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[TSU: This chapter has been allocated 60 template pages, currently it counts 72 pages (excluding this page and the bibliography), so it is 12 pages over target. Reviewers are kindly asked to indicate where the chapter could be shortened.]

Table of changes

No	Date	Version	Place	Description	Editor
1	07.05.2012	01		First consolidated FOD – many sections not yet updated since ZOD	Pete & Mercedes
2	22.05.2012	02		New section 11.2	Pete & Mercedes
3	28.05.2012	03		New section 11.3.1.4	Pete & Mercedes
4	19.06.2012	04		All new sections since 31.05.2012 incorporated	Pete & Mercedes
5	25.06.2012	05		New sections on systemic issues, costs and potentials, transformation pathways, bioenergy sections, missing section of Figure 11.6 added, HH edits added	Pete & Mercedes
6	28.06.2012	06		New sections on biochar, policy, section 11.7, demand side forestry, cross-sectoral biofuels text, HH edits, Zotero refs added (in main text – not yet figures and tables)	Pete & Mercedes
7	30.06.2012	07		New FAQ, Zotero refs added throughout. Complete chapter edit and update of figures / tables etc.	Pete & Mercedes

Chapter 11: Agriculture, Forestry and Other Land Use (AFOLU)

Contents

Executive Summary

Agriculture, Forestry and Other Land Use (AFOLU) is a unique case among the various sectors with potential for greenhouse gas mitigation, since it has a central role in providing food security (Godfray et al., 2010)(Godfray et al., 2010), water and livelihoods, and supporting sustainable development. The degree to which mitigation is achieved will depend on consideration of these issues. GHG mitigation in the AFOLU sector is therefore complex and the implications of measures need to be considered in light of the many economic and social benefits as well as the ecosystem services provided by land.

The average annual value for global C flux from AFOLU from 2000 to 2009 is within the uncertainty ranges determined for the 1980s and 1990s (1.1-1.3 Gt C/yr) [11.2, high agreement; robust evidence]. The AFOLU sector is responsible for about one third of anthropogenic GHG emissions, mainly from deforestation and agricultural emissions from livestock and soil and nutrient management. Forest degradation and biomass burning (forest fires and agricultural burning) also represent relevant contributions. Leveraging the mitigation potential in the sector is extremely important in meeting emission reduction targets [11.3, high agreement; robust evidence]. Opportunities for mitigation include production-side measures, i.e. by reducing GHG emissions per unit of land or per unit of product, and demand-side options (, i.e. by reducing losses and wastes of food, changes in diet, changes in wood consumption). Carbon sequestration in soils and plants and the displacement of fossil fuels through bioenergy are also important options. Considering demand-side options, changes in diet can have a significant impact on GHG emissions from food production (11.3. high agreement, medium evidence). For demand-side and supply-side measures considerably different synergies and trade-offs may have to be considered.

The nature of the sector means that there are, potentially, many barriers to implementation of available mitigation options. Similarly, there are important feedbacks to adaptation, conservation of natural resources such as water and biodiversity and provision of bioenergy. There can be competition between different land-uses due to different motivations and objectives but also potential for synergies, e.g. integrated systems or multifunctionality at landscape scale [11.4, high agreement; medium evidence]. The developing area of environmental services provides a framework for valuing the multiple synergies and trade-offs that may arise from mitigation projects [high agreement, medium evidence]. Sustainable management of agriculture, forests, and other land uses is essential to achieving sustainable development [11.4, high agreement; robust evidence].

Available top-down estimates of costs and potentials suggest that AFOLU mitigation will be an important part of a global cost-effective abatement strategy [11.6, high agreement, medium evidence] under different stabilization scenarios. A consolidated estimate of economic potentials for GHG mitigation within the AFOLU sector as a whole is still difficult because of potential leakages derived from competing demands on land and only some of the potentials are additive. Global estimate for economic mitigation potentials in agriculture at 2030 is up to 4.3 $GtCO_2$/yr at carbon prices up to 100 US$/$tCO_2eq$ while forestry mitigation options are estimated to contribute between 1.3 and 4.2 $GtCO_2$/yr [Note from TSU: new numbers will be added when available]. However, there are significant regional differences in terms of mitigation potential, costs and applicability, due to differing local biophysical, socioeconomic and cultural circumstances, for instance between developed and developing regions and among developing regions [11.6. high agreement, medium evidence]. In developing countries, agriculture is often central to the livelihoods of many social groups and a significant share of the GDP.

The size and regional distribution of future mitigation potential is difficult to be estimated accurately as it depends on a number of factors that are inherently uncertain. Critical factors include population (growth), economic and technological developments, changes in behavior over time and how these translate into fiber, fodder and food demand and development in agriculture and forestry sectors. Additional important factors are: climate change impacts on carbon stocks in forests and future land use including its adaptation capability [11.5. high agreement, medium evidence]; considerations set by biodiversity and nature conservation requirements; and interrelations with land degradation and water scarcity [11.8. high agreement, robust evidence].

