stock of carbon. Short rotation plantations managed for fibre production will have a lower average carbon stock, across successive rotations, than long rotation plantations managed for timber production.

Afforestation/reforestation of cropped or degraded land will enhance soil carbon stocks as well as biomass stocks. However, reforestation of pasture land may lead to a loss of

[4] Climate change will alter the carbon carrying of a site.

soil carbon, at least in the short term (Paul et al, 2002; Cowie et al, 2006). Reforestation with coniferous species generally decreases soil carbon stocks by around 15% (Guo and Gifford, 2002; Paul et al., 2002), partly offsetting the mitigation benefits of sequestration in tree biomass.

The mitigation benefit through reforestation of a particular site is finite – determined by the difference in long term average carbon stock between the forest system and prior land use. However, the net mitigation benefit of afforestation or reforestation projects can be increased through utilisation of forest biomass for bioenergy, thereby providing ongoing mitigation through avoidance of fossil fuel emissions (Marland and Schlamadinger, 1997). Afforestation and reforestation projects can provide an additional benefit through provision of building materials that can displace more greenhouse-intensive materials (eg Börjesson and Gustavsson, 2000; Pingoud et al., 2003).

Reforestation of cropped or degraded land can have positive impacts for biodiversity conservation and mitigation of degradation. Afforestation and reforestation with native species may help promote the return, survival, and expansion of native plant and animal populations. If the plantation provides a corridor function for species migration (for instance under climate change pressure) and gene exchange, biodiversity will be positively affected.

When sited strategically within the catchment to reduce salt export and manage deep drainage, reforestation can mitigate dryland salinity, protecting productivity of agricultural land (eg Stirzaker et al., 2002; Ellis et al., 2006) and the biodiversity in conservation areas threatened by rising saline water tables (Goudkamp et al., 2003).

Plantations may benefit biodiversity indirectly if they reduce pressures on natural forests by serving as sources for forest products.

Systems designed to maximise carbon sequestration may not deliver optimal outcomes for other environmental objectives. Biodiversity value is likely to be lowest in short rotation monocultures, greater in long rotation sawlog plantations, and highest in permanent mixed stand of endemic species, though growth rate, and therefore carbon sequestration, is likely to be greater in an exotic monoculture plantation, at least in the short term. Afforestation and reforestation activities that replace species-rich grasslands or shrublands, while delivering climate change benefits, are likely to reduce biodiversity.

### *4.3 Agroforestry*

Agroforestry refers to the integration of trees (alleys, tree belts, small block plantings, riparian strips) into cropping or pastoral systems. Increase in use of trees in agricultural landscapes through agroforestry systems has a large potential to sequester carbon, both in woody biomass and in soil (Vagen et al., 2005), due to the vast areas of land used for agricultural purposes (Montagnini and Nair, 2004). Integration of a tree component may also enhance carbon stock of the adjacent agricultural enterprises such as by reducing wind erosion and providing habitat for beneficial organisms.

Agroforestry can be beneficial for biodiversity, especially in agricultural regions dominated by crop monocultures. As with afforestation and reforestation, agroforestry is most beneficial for biodiversity when it replaces degraded or deforested sites. Even small tree blocks or individual paddock trees can provide valuable contributions to biodiversity in agricultural landscapes (Kavanagh et al., 2005).

Agroforestry is recognised as a major contributor to combating desertification, particularly through reduction in soil erosion (FAO, 1992), and agroforestry programs are major components of the national and regional action programmes under the UNCCD.

Agroforestry can be effective in managing dryland salinity: strategically sited belts of trees within an agricultural landscape can intercept runoff and lateral flow, reducing salt movement to streams and accession to groundwater (Ellis et al., 2006). Tree belts can lower the water table locally, permitting cropping on sites that have become unproductive due to shallow saline groundwater (Robinson et al., 2006).

Agroforestry increases the diversity of agricultural systems, enhancing resilience, both ecologically and economically. Agroforestry may be more acceptable to communities than large scale reforestation, as traditional agricultural commodities can continue to be produced, and agroforestry can be introduced through modification of existing farming practices rather than complete change in land use.

## *4.4 Revegetation*

Revegetation refers to enhancement of carbon stocks other than by establishment of vegetation that meets the definition of "forest". This may include establishment of shrubs, or tree planting at low stocking rate. Revegetation practices have limited scope to increase carbon sequestration compared with reforestation, but may have a significant impact through increase in soil carbon stocks. Revegetation can have major benefits for biodiversity and land degradation.

## *4.5 Land management*

The term land management refers to the management of forests, croplands and grazing lands.

Forest management practices that mitigate GHG emissions are those that increase forest carbon stocks, including reduction in disturbances such as fire, extending rotation length, and fertilisation. Management of fire to reduce widespread stand-replacing wildfires, and extending rotation length, also have positive impacts for conservation of biodiversity and mitigation of desertification.

In cropping and grazing systems, the major factors that can deliver net greenhouse gas emissions reduction are increase in soil C stocks, and reduction in non-$CO_2$ emissions such as nitrous oxide from fertiliser application. Soil carbon stock reflects the balance between inputs, from plant litter or organic amendments, and losses due to oxidation and, to a lesser extent, erosion of topsoil (Cowie et al., 2006). Therefore, soil C stock is increased by practices that increase plant production (eg irrigation, fertilisation) and reduce loss of organic matter (eg reduction in tillage or grazing pressure) (Sampson et al., 2000). Due to the vast areas of cropping and grazing land, small increases per unit area can deliver significant mitigation of GHG emissions.

There is growing interest in the use of crops for production of biofuels and other non-food commodities. Use of ethanol or butanol produced by fermentation from sugar and starch crops, and biodiesel from oilseeds, can give significant mitigation benefit through substitution for fossil transport fuels (eg Sheehan et al., 1998; Farrell et al., 2006). Similarly, short rotation woody crops can be used to generate heat and electricity. Novel crops such as jatropha, crambe and guayule may play a role in replacing petrochemicals. Besides concern over climate change, recent sharp increases in fuel prices and concerns over energy security are added incentives for expansion of non-food crops. There is a risk that increased removal of biomass in bioenergy systems could reduce soil carbon, but as long as the root and leaf litter biomass, that constitute the major input to soil C, are retained on site, the impact on soil C of removal of biomass for bioenergy should generally be small (Cowie et al., 2006).