Land use and land use change associated with bioenergy expansion can affect GHG balances, albedo and other climate forcers in several ways, and can lead to both beneficial and undesirable consequences for climate change mitigation (11.3 high agreement, robust evidence). Under limited availability of productive land due to growing food and bioenergy consumption, demand may induce either substantial LUC causing high GHG emissions and/or agricultural intensification, which imply more fertilizer use, energy use for irrigation and higher N_2O emissions. However, societal preferences and technological changes also shape the LUC and intensification outcomes. AFOLU mitigation options can promote innovation and many technology production-side mitigation options also increase agricultural and silvicultural efficiency (11.3. high agreement, robust evidence).

Large-scale reliance on bioenergy and sequestration in afforestation and reforestation projects will likely increase the competition for land, water, and other resources and conflicts may arise with important sustainability objectives such as food security and soil, water and biodiversity protection, meaning that sustainability frameworks to guide development of such mitigation projects need to consider competition for land. Emphasis should be given to multifunctional systems that minimize food-energy competition and to the harnessing of residues for bioenergy.

Adequate policies are needed for orienting practices in agriculture and in forest conservation and management to cope with mitigation and adaptation. One of the most striking aspect of policies for the AFOLU sector is the implementation of REDD mechanisms and its variations that can represent a very cost-effective option for mitigation (11.10. high agreement, medium evidence) with social and other environmental co-benefits (e.g. conservation of biodiversity and water resources).

AFOLU forms a critical component of transformation pathways, offering a variety of mitigation options and a large, cost-competitive mitigation potential [Note from TSU: new numbers will be added when available].

11.1 Introduction to the integrated assessment of AFOLU

In the IPCC SAR (IPCC WGIII, 1996) and in AR4 (IPCC WGIII, 2007), agricultural and forestry mitigation were dealt with in separate chapters. In the TAR (IPCC WGIII, 2001), there were no separate sectoral chapters on either agriculture or forestry. In AR5, for the first time, the terrestrial land surface, comprising agriculture, forestry and other land use (AFOLU), is considered together in a single chapter. This ensures that all land based mitigation options can be considered together, minimises the risk of double counting or inconsistent treatment (e.g. different assumptions about available land) between different land categories and allows the consideration of systemic feedbacks between mitigation options related to the land surface. The treatment of AFOLU in a single chapter allows phenomena that are common across land use types such as competition for land (e.g., Smith et al., 2010; Lambin and Meyfroidt, 2011) and water (e.g., Jackson et al., 2007), and co-benefits (Sandor et al., 2002; Venter et al., 2009) to be considered consistently. Further, the consideration of AFOLU for the whole terrestrial land surface mirrors moves towards harmonised accounting of land use emissions and removals in national greenhouse gas inventories (IPCC, 2006).

Since climate mitigation is not the primary use of land, we consider the conflicting uses of land for food and fibre provision, for energy production and for conservation of biodiversity and ecosystem services and natural resources in this chapter. Unlike the chapters on agriculture and forestry in AR4, impacts of sourcing bioenergy from the AFOLU sector are considered in this chapter. Also new to this assessment is the explicit consideration of demand-side measures for GHG mitigation in the AFOLU sector.

Notwithstanding a number of issues common across all land uses, it should be noted that there are still significant differences between the sectors affecting the land surface. Agriculture and forestry, for example, are often governed by different policies, and are often governed by different departments or ministries within government. The land managers are also very different; agriculture is managed mainly for short term by farmers, forestry mainly for long term by foresters, and with some notable examples, the different land managers have perceptions of themselves as one or the other of these. Similarly, the tenure varies between the sectors; agriculture tends to be managed by small private landholders; forestry by Government and corporate entities. There are also growing areas of cross-over between the sectors such as agroforestry or the reforestation of farmland, and these feedbacks are likely to increase as various land-based mitigation options are implemented.

In this chapter we deal with AFOLU in an integrated way with respect to the underlying scenario projections of e.g. population growth, economic growth, dietary change, land use change and cost of mitigation by adopting the scenarios also being considered by IPCC WGI and WGII (i.e. the Representative Concentration Pathways [RCPs]), but when considering the mitigation options, their likelihood of acceptability and adoption, and the policies used to influence behaviour, we take a sectoral approach, for the reasons outlined in the previous paragraph. As in AR4, we attempt to draw evidence from both “bottom-up” studies that estimate mitigation potentials at small scales and the scale up, and multi-sectoral “top-down” studies that consider AFOLU as just one component of a total multi-sector system response.

Mitigation potentials in the agricultural sector in IPCC AR4 were estimated to be 1.5-1.6, 2.5-2.7, and 4.0-4.3 Gt CO_2-eq. yr^{-1} at 20, 50 and 100 USD / t CO_2-eq. in 2030 (P. Smith, Martino, Cai, Gwary, HH Janzen, et al., 2007). The equivalent figures for forestry, from bottom-up estimates, range from 1.27 to 4.23 Gt CO_2-eq yr^{-1} (Nabuurs et al., 2007). In this chapter we provide updates on emissions trends and changes in drivers and pressures in the AFOLU sector, and we provide refined estimates of mitigation costs and potentials for the AFOLU sector, by synthesising studies that have become available since IPCC AR4 [AUTHORS: will be updated with actual numbers when available from Ch8].

11.2 New developments in emission trends and drivers

This section describes changes in recent GHGs trends, compares to those presented in AR4, and notes major changes in drivers. Anthropogenic sources and sinks of GHGs in AFOLU include net CO_2 fluxes from management of land (croplands, forests, grasslands, wetlands), changes in land use (e.g. deforestation) and non-CO_2 emissions from agriculture (e.g. CH_4 from livestock and rice cultivation, N_2O from manure storage and agricultural soils). Global trends in total emissions from AFOLU activities between 1971 and 2010 and contributions of single sources are shown in figure 11.1a; figure 11.1b shows net C fluxes from land use, land use change and forestry. Land management and land use change are the main drivers of CO_2 fluxes, while CH_4 and N_2O emissions mostly derive from livestock, manure management, and the use of nitrogen fertilization. The detailed descriptions of drivers and trends are presented below.

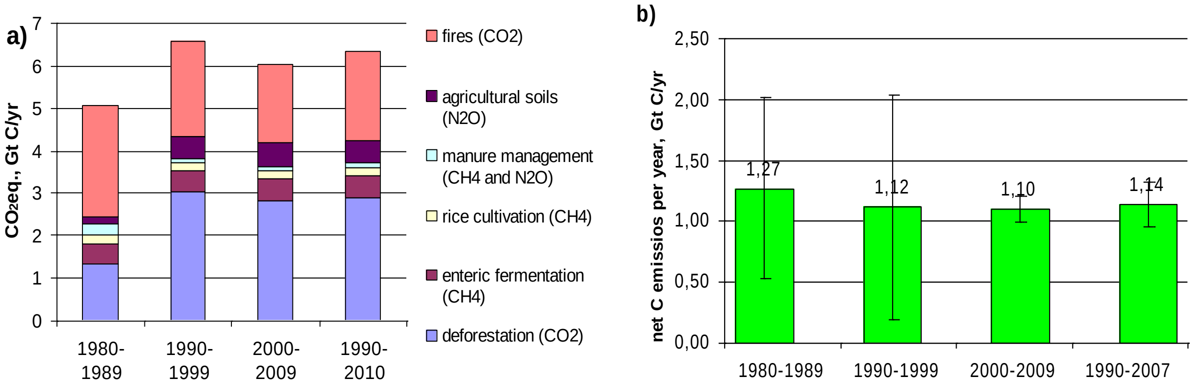

Figure 11.1 Global trends in CO2 eq emissions from AFOLU (a) and net C emissions from land use, land use change and forestry activities (b), Gt C/yr.

(a) CO_2 emissions from deforestation for 1980-1989 is the median of data available in (Ramankutty et al., 2007) and (Piao et al., 2009) and for 1990-2007 are taken from (Y. Pan et al., 2011) - data on deforestation in the 1980s are not fully comparable to data for 1990-2010 (Y. Pan et al., 2011) due to different coverage, approaches and assumptions used; C emissions from fires for 1980-1989 are from (Seiler and Crutzen, 1980 as cited by (GR van der Werf et al., 2010) and for 1980 only; for 1990-1999 are average of (Randerson et al., 2005 as cited by (GR van der Werf et al., 2010) and data from GFED for 1997, 1998 and 1999; and for 2000-2010 are from (GRED, http://globalfiredata.org); Non-CO_2 emissions for 1980-1989 are taken from ([CSL STYLE ERROR: reference with no printed form.]), table 23-11 (enteric fermentation, manure management and agricultural soils) and rice cultivation from (Stern and Kaufmann, 1988); data for 1990-1999 are from FAO, 2011 (enteric fermentation) and (U.S. EPA, 2011) (ag. soils, manure management and rice cultivation); data on N_2O emissions from agricultural soils in 1980s are not fully comparable to data for 1990-2000 due to different coverage of sources (only N fertilizers, N fixation and biomass burning included) and different approaches.

(b) Values for 1980-1999 are medians from (RA Houghton, 2003, 2010; Strassmann et al., 2008; S. Piao et al., 2009; Pongratz et al., 2009; Shevliakova et al., 2009) and uncertainty range are standard deviations between different research results; values and its uncertainty ranges for 2000-2009 and 1990-2007 are taken from (RA Houghton et al., 2012).