Modification of cropping and grazing practices impacts biodiversity. Generally, low intensity of fertilization, pesticide, and cutting and grazing promote a diverse and ecologically more desirable species composition (Muller, 2002; Buckingham et al., 2006). Practices that enhance soil carbon stock and prevent land degradation, will generally enhance conservation of native species present in those landscapes (eg Adl et al., 2006). However, pressure to expand crop production for biofuels may lead to conversion of pasture and woodland to cropland, with negative consequences for biodiversity.

Modification of cropping and grazing practices can have significant impacts in mitigation of desertification: reduced tillage and stubble retention, establishing perennial pastures, managing grazing to maintain vegetative cover will reduce land degradation through soil erosion; maintaining vegetative cover and introducing deep-rooted perennials can contribute to mitigation of dryland salinity. Risk of desertification is minimised when land is used according to its "capability", that is, its ability to produce outputs without resulting in land degradation or negative off-site impacts. Land capability assessment determines the suitability for alternative land uses, within constraints imposed by hazards such as erosion, acidification and salinisation due to attributes including soil type, slope and landscape position. For example, an assessment of land capability would steer cropping away from steep slopes with erodible soil types toward lower slopes and soils with high aggregate stability. Pressure to expand cropping for production of biofuels may exacerbate land degradation, if lands of lower capability are cropped.

### 4.6 Avoidance of deforestation

Deforestation leads to immediate loss of biomass carbon stocks and associated soil carbon, and ecosystem services provided by forests. Clearing of natural forests directly reduces abundance of native species, and forest fragmentation may threaten survival of remnants. Fragmentation increases exposure to pest incursion and fire, may reduce populations below viable threshold, and reduces capacity to adapt. Many of the tropical forests in developing countries of South America and Asia have high carbon stocks, are recognised as biodiversity 'hotspots', and are threatened by deforestation (Huston, 1993). Deforestation leads to land degradation through soil erosion and development of soil salinity.

### 4.7 Common themes: beneficial practices

The impacts of LULUCF on climate change mitigation, protection of biodiversity, and desertification discussed above and listed in Table 2 are a result of the influence of human intervention on the underlying processes that drive greenhouse gas emissions, integrity of natural ecosystems, and land degradation, respectively. Climate mitigation benefits are afforded by practices that

- avoid deforestation, devegetation and degradation
- increase carbon stock in biomass pools
- reduce direct and indirect fossil fuel use (eg reduced tillage)
- protect and enhance the soil organic matter pool

- reduce emissions of non-$CO_2$ greenhouse gases.

Biodiversity is generally conserved by (inter alia)

- management of threats to natural ecosystems such as deforestation, dryland salinity
- increased diversity of production species in managed systems
- afforestation/reforestation and revegetation of arable and degraded land
- reduced soil disturbance and enhanced soil organic matter.

Protection against desertification is provided by

- maintenance of perennial vegetative cover to reduce erosion of topsoil
- maintenance of soil organic matter, which enhances aggregation, thus increasing infiltration and thereby reducing runoff and consequent erosion, and increases nutrient and water holding capacity, thus increasing productivity and resilience against drought.
- reforestation to mitigate dryland salinity
- management of irrigation practices and reforestation to reduce salinisation.

While some LULUCF measures can be detrimental to conservation of biodiversity or mitigation of land degradation, as indicated in Table 2, there are many opportunities for synergistic interactions. For example, many dryland ecosystems are sites of significant biodiversity; conservation and restoration of this habitat, while protecting these ecosystems, also increases carbon stocks, and reduces land degradation. Reversing land degradation builds resilience in natural and managed systems, sustaining production and protecting biodiversity. Activities that promote adaptation to climate change can also contribute to the conservation and sustainable use of biodiversity and sustainable land management. Measures that protect or enhance biomass and soil OM stocks tend to deliver benefits for all three environmental objectives. The most significant measures are reforestation, avoided deforestation and avoided degradation. The optimal mix of LULUCF measures will vary between locations because of the diversity in current land use, conservation status and socio-economic situation.  Reducing deforestation is a major opportunity in countries such as Brazil, Indonesia, Malaysia (e.g., Fearnside, 2001). In countries such as India, China and the USA there are opportunities for reforestation of marginal and degraded agricultural lands, and modification of agricultural practices. Adjusting forest management regimes, and utilisation of forest products, are significant options in many industrialised countries.

# 5 Economic impacts of multi-environmental objectives in agriculture and forestry systems

Pursuing multiple environmental objectives through LULUCF measures will affect social welfare in various ways. Direct and indirect benefits of improved environmental quality must be weighed against economic surplus changes in commodity markets, diverse externality impacts, and policy transaction costs. Here we will focus on those impacts which differ between independent and joint regulation of climate change, biodiversity, and land degradation. In examining the economic implications, we will discuss the opportunity costs of LULUCF measures resulting from the scarcity of land, land use responses to environmental policy instruments, and externality feedbacks.

## 5.1 Land opportunity cost impacts

Numerous LULUCF measures have been classified as potentially beneficial with respect to one or more environmental qualities. While the direct costs of using these strategies may be quite low[5], the true cost of implementation may be much higher. An often ignored or underestimated[6] economic barrier for LULUCF measures relates to the scarcity of land and resulting rents. Economically, land rents constitute opportunity costs and equal the difference between marginal revenues[7] and marginal production cost for the most profitable land use option. This difference equilibrates market demand and supply of land based products and services, where scarcity limits supply. Thus, diverting land from productive agricultural zones for afforestation, perennial bioenergy crop plantations, conservation reserves, or soil protecting buffer zones causes a loss of agricultural profits and constitutes an indirect cost for these abatement strategies (Schneider and McCarl, 2006).

Four issues are important when considering LULUCF opportunity costs in the context of multi-environmental objectives. First, each internalized environmental objective changes the opportunity costs. For example, demand for carbon sequestration credits establishes a potential revenue opportunity for some LULUCF measures, equalling the product of sequestered carbon credits times the credit value. This increases the opportunity costs of all land use options with zero or negative sequestration rates. Furthermore, environmental subsidies frequently increase commodity prices because

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[5] For example, to protect native ecosystems, direct costs may only consist of monitoring and enforcement.
[6] This refers to the omission of opportunity costs in a large number of abatement studies.
[7] Revenues also include subsidies where they apply.

abatement strategies decrease commodity supply. Higher commodity prices in turn increase possible revenues from land use and make land more valuable.

Second, opportunity costs differ considerably across regions and reflect site specific soil, climate, and market conditions. Particularly, the market profit is dependent on local commodity prices, crop yields, and production costs; the carbon sequestration benefit is determined by plant growth rate, which is dependent, inter alia, on climatic and edaphic regime; the biodiversity benefit is affected, inter alia, by the bioregion, current land use and distance to remnant native vegetation; the salinity mitigation benefit is governed by geology (whether there are salts in the soil and underlying rock strata), surface and groundwater hydrology (whether the site is discharging saline water to streams or groundwater) and plant growth rate (which determines water use); the soil retention benefit is dependent on soil type, slope, landscape position and location within the catchment.

Third, while opportunity costs are site specific, they also respond to macro-economic market adjustments. As trade barriers decline, price changes are transmitted globally. If large-scale environmental regulations reduce commodity supply, world prices and hence opportunity costs of these commodities will increase globally. Fourth, opportunity costs change in a nonlinear fashion. This applies especially to opportunity costs from food production. Demand for food is relatively inelastic because – regardless of food prices – people must eat a certain minimum amount but will not consume food beyond a certain level[8]. Supply shifts in inelastic commodity markets cause strong price

[8] We recognise that many people suffer from malnutrition and that low prices may cause a change of eating habits towards more animal products which results in increased demand for land allocated to food

responses. Therefore, if environmental abatement decreases food supply, food prices may increase more than proportionally, as will the marginal opportunity costs of additional abatement.

In summary, pursuing single or multiple environmental objectives alters local and supra-regional demands for LULUCF activities which in turn changes opportunity costs of land use. Increases in demand for land are highest under multiple separate, subsidy based environmental regulations. Opportunity costs are an important component for determining the likely LULUCF response to environmental policies, which is discussed in the following section.

### *5.2 LULUCF response to environmental regulations*

How do single-policy based LULUCF responses compare to those from multiple environmental policies? First and foremost, preferred strategies are those which yield the highest net revenue under local conditions. Net revenues are the sum of market revenues and non-market net benefits over all internalized environmental attributes. Both market and non-market benefits for LULUCF measures are different under single-criterion than under multi-criteria regulations.

Let us first consider non-market impacts. As discussed in Section 4, LULUCF measures affect many environmental attributes simultaneously. In some cases, LULUCF actions could deliver "win-win" outcomes: actions that provide benefits in terms of climate change mitigation and also provide increased biodiversity and mitigation of desertification. For example, in dryland agricultural areas, reforestation can

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production. However, the emphasis here is on the "relative" (in)elasticity of demand for food relative to that of non-basic commodities (eg entertainment).

simultaneously sequester carbon, enhance biodiversity, reduce salinisation, and decrease soil erosion. Win-win options become most attractive under multi-criteria environmental regulations because incentives accumulate.

Other measures that maximise outcomes for one environmental attribute may deliver sub-optimal solutions in one or some other areas. For example, monoculture plantations may have high carbon sequestration rates, but are likely to have low biodiversity value. LULUCF measures with mixed environmental effects[9] are very attractive under single criteria policies which internalize the environmental attribute for which the measure is well-suited. Under joint environmental regulations, negative environmental impacts would be subtracted from positive ones, altering the profitability of some LULUCF measures. Enhancing productivity far in excess of the natural carbon carrying capacity[10] may not only be expensive to sustain, but may also have adverse off-site environmental and economic impacts: afforestation of grasslands may utilise freshwater lenses overlying saline groundwater, leading to land salinisation and threatening drinking water supply (Jackson et al., 2005); reduction in stream flow due to afforestation (Farley et al., 2005) may adversely impact downstream ecosystems and communities; introduction of irrigation may cause land salinisation, reduced quality of surface- and ground-water supplies for urban and rural uses, and damage to infrastructure; excessive fertilisation may cause eutrophication of waterways, impacting aquatic biodiversity and water quality for downstream users. Under joint regulation, some of these land use options may be unprofitable. For other measures with mixed effects, multi-criteria regulations could create an incentive to adapt management practices to gain

[9] That is, positive for some attributes and negative for others.
[10] Carbon stock maintained under available biophysical resources

benefits for one attribute without jeopardising another. For example, interplanting a nitrogen-fixing species with a non-N-fixing species can increase total biomass, reduce fertiliser requirements, and increase biodiversity compared with a monoculture of the non-N-fixing species (eg Forrester et al., 2005a, 2005b). Similarly, if climate policy incentives are coupled with consideration of water and nutrient balance, sustainable systems with enhanced productivity may be devised. For example, if macro and micro nutrients are added in sufficient quantity to match outputs, (offtake in product, plus losses due to volatilisation, erosion, runoff, leaching), and efforts are taken to minimise off-site impacts due to those losses, productivity of a low fertility site can be increased sustainably. Similarly, irrigation systems designed to achieve maximum water use efficiency may enhance growth rates in dry environments with minimal off-site impact. Plantations sited such that they intercept runoff from non-forested areas will achieve higher growth rates than those relying on incident rainfall and, if located appropriately, may reduce salt delivery to streams (Ellis et al., 2006).

Multi-environmental agreements also affect market profits from LULUCF measures. Price changes in response to LULUCF commodity supply shifts change the direct net revenues but also opportunity costs. Schneider, McCarl, and Schmid (2006) illustrate this complex LULUCF behaviour for hypothetical climate policies imposed on the US agricultural sector. At a low value for carbon, the optimal LULUCF response is predominantly tillage reduction to sequester soil carbon. Higher incentives lead to a double strategy. On one hand, substantial agricultural areas are diverted to perennial energy crop plantations and new forests. At the same time, the reduced area remaining in agricultural production is managed more intensively, i.e. irrigation and fertilization increases. This happens because of market price feedbacks. Afforestation and energy crop plantation decrease supply of traditional agricultural commodities and thereby cause prices to increase. Higher prices in turn promote yield intensive strategies. Thus, different policy incentives can lead to very different LULUCF responses.