11.2.1 Production and consumption trends in agriculture and forestry

Agriculture. In 2009 total agricultural land occupied 4889 Mha (FAOSTAT, 2011) and the share of pastures – 69% (3356 Mha) and croplands – 31% (1533Mha) has remained almost stable since 2002 (see AR4). Together, croplands and pastures are one of the largest terrestrial biomes on the planet, rivalling forest cover in extent and occupying 40% of the land surface. The definition of pasture in FAO databases is not fully harmonized across countries so that there is substantial uncertainty regarding the pasture area (Erb et al., 2007). In accordance to the wider definition of grazing lands used in the IPCC Good Practice Guidance for grasslands (see section 11.5.3 of this report), total grazing land area comprises about 25% of the global land surface. Grazing intensity on pasture land varies greatly between regions, and there is evidence that a considerable fraction of livestock grazing occurs on land not included in the FAO 'permanent meadows and pasture' category (Young, 1999; Erb et al., 2007; FAO, 2008). This includes, but is not limited to, traditional pastures. Overgrazing often happens on drylands as a result of pressure from food demand, especially in economically poor regions leading to soil degradation and desertification (Mortimore, 2009).

The amount of arable and pasture land per-capita has increased in developing countries by 5% and 10% respectively between 2000s and 1970s, despite a continued decreasing trend in developed countries (FAOSTAT, 2011). Changing land-use practices have enabled world grain harvests to double in the past four decades, so they now exceed 2 billion tons per year (FAO, 2011 www.ftp.fao.org/docrep). Some of this increase can be attributed to a 7% increase in world agricultural land area since 1970s (by 311 Mha), though after 1990s agricultural land area decreased by 53 Mha (-1%) due to a rapid decline of permanent meadows and pastures in developed countries (7.0% or 75 Mha for last decade). The trend in agricultural area of developing countries after the 1990s first show stabilization, and then a decrease in the area under permanent crops (-3.1% or 31.6

Mha) and arable land (-16.6% or 17.6 Mha) since 1970 (FAOSTAT, 2011). However, increased production has mainly resulted from ‘‘Green Revolution’’ technologies, including high-yielding cultivars, chemical fertilizers and pesticides, and mechanization and irrigation. During the past 40 years, there has been a 700% increase in global fertilizer use (22% since 2002 (FAOSTAT, 2011) and a 70% increase in irrigated cropland area (J. A. Foley et al., 2005); agricultural intensification has mainly occurred in the Southern Asia (e.g. Bangladesh and Sri Lanka) (Royal Society, 2009).

Rising demand for meat and dairy products over the last 50 years has lead to a ~1.5 fold increase in global numbers of cattle, sheep and goats, with equivalent increases of ~2.5 and ~4.5 fold for pigs and chickens, respectively (FAOSTAT, 2011). By 2050, the human population is predicted to reach 9 billion and the demand for livestock products is expected to double (United Nations, 2009). In 2010, the total number of livestock comprised about 4700 M head (except poultry) (FAOSTAT, 2011) with major contributions of sheep and goats (2000 M head), and cattle and buffaloes (1623 M head). The largest livestock populations are in Asia (more of 50% of sheep and goats and 40% of cattle and buffalo), followed by sheep and goat populations in Latin America (36%), and cattle and buffalo populations in African and the Middle East (25%). Major regional trends for 1971-2010 include a rapid decrease in the total number of ruminants in OECD countries (-40% for sheep and goats and -8% for cattle and buffalo populations), with a tendency for substitution of the cattle population (-13%) with smaller other animals (+60%) in EIT countries, and continuous growth of livetock populations in developing regions which has almost doubled in the Middle East and Africa (ruminants), Latin America (cattle and buffalo) and in Asia(sheep and goats) since 1971 (FAOSTAT, 2011). Global and regional trends for major drivers of GHG emissions in AFOLU for the period from 1971 to 2010 are shown on figure 11.2.

Population growth and increasing food demand have been accompanied by an increase in per-capita food availability, by 14% on average for the world (up to 2756 kcal/capita/day), while for developing regions, particularly for Asia, the increase reached 25%. The share of animal products in the diet has increased consistently in developing countries, up 92% since 1970s (though it has decreased in Africa and the Caribbean), while for developed regions livestock products in the diet have tended to decline (FAOSTAT, 2011). As a result of population growth, rising per-capita caloric intake and changing dietary preferences, such as an increased consumption of meat and dairy products, the demand for agricultural products in the future is anticipated to increase significantly, especially in Asia, Latin America, and Africa (K.-H. Erb et al., 2012); (A. Popp et al., 2010); FAO, 2006; Tilman et al., 2011). This trend is largely driven by the demand projection of increases in global meat consumption of 68% and in global milk consumption of 57% by 2030 compared to 2000 (Food and Agriculture Organization, 2009). Increased crop and livestock production is likely to be met through the expanded use of synthetic fertilizers and livestock production capacity, particularly in developing South and East Asia, Sub-Saharan Africa, and Latin America and the Caribbean (U.S. EPA, 2011).