## 5.3 Externality impacts

Externalities of environmental agreements include i) changes in the distribution of economic welfare between different segments of society, ii) impacts on other governmental policies, iii) environmental impacts on unregulated environmental goods, and iv) sub-optimal outcomes of short term decision-making. Changes in welfare distribution depend on how policy-induced land use changes affect traditional agricultural and forest production. Afforestation, perennial bioenergy crops, and expansion of nature reserves compete directly with traditional food, fibre, and timber production and decrease supply. Agroforestry, reduced tillage, and other soil preserving LULUCF measures are more complementary to traditional agricultural and forest production and, therefore, have limited supply impacts. While these impacts may be slightly negative in the short term, they could be positive in the longer term because soil conservation measures also augment productivity levels. Furthermore, production will be affected by the choice of policy instrument. Generally, environmental taxes increase the production costs of agriculture and forestry and therefore cause negative supply shifts. This is based on the assumption that the tax revenue is not returned entirely to agricultural and forest producers; responses to subsidies are opposite.

The social welfare implications of food supply shifts are complex. In the US and EU, declining agricultural commodity prices have made it more and more difficult for domestic agricultural businesses to survive without governmental support. As a result, income support policies such as the US farm bill (Sumner, 2003) or the Common Agricultural Policy (OECD, 2006) have emerged which transfer a large amount of general governmental tax money to farmers. Environmental policies that cause negative supply shifts resulting in higher commodity prices would alleviate the need for these controversial farm policies. More generally, the aforementioned relatively low elasticity of food commodity demand is likely to shift economic welfare from consumers of agricultural commodities to producers (Schneider et al., 2007). In relatively affluent societies, this redistribution is welcome because it transfers economic surplus from society as a whole to a relatively small segment of society [11] with below average income. In poor countries, rising prices for food would also increase business opportunities in the LULUCF sector but at the same time could exacerbate malnutrition for other segments of society.

Multi-environmental policies are likely to have stronger negative food supply impacts in the short term because more environmental objectives have to be met. Thus, affluent societies may favour such agreements over single-criterion policies because on top of the increased environmental gains, farmers and foresters may require less governmental support. In the longer term, food supply under multi-environmental agreements may in fact be higher than under single-criteria policies. Bioenergy policies leading to excess biomass removal may over time degrade soils and productivity. In

[11] The ratio of people working in agriculture relative to the total number of workers in some countries has decreased to less than 1:50 (calculated from FAO, 2006).

contrast, combined climate mitigation and soil preservation policies may increase future productivity.

Let us now consider the impact of environmental policies on unregulated environmental qualities. As discussed above, both positive and negative impacts are possible. Farmers adopting reduced tillage systems in response to climate policies may – depending on local conditions – deliver additional positive environmental impacts through reduced erosion, more biodiversity, and reduced nutrient leaching into rivers (Lal et al., 2004; Power et al., 2001). However, the same climate policy may trigger the replacement of a native pasture by a biomass maximizing monoculture stand with detrimental biodiversity impacts (Ranney and Mann, 1994). When comparing single and multi-criteria environmental policies, the essential question is: do the positive externalities of single criteria policies outweigh possible negative externalities? The answer is no. As argued in section 5.2, single-criterion policies offer fewer incentives to "win-win" strategies but higher incentives to strategies with negative environmental externalities. Thus, single-criterion environmental regulations are likely to generate a *cross-pollutant leakage*, i.e. benefits from regulated pollutants decrease through environmental costs from increased unregulated pollution. Nevertheless, single criteria policies may have positive environmental side effects if the reduced incentive of "win-win" strategies is still higher than the enhanced incentive of "win-loss" strategies.

Another potential externality involves *cross- regional leakage*, that is, off-site consequences of the LULUCF project: reforestation of arable land may lead to conversion of other land – forest or grazing land - to cropping in order to supply the demand for food and fibre. Cropping may be pushed onto marginal lands, requiring greater area to achieve the same yields. Thus, there may be loss of carbon stocks, increased fossil fuel emissions, and possibly loss of biodiversity, or increased risk of land degradation off-site caused by the reforestation project. Offsite leakage can occur at different scales spanning local to international ranges. Legislation limited to individual counties or states may result in negative impacts in neighbouring states, and may be easily detected. In the following example, however, leakage is indirect, and may not be identified: introduction of legislation governing land clearing in the Australian States of Queensland and New South Wales has halved emissions due to deforestation in 2004 compared with 1990 (Australian Greenhouse Office, 2006). Leakage is not immediately apparent: although rate of clearing, which is undertaken to provide land for grazing cattle, has been severely curtailed, beef production has continued to expand in Australia since 1990, at least partly due to the concomitant increase in lot feeding of cattle (Australian Bureau of Statistics, 2005). However, supply of grain to lot fed cattle requires conversion of pasture to cropland, which may increase soil erosion and increase fossil fuel use, thus increasing greenhouse gas emissions (Van der Nagel et al., 2003).

Solutions to the leakage problem exist but under current political reality are difficult to implement. Comprehensive coverage of all sectors and all countries would avoid leakage. So far, global coverage has not been achieved in any environmental arena. In the absence of such universal action, policy measures such as tariffs and restrictions on import (eg requiring certification of sustainability) can be used to reduce leakage. However, trade restrictions may be difficult to implement because they would work against the current effort to achieve trade liberalization.

Yet another externality relates to short term decision making. Landholders who care only about the near future will not worry much about long term effects of either soil degradation or soil improvements. Generally, these people are more likely to be found among land managers who rent the land rather than owning it. The extent of this externality depends on the ability to accurately assess the soil status. If soil conditions could easily be determined, land rental contracts would include provisions for maintenance of land quality. In absence of such means, political action is warranted.