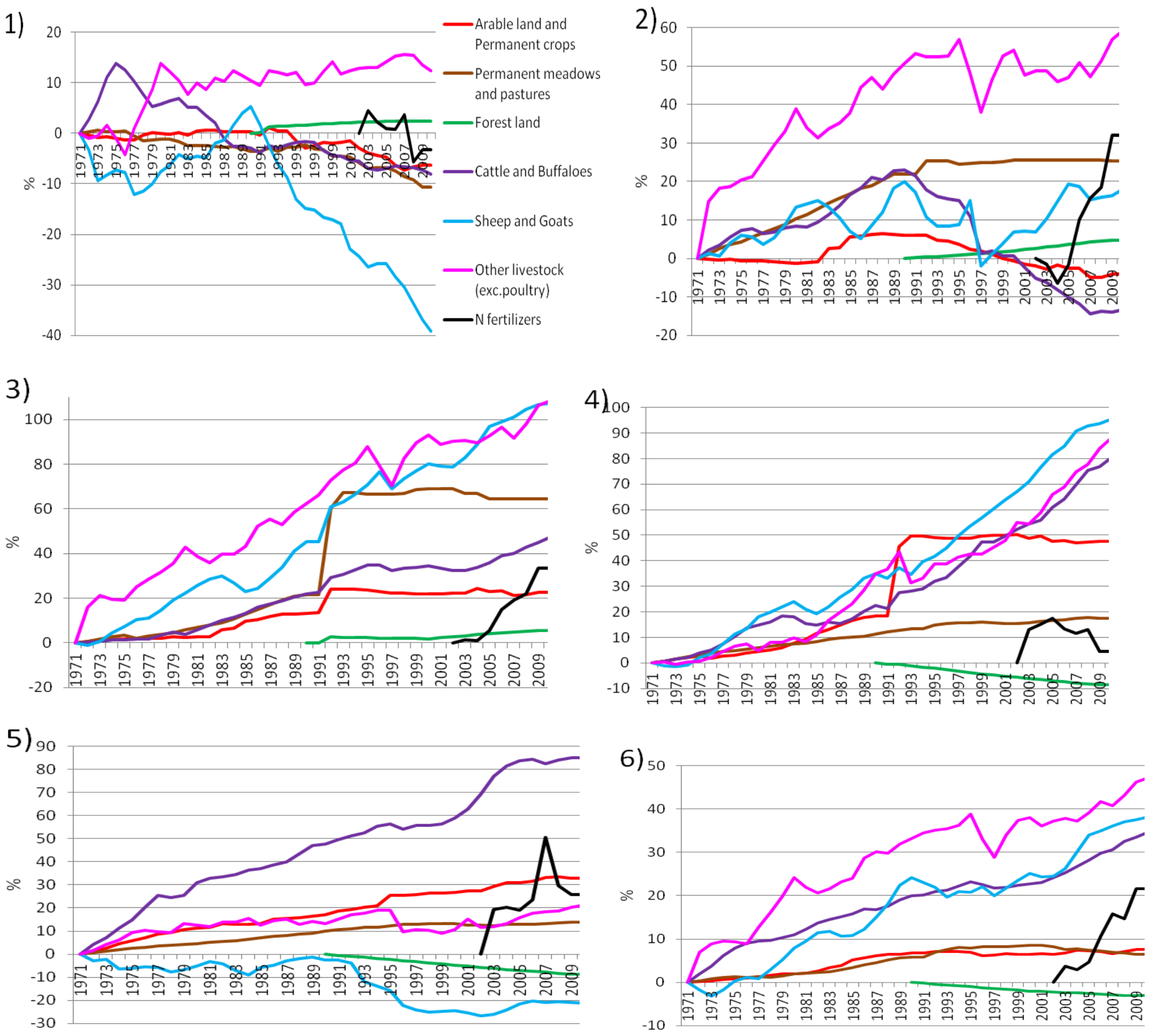

Figure 11.2 Global trends from 1971 to 2010 in the area of land use, number of livestock and amount of N fertilizers by regions – relative change from 1971 (forest land – from 1990; N fertilizers – from 2002): 1) OECD90 countries; 2) countries with reforming economies (EIT); 3) Asia; 4) Middle East and Africa; 5) Latin America and 6) World. (FAOSTAT, 2011)

There are indications that current climate changes have already impacted agricultural production around the world. Global maize production is estimated to be 3.8% lower than it would be if there had been no warming. For the US, wheat production has dropped during 1980 to 2008 by 2.5%. However, yields of rice and soya beans have increased by 2.9% and 1.3%, respectively (D.B. Lobell, 2011). Future changes in global average yields of wheat, maize and barley by 2030 under the SRES A1B scenario indicate +1.6%, -14.1% and -1.8% with 95% probability intervals of (-4,1, +6,7), (-28,0, -4,3) and (-11.0, +6.2) in percent of currents yields, respectively (Tebaldi and D.B. Lobell, 2008). However, adapting planting dates and cultivar choices may increase yield in temperate regions and avoid the projected 7-18% global losses that would occur without adaptation (Gornall et al., 2010; Deryng et al., 2011).

Forestry. At a regional level, South America experienced the largest net loss of forests between 2000 and 2010 – about 4.0 Mha yr^{-1} – followed by Africa, which lost 3.4 Mha yr^{-1}. Oceania also reported a net loss of forest (about 700 kha yr^{-1} over the period 2000–2010), mainly due to large losses of forests in Australia, where severe drought and forest fires have exacerbated the loss of forest since 2000. The area of forest in North and Central America was estimated to be almost the same in 2010 as in 2000. The forest area in Europe continued to expand, although at a slower rate (700 kha yr^{-1}) than in the 1990s (900 kha yr^{-1}). Asia, which had a net loss of forest of ~ 600 kha yr^{-1}in the 1990s, reported a net gain of forest of more than 2.2 Mha yr^{-1} in the period 2000–2010, primarily due to large-scale afforestation in China, and despite continued high rates of net loss in many countries in South and Southeast Asia.Trends in the extent of forest area are shown in Table 11.1.

Table 11.1 Trends in extent of forest 1990-2010

Country/area	Annual change rate					
	1990-2000		2000-2005		2005-2010	
	1 000 ha.yr^{-1}	%[a]	1 000 ha.yr^{-1}	%[a]	1 000 ha.yr^{-1}	%[a]
Africa total	-4067	-0.56	-3419	-0.49	-3410	-0.50
Asia total	-595	-0.10	2777	0.48	1693	0.29
Europe	877	0.09	582	0.06	770	0.08
North and Central America total	-289	-0.04	-40	-0.01	19	n.s.
Oceania	-36	-0.02	-327	-0.17	-1072	-0.55
South America	-4213	-0.45	-4413	-0.49	-3581	-0.41
World	-8323	-0.20	-4841	-0.12	-5581	-0.14

Source: (FRA, 2010)

Considerable mitigation potential could be derived from reducing emissions from deforestation and forest degradation including the maintenance and enhancement of forest carbon stocks (known as REDD+) (J.G. Canadell and M.R. Raupach, 2008). As a result of concerted efforts, taken both at local and international level, global deforestation rates were significantly reduced in 2000s, particularly in Brazil and Indonesia, which had the highest loss of forests in the 1990s. In addition, ambitious tree planting programmes in countries such as China, India, the United States and Vietnam - combined with natural expansion of forests in some regions - have added more than 7 Mha of new forests annually. As a result the net loss of forest area was reduced to 5.2 Mha y^{-1} between 2000 and 2010, down from 8.3 Mha yr^{-1} in the 1990s (FRA, 2010).

11.2.2 Trends of C fluxes from land use and land use change

Total land use change C flux trends: Since pre-industrial times, land use and land-use change have released C to the atmosphere. The total amount of C released to the atmosphere has been estimated at 138 – 294 Gt C since 1700; 108 – 188 Gt C for the period 1850-2000 (Pongratz et al., 2009; Shevliakova et al., 2009) or 156 Gt C during 1850-2005 (RA Houghton, 2010). The inclusion in modelling of current changes in climatic parameters, and the global increase of NPP of terrestrial ecosystems during the 20th century (due to rising CO_2 concentrations and temperature and precipitation changes) have resulted in a much lower estimates of total carbon emissions from land use and land use change, being about 31 Gt C for the period 1901-2002 (Piao et al., 2009).

All studies agree on the increasing trend of annual C losses from 1850 (1700) to the middle of the 20th century. The net flux from land use and land-use change over the recent period 1950–2005 is estimated to have ranged between emissions of 0.7-1.6 Gt C yr^{-1} (Houghton, 2010) to a sink of 1.0 Gt C yr^{-1} (Piao et al., 2009). For 1990-2009 the mean global emissions are found to be 1.14±0.18 Gt C yr^{-1} (RA Houghton et al., 2012). The large range arises from uncertainties in the input data, and assumptions used for each analysis (e.g. rates of land use change; density of C stocks; processes and activities considered; fate of affected ecosystems; changing climatic parameters). The mean value of annual C flux from land use and land use change activities in the 1980s is estimated about 1.1±0.8 Gt C yr^{-1} and in the 1990s – 1.1± 0.9 Gt C yr^{-1}. Median values are 1.3 and 1.1 Gt C yr^{-1} respectively. Within variations between different estimates, fluxes from land use and land use changes between 1980 and 2000 were nearly constant (Figure 11.1b).