# 6 LULUCF Governance

## *6.1 Guidelines for planning LULUCF measures*

Reducing GHG emissions, or increasing removals, by a particular quantity of carbon dioxide equivalents will deliver equal mitigation benefit wherever it occurs, globally. In contrast, actions to mitigate biodiversity loss and desertification must be undertaken at the sites where threats are manifest, and the direct benefits will be experienced locally[12]. Although the impacts of climate change mitigation measures are experienced globally, the potential for mitigation through LULUCF activities at a particular site is dependent on the resource condition and constraints at that location. Similarly, the potential for land use measures to mitigate biodiversity loss and desertification depends on the biophysical attributes of the site. Thus, the magnitude of the benefits in terms of all three environmental objectives is dependent on the location of the action. Because the impacts of LULUCF measures are site-specific, the optimal solution to land use decisions is unique to each location.

[12] Nevertheless, there may be considerable offsite benefits from land and biodiversity preservation.

In many biophysical systems, critical thresholds have been identified; that is, relationships where the environmental outcome changes suddenly with a small change in the input (pressure) variable (Scheffer et al., 2001). These systems cannot readily recover if pushed past this threshold – the change may be irreversible, or the financial costs of remediation may be prohibitive (eg Antle et al., 200. Passing the threshold will result in a regime shift (Walker and Meyers, 2004), which can have significant implications for climate mitigation (e.g., deforestation of tropical rainforests may lead to loss of fertility and, consequently, greatly reduced capacity to maintain carbon stocks), biodiversity conservation (e.g., eutrophication of waterways may catastrophic loss of aquatic diversity) and desertification (e.g., loss of vegetative cover leading to soil erosion and loss of nutrients may prevent re-establishment of vegetation). Climate change may push natural and managed ecosystems towards critical thresholds. LULUCF measures will deliver the greatest benefits if targeted at sites that are vulnerable and responsive – that is, at systems that may be approaching but have not crossed such thresholds.

It is possible to artificially enhance productivity at a site, and therefore GHG removal, by relieving resource limitations, such as through irrigation or fertilizer application. It is also possible that exotic species can achieve greater biomass production than the natural ecosystem at a location, because the exotic species is not affected by herbivory and disease. However, it may not be desirable to seek to maximise carbon sequestration in the short term: artificially enhanced ecosystems may lack resilience and capacity to adapt; as they commonly have a narrow genetic base, exotic monocultures are vulnerable to introduction of pests and diseases, to climate variability, and to climate change. Irrigated systems may not be sustainable due to development of salinity. Afforestation/

reforestation in dry landscapes may achieve high growth rates initially while trees are able to access groundwater or moisture stored in the soil profile, but this growth rate may not be maintained when these stores are depleted and trees become reliant on incident rainfall (Harper et al., 2002). If systems are not sustainable, the environmental gains achieved will be at risk. To be sustainable, therefore, the land use systems implemented require resilience, that is, capacity to survive perturbation and adapt to change (Walker et al., 2002). Resilience is enhanced by functional redundancy, diversity and spatial heterogeneity (eg Kennedy and Smith, 1995) Resilience in agricultural and forestry systems is increased where the genetic base of each production species is broad, and where diversity of land uses produces spatial heterogeneity.

## *6.2 Steering LULUCF trends by policy instruments*

At a national and regional level, resource management authorities have developed and implemented policy measures to promote sustainable land management, including those listed in Table 1. Policy instruments range from mandatory measures introduced through legislation that imposes penalties for non-compliance through to voluntary measures and incentive schemes. Examples of this range of instruments, as applied in the State of New South Wales, Australia, are given in Box 1.

As explained in Section 5, joint regulation is the most efficient means of meeting multiple environmental objectives. In order to facilitate land use changes that are beneficial for mitigation of desertification and conservation of biodiversity in addition to mitigation of climate change, policy instruments need to recognise multiple objectives. Policy measures may impose constraints on the outcome of land use decisions: acceptable land use options may be limited to allow only those land use changes for which predicted impacts on the target environmental attributes are neutral or positive. Where activities with negative consequences for some environmental attributes are permitted, "compensatory mitigation" (National Academy of Sciences, 2001) may be required. For example, permission to clear land may be granted under the condition that another site is reforested.

Acceptance of policy measures will govern their success, that is, the rate and scale of adoption, and the longevity of the land use change. Incentive-based policies are more likely to be embraced by landholders than command-and-control policies. Policy development that includes participation of local and distant stakeholders is also more likely to be accepted. For example, the "ecosystem approach" of the Convention on Biological Diversity considers ecological, economic, and social considerations over multiple temporal and spatial scales, and incorporates the "adaptive management" approach to on-going evaluation and modification of the implementation plan. "Participatory development", the mechanism promoted under the UNCCD and CBD, encourages active participation in development and execution of action programmes by local communities, which is intended to build local capacity and ownership, take advantage of local knowledge and expertise in managing the local landscape, and facilitate adaptive management. The "Negotiation support model" (van Noordwijk et al., 2001) and "Resilience management" proposed by Walker et al. (2002) are based on negotiation between stakeholders, evaluation of alternative scenarios and implementation of iterative adaptive learning, to support decision-making aligned with the goal of sustainable development.

Measures that can be used to internalise the environmental costs of land use decisions include both price-based instruments, that is, taxes and subsidies, and quantity-based instruments, that is, quotas with or without tradable permits. Market-based mechanisms are generally recognised as the most effective means of internalising environmental impacts and thus encouraging change in practice by industry. Mandatory emissions trading markets have now been established in the European Union and the Australian State of NSW, and voluntary emissions trading is occurring, for example through the Chicago Climate Exchange and a rapidly growing number of emissions offset providers. The NSW and Chicago schemes allow for trading in offsets generated through a restricted range of LULUCF activities (IPART, 2006; Chicago Climate Exchange, 2006).

As explained in Section 5, introduction of a market for one environmental service may create a bias towards maximising outcomes for that attribute, to the detriment of other environmental and social objectives. For example, assessments of the impacts of CDM projects have concluded that the objective of sustainable development is suffering at the expense of low-cost emissions mitigation (e.g., Kill, 2001). On the other hand, emissions trading can provide financial support for reforestation undertaken for conservation of biodiversity and/or management of land degradation. The International Finance Corporation of the World Bank has proposed that biodiversity could be marketed in a similar fashion to carbon – with the objective of conserving resources for future exploitation to mitigate the risk of losing wealth in the form of biological resources. The demand for "biodiversity credits" would be greatly enhanced by legislation requiring their purchase, for example to offset habitat losses through urban and agricultural development. Such a policy could involve a "mitigation banking" approach analogous to that implemented under the US Clean Water Act, which facilitates compensatory mitigation in advance of authorized impacts to similar resources (US EPA, 1995).

**Box**: Land use policy instruments employed in NSW, Australia

The land resource management policy implemented in NSW, Australia, exemplifies a range of policy instruments that can be used together to foster sustainable land use.

**Incentives**: Under the NSW Environmental Services Scheme, payments have been made to landholders to support land use change: landholders' proposals were assessed on the basis of the predicted environmental benefits in terms of carbon sequestration, biodiversity impact, stream salinity, soil retention and water quality. Methods to quantify impacts on these environmental attributes were developed for the scheme, and have subsequently been incorporated into a software tool known as the Land Use Options Simulator (LUOS, Herron and Petersen, 2003). LUOS is intended as a decision support tool to be used by individual landholders and catchment management authorities for property- and region-scale land use planning, in order to direct government support to land use changes predicted to have greatest net environmental benefit. (Forests NSW, 2004)

**Penalties**: NSW Native Vegetation Act 2003 regulates clearing of native vegetation and imposes severe financial penalties for non-compliance. Applications for clearing are assessed using a software tool (Property Vegetation Plan Developer) that predicts the impact of clearing on biodiversity, including threatened species, salinity, water quality, land and soil conservation and invasive native species. Land uses changes that are predicted to deliver a negative outcome for any of these environmental attributes are not permitted. (NSW Government, 2005)

**Offsets:** Removal of small forest patches or individual trees are allowed under the Native Vegetation Act in some circumstances under the condition that a substantial area of native vegetation is established elsewhere.

**Market-based mechanism:** The NSW Greenhouse Gas Abatement Scheme imposes mandatory emission limits on all NSW electricity retailers and some large electricity users. The scheme allows targets to be met through a variety of measures including carbon sequestration in eligible forestry activities. (IPART, 2006)

**Guidance:** Recent legislative changes have devolved responsibility for natural resource management to regional Catchment Management Authorities that operate within guidelines developed by the NSW Natural Resources Commission. The NRC sets standards and targets for vegetation retention or revegetation, soil management, salinity, threatened species, wetlands and coastal estuaries. CMAs develop catchment action plans to meet these targets, and utilise LUOS to guide investment in land use change to achieve multiple objectives – to meet the targets specified by the NRC, to manage vegetation clearing as required by legislation, and to plan reforestation that delivers carbon sequestration and generates offset credits through the NSW Greenhouse Gas Abatement Scheme.

**End box**

## 7 Conclusions

Land use, land use change and forestry impact greenhouse gas emissions, biodiversity, and soil and water quality. Left unregulated, LULUCF respond optimally to current market demands for food, fibre, fuel, and timber but fail to acknowledge the above named environmental externalities. Consequently it is critical that national and international environmental policy is developed to manage these externalities. This paper argues that this process should be jointly pursued for all major environmental goals and not independently as is the dominating current practice. The arguments discussed in this paper can be summarised in seven major points.

First, choice of land use, from among the numerous alternatives, affects climate, biodiversity, and land quality simultaneously. Second, land is scarce and many land use decisions are mutually exclusive. Therefore, land use changes aimed solely at meeting the goal of one environmental convention are likely to reduce the potential to meet goals of the other conventions. Third, the land use strategies implemented to pursue the goals of the three conventions can be complementary; land use decisions that may deliver the greatest simultaneous benefit for all three environmental objectives are reforestation, avoided deforestation and avoided degradation. However, tradeoffs are also likely. Pursuing the environmental goals of these conventions individually may promote unsustainable land uses which cause unnecessary harm in other environmental areas. Fourth, opportunity costs of land are heterogeneous, as are the local soil, climate, and market conditions. Only joint implementation of the environmental conventions ensures that this heterogeneity is adequately internalized and gives appropriate incentives and disincentives.

Fifth, implementation of policy incentives to promote environmental goals may have a higher cost if each goal is pursued independently because tradeoffs and complementarities are ignored. Sixth, the optimal LULUCF pattern under a joint policy setting can differ substantially from the LULUCF pattern under individually-implemented policies. These differences may involve the regional balance between forestry, agriculture, and nature reserves, and management related to species choice and production intensity. Seventh, environmental policy goals may alleviate the need for existing agricultural subsidies. Huge governmental payments through farm income support policies in the US, Europe, and other countries could be saved by internalizing the environmental cost of agricultural production.

Within the current negotiation cycle for the UNFCCC, CBD and UNCCD there may be the option for a joint implementation protocol for LULUCF that may include common measures that are beneficial to the achievement of the goals of all three conventions. Policy that promotes change in land use patterns towards sustainable land management is the most effective way forward towards mitigating negative climate change trends, preserving biodiversity and fighting desertification.

Several alternative accounting approaches for land use and land use change, suggested for consideration in the development of the policy framework for a future climate agreement, are presented in other papers in this volume. We should take advantage of the impetus to address climate change to ensure that LULUCF policy promotes optimal outcomes for environmental integrity and sustainable development.