A major contribution to the overall increasing trend in the net C flux to the atmosphere during the 20th and beginning of the 21st century comes from increased deforestation activities and agricultural development in the tropics (more rapidly after 1960). Dominant sources are fire emissions from tropical deforestation (Le Quere et al., 2009). Nearly 70% of gross CO_2 emissions derive from the tropical and subtropical zones with the largest sources in South America and southern Asia rather than Africa, estimated to be 1.5, 1.1 and 0.24 – 0.5 Gt C yr^{-1} at present, respectively (Ciais et al., 2011; Richter and Houghton, 2011). In the temperate zone, the trend during the 20th century is in the opposite direction, indicating growing CO_2 sinks and decreasing gross CO_2 sources (Y. Pan et al., 2011) Richter and Houghton, 2011). Increased secondary vegetation sinks, in both temperate and tropical zones, decelerated net conversion of primary forests to agricultural land (Shevliakova et al., 2009) as well as increased net primary production of terrestrial ecosystems during second half of 20th century due to raised temperatures and CO_2 concentrations (Piao et al., 2009; Zhao and Running, 2010), which have partly counteracted the growth of gross CO_2 sources in the tropics and rendered the net global C flux to be nearly steady during the 1980s and 1990s.

Most recent data on total C flux from land use and land use change activities for the period 2000-2009 (RA Houghton et al., 2012) suggest mean global emissions 1.1±0.11 Gt C $yr^{-1.}$. For land use change emissions only, the annual global flux for the period 2000-2008 was estimated as high as 1.5 Gt C yr^{-1} (Richter and Houghton, 2011), the same average value reported for the period 1990-2005 by Le Quere et al. (2009). These estimates are supported by the estimate of 1.3 Gt C yr^{-1} for the average annual emissions from tropics for the period 1990-2007 (Y. Pan et al., 2011). Global emissions from land use change estimated for 2008 by Le Quere et al. (2009) suggest a slightly lower value (1.2 ±0.7 Gt C yr^{-1}) that is explained by reductions of deforestation activities in 2008 in southeast Asia (-65%) and tropical America (-40%), compared to the average levels in 1998-2007.The enhanced terrestrial NPP observed at the end of the 20th century might not be continuing into the first decade of the 21st century. Thus, Zhao and Running (2010) indicated the reduction in global NPP of 0.55 Gt C for the period 2000-2009 as a result of large-scale droughts and a drying trend in the Southern Hemisphere, which counteracted an increasing trend of NPP in Northern Hemisphere. According to some projections up to 2100, climate warming and CO_2 fertilization might result in the additional terrestrial C uptake by global ecosystems in the range 105-225 Gt C (Müller et al., 2007). However, there are indications that current global warming has already started accelerating C loss from terrestrial ecosystems by enhanced decomposition of soil organic carbon and that in the response to warming trends only, the global net C uptake significantly decreased after 2002, offsetting about 70% of the increase in the global net C uptake owing to CO_2 (Piao et al., 2009). The average annual value for global C flux from AFOLU during 2000-2009 is within the uncertainty ranges determined for 1980s and 1990s (see Figure 11.3).

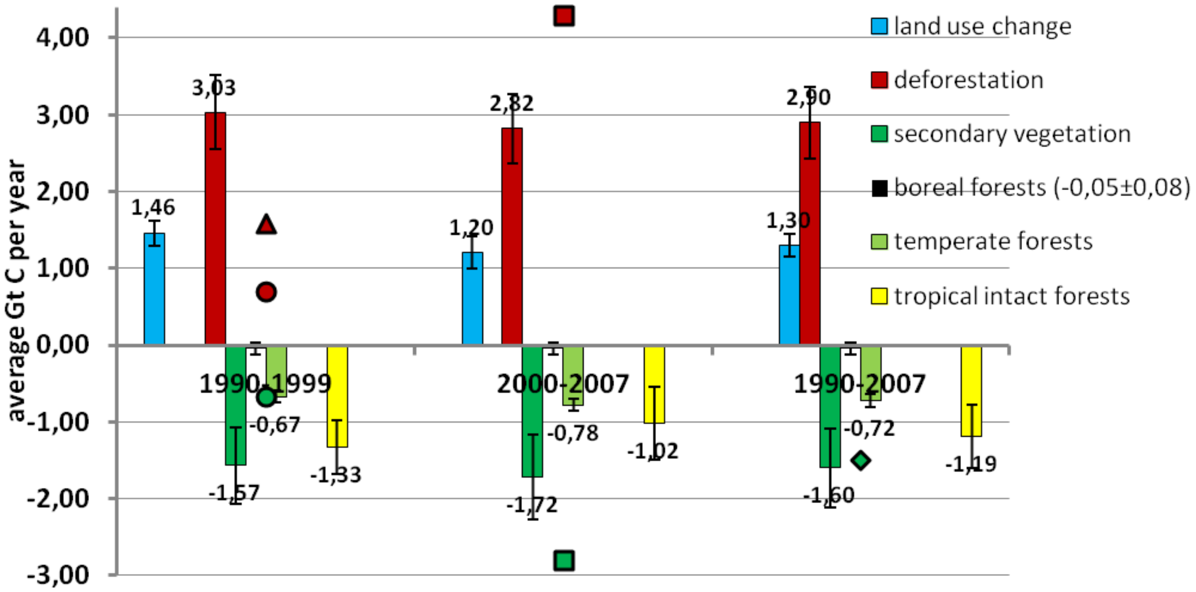

Figure 11.3 Global trends in average annual C fluxes from land use and land use change for decades 1990-1999, 2000-2007 and for the period 1990-2007, Gt C: sources are positive values; sinks are negative values. Values of total land use change are medians from (Le Quere et al., 2009; Piao et al., 2009; Richter and Houghton, 2011) (Y. Pan et al., 2011) and uncertainties are standard deviations between different research results. Bars represent data by (Y. Pan et al., 2011). Single points are data from different studies for deforestation (red) and secondary vegetation (green): circles – (Y. Pan et al., 2011); triangle – (Denman et al., 2007); squares – (Richter and RA Houghton, 2011) and lozenge – (Shevliakova et al., 2009) and (RA Houghton, 2010)