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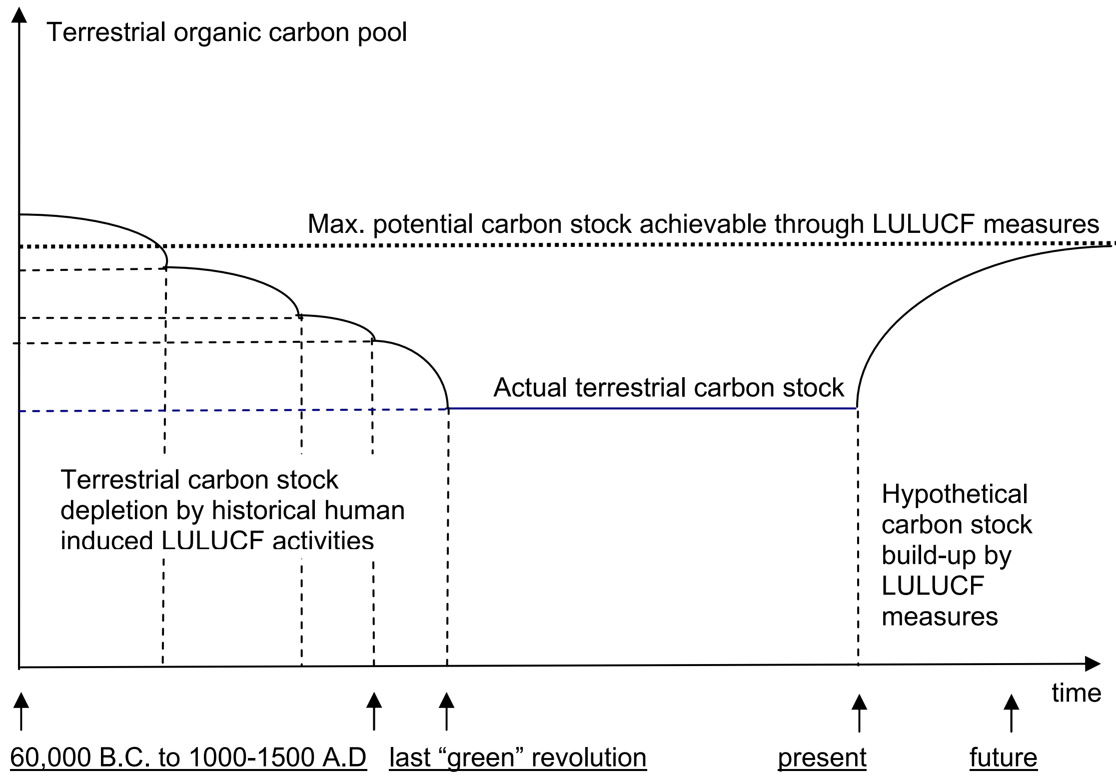


Figure 1: Simplified representation of the dynamics of the terrestrial organic carbon pool over time.

**Table 1: Global environmental and sustainable development agreements that impact on LULUCF activities and examples of regional and national policies enacted to implement these agreements**

| Global treaties, conventions, etc | Regional Agreements (Examples) | National/State strategies, policies (Examples) |
|---|---|---|
| **Climate change** | | |
| United nations framework convention on climate change (1992/1994)[1]<br>Kyoto Protocol (1997/2005) | European Climate Change Programme (2000)<br>EU Emissions Trading Scheme<br><br>EU Renewable Energy target 2010<br>EU Energy crop subsidy<br><br>Asia Pacific Partnership on Clean Development and Climate 2006 | UK Climate Change Programme<br>New South Wales Greenhouse Gas Abatement scheme (Australia)\<br>Regional Greenhouse Gas Initiative (NE States USA)<br>National renewable energy targets (eg USA, Canada, Brazil, Australia, UK Renewables Obligation)<br>National programs for reforestation (e.g., Canada, New Zealand, Ireland) |
| **Biodiversity** | | |
| Convention on Wetlands (Ramsar, 1971/1975)<br>Convention Concerning the Protection of World Cultural and Natural Heritage (1972/1975)<br>Convention on International Trade in Endangered Species of Wild Fauna and Flora (1973/1975)<br>World Conservation Strategy IUCN/UNEP/WWF 1980<br>UN World Charter for Nature 1982<br>Convention on Migratory Species (Bonn, 1979/1983)<br>UN Convention on Biological Diversity (1992/1993)<br>Cartagena Protocol On Biosafety (2001/2003) | The Convention on the Conservation of European Wildlife and Natural Habitat (Bern Convention, 1982)<br><br>European Conservation Strategy 1990<br><br>EC Biodiversity Strategy 1998<br><br>Pan-European Biological and Landscape Diversity Strategy | National policies on conservation of Biodiversity and protection of threatened species (e.g. Australia, New Zealand)<br><br>Legislation controlling land clearing (e.g., Queensland and New South Wales, Australia)<br><br>National Biodiversity Action Plans (Parties to the CBD) |
| **Desertification/Land degradation** | | |
| Plan of Action to Combat Desertification 1977<br><br>World Soils Policy UNEP 1980<br>World Soil Charter FAO1981<br><br>United Nations Convention to Combat Desertification (1994/1996) | European Landscape Convention 2000/2004 | Soil conservation policies (eg Iceland, Australia, New Zealand, USA)<br>Farm income support/Rural adjustment eg US Farm program; The Canadian Agricultural Income Stabilization (CAIS) Program; Agriculture Advancing Australia<br>Conversion of cropland to forest program (China)<br>National water initiative (Australia)<br>National Action Programmes – Parties to the UNCCD<br>Desertification prevention and control law (China) |
| **Sustainable development** | | |
| Agenda 21 1992<br>Millennium Development Goals 2000<br>World Summit for Sustainable Development Johannesburg Declaration 2002 | EC Environmental Action Programmes,1993, 2002<br><br>EU Sustainable development strategy | Local Agenda 21<br><br>Eg Canada: Sustainable Development Technology Fund |

Table 2: LULUCF measures proposed for climate change: their likely impact on climate change, biodiversity and desertification. Positive and negative trends are indicated by + and -, respectively. The significance of the impact increases from 0 (no impact), + or - (minor impact) to +++ or ---(large impact).

| **Land use change** | **Climate change** | **Biodiversity** | **Desertification** |
|---|---|---|---|
| **Conversion from conventional cropping to:** | | | |
| Reduced tillage | Increase or no change in SOC 0-+<br>Decreased fossil fuel use + | Increased biodiversity in soil depending on herbicide use + | Reduced erosion +<br>increased water holding capacity + |
| Crop residue retention | Increased SOC ++ | Increased soil biodiversity ++ | Improved soil fertility + reduced erosion ++ increased water holding capacity + |
| Perennial pasture and permanent crops | Increased SOC ++ increased biomass 0-++ Leakage: Decreased biomass and SOC on other land converted to arable - - to - | Minor; dependent on species + to ++ Leakage: Decreased biodiversity on other land converted to arable - - to - | Reduced erosion, ++<br>Increased infiltration and water holding capacity + |
| Organic amendments such as manure, compost, mulch, biosolids | Increased SOC + to +++ | Possible increase in soil biodiversity, or decrease if amendments are contaminated eg with heavy metals – to ++ | Improved soil fertility +++<br>reduced erosion +<br>increased water holding capacity ++ |
| Improved rotations e.g. green manure, pasture phase, double cropping (no fallow) | Increased SOC + | increased soil biodiversity, and above ground biodiversity + | Improved soil fertility +<br>increased water holding capacity + |
| Fertilisation | Increased biomass + to ++ Increased $N_2O$ emissions - - to -<br>GHG costs of chemical fertiliser production - | Possible negative offsite impact on native, especially aquatic, species -- | Increased fertility increases land cover +++<br>Some fertilisers e.g. ammonium salts can cause acidification - |
| Irrigation | Increased biomass +<br>GHG costs of pumping irrigation water - Increased fertiliser use -<br>Higher $N_20$ emissions -<br>Salinisation may cause off-site loss of biomass -<br>Off-site carbon gains because less land is needed for food crops and more land can be allocated to renewable energy or afforestation + to ++ | Impact dependent on the land use system displaced, but may include loss of native remnants, reduced diversity of crop species - - to 0<br>Salinisation may cause off-site loss of biodiversity - - to -<br>Off-site biodiversity gains because less land is needed for agriculture and more land can be allocated to conservation reserves + to ++ | Increased productivity but high risk of soil salinisation --- to + |
| Bioenergy crops | Displacement of fossil fuels +++ Impact on biomass dependent on bioenergy crop species: annual crops | Impact on biodiversity dependent on bioenergy crop species: annual crops 0 perennial woody crops | Dependent on bioenergy crop species; Strategic establishment of perennial bioenergy crops may increase land cover, |

| | | | |
|---|---|---|---|
| | - to 0<br>perennial woody crops + to ++<br><br>Increased biomass removal may reduce SOC - to 0<br><br>Increased fertiliser requirements to replace additional nutrients removed - | + to ++ | reduce salinity<br>+<br><br>Increased removal of biomass in annual bioenergy crops may reduce soil protection and increase removal of SOC - |
| Organic farming | Possibly higher SOC<br>0 to +<br><br>Leakage: Lower yield per ha so more area required: Decreased biomass on other land converted to arable<br>- - to - | Increased on-site biodiversity (no pesticides)<br>+<br><br>Leakage: Lower yield per ha so more area required:<br>- - to - | Increased SOM reduces erosion, increases water holding capacity<br>+<br><br>Leakage: Lower yield per ha so more area required:<br>- - to - |
| Reforestation to plantation | Increased biomass +++<br>Potential leakage -<br>Decreased biomass and SCO if other land converted to arable; impact dependent on C stock of other land - - to - | Biodiversity increase above ground and belowground ++<br><br>Potential leakage - Decreased biodiversity off-site if other land converted to arable - - - to -<br><br>Reduced streamflow - - | Reduced wind and water erosion<br>+++<br><br>Reduction in dryland salinity ++ |
| Afforestation/Reforestation to native forest/woodland | Increased biomass ++<br>Increased SOC ++<br>Decreased fossil fuel use +<br>Potential leakage -<br>Decreased biomass and SOC increased GHG emissions if other land converted to arable; impact dependent on C stock of other land - - to - | Biodiversity increase above ground and belowground +++<br><br>Potential leakage - Decreased biodiversity off-site if other land converted to arable - - - to -<br><br>Reduced streamflow - | Reduced wind and water erosion<br>+++<br><br>Increased transpiration reduces dryland salinity<br>++ |
| **From conventional grazing to:** | | | |
| Higher productivity pasture species – eg convert annual to perennial species, add legume | Increased biomass +<br>Increased SOC ++<br>Reduced CH4 from enteric fermentation due to higher quality feed + | May increase plant biodiversity 0 to +<br><br>Increase in bg biodiversity<br>+ | Increased land cover reduces erosion<br>++ |
| Conservative grazing/Cutting method and frequency | Increased biomass and SOC + | Protects species sensitive to over-grazing<br>+ | Increased land cover, reduced compaction reduces erosion<br>++ |
| Fertilisation | Increased biomass and SOC +-++ | Possible negative impact on native grasslands<br>-- to 0 | Increased productivity increases land cover<br>++ |
| Afforestation/reforestation | SOC may increase or decrease depending on relative productivity - to +<br>Increased biomass +++<br>Leakage: Decreased | Impact dependent on the pasture system replaced, and forest type but may include loss of native grasslands | Increased transpiration reduces dryland salinity<br><br>++<br><br>Reduced wind erosion |

| | | | |
|---|---|---|---|
| | biomass and SOC on forested land converted to grazing<br>- - to - | - - to -- | +-+++ |
| Bioenergy crops | Displacement of fossil fuels +++<br>Impact on biomass dependent on bioenergy crop species: annual crops 0 to -<br>perennial woody crops + to ++<br><br>Reduced SOC due to increased biomass removal and soil disturbance, especially for annual crops<br>- - to -<br><br>Increased fertiliser requirements to replace additional nutrients removed - | Impact on biodiversity dependent on pasture system replaced and bioenergy crop species: annual crops -<br>perennial woody crops + to ++<br><br>If native grasslands replaced<br>-- | Impact dependent on bioenergy crop species:<br><br>Tillage reduces land cover, increases soil erosion annual crops - - to -<br>perennial woody crops – to 0 |
| **Forest management** | | | |
| Irrigation or fertilisation | Increased biomass +<br><br>Increased SOC + | May inhibit native species<br>- | Increased cover and SOC<br>+<br><br>Potential for salinisation<br>- - |
| Extend rotation | Increased average carbon stock in biomass and SOC<br>+ to ++ | Enhanced onsite biodiversity ++ | Less frequent soil disturbance + |
| Protection against deforestation/degradation | Avoids loss of biomass and SOC +++ | Protects biodiversity +++ | Prevents degradation +++ |

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**Research Unit Sustainability and Global Change**

**Hamburg University and Centre for Marine and Atmospheric Science**


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