Forests: Recent estimates of global terrestrial C sink in forest ecosystems show the range of 2.0 to 3.4 Gt C yr^{-1} (Canadell et al., 2007; Le Quere et al., 2009 (Y. Pan et al., 2011). The bottom-up estimates using recent data from forest inventories and long-term field observations, coupled to statistical or process models resulted in an estimated average annual C sink of 2.4±0.4 Gt C yr^{-1} globally for 1990-2007 (see Figure 11.4) (Y. Pan et al., 2011). The contribution of vegetated land of the Northern Hemisphere was assessed to be 1.7±0.8 Gt C yr^{-1} for the period 2000-2004 (P. Ciais et al., 2011).

Inverse modelling studies usually report higher results. Thus, the forest sink for boreal Asia only is estimated to be an average of 0.48 (ranging from 0.33 to 0.63) Gt C yr^{-1} (Shvidenko et al., 2010; Quegan et al., 2011). A consistent average C sink of 0.5±0.1 Gt C yr^{-1} for recent decades (see Figure 11.4) for the boreal zone is a result of contrasting trends between increasing emissions from disturbances in Asian Russian and Canadian forests, and growing sinks within Europe (Kurz et al., 2008); (AZ Shvidenko et al., 2010; P. Ciais et al., 2011). Temperate forests contributed 27% and 34% of global C sink for 1990s and 2000s, respectively. That positive trend is explained mostly by increased forest area in US (Y. Pan et al., 2011)(Yude Pan et al., 2009; Masek et al., 2011) and China (Tian et al., 2011). The reduction of the C sink in tropical intact forests for the period 2000-2007 was mostly caused by deforestation of intact forest area, which is a primary source of new agriculture land in the tropics (55%), and a severe Amazon drought in 2005 (Phillips et al., 2009; Gibbs et al., 2010; Zhao and Running, 2010(Y. Pan et al., 2011), which resulted in the decrease of net carbon balance of South America by nearly 1 Pg C during 2005-2010 (Gloor et al., 2012). The regional trends are presented in **Figure 11.4**.

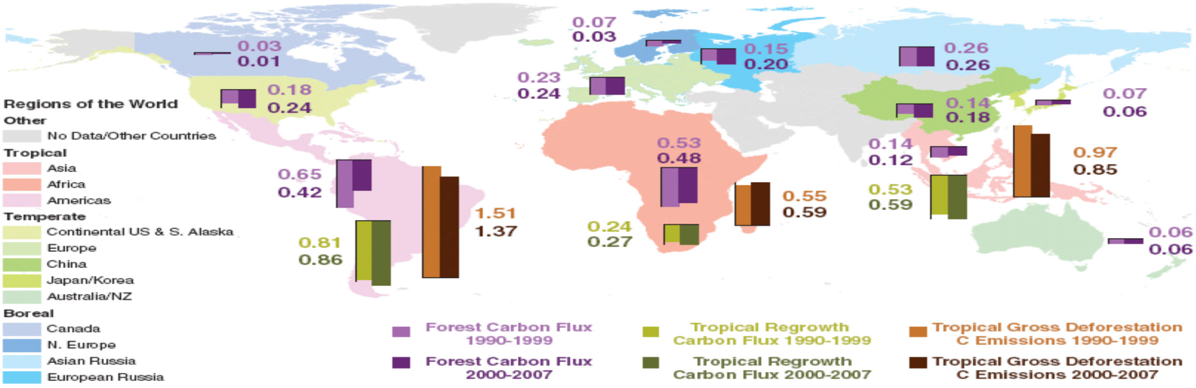

Figure 11.4 Carbon sinks and sources in world's forests (Gt C yr-1). Negative bars (below the x axis) represent sinks; positive bars (above the axis) represent sources. Purple bars represent established forests (boreal, temperate and intact tropical); green bars represent tropical secondary vegetation after disturbances and brown bars represent deforestation emissions (Y. Pan et al., 2011).

The FAO assessment of carbon stocks in the world's forest biomass suggest a decrease by 0.5 Gt C yr^{-1} in 2000-2010, mainly due to a reduction in total forest area (FRA, 2010)(FAO, 2011). Conversion of primary forest to agricultural lands also significantly decreases soil C stocks by 12-30%, and cannot be fully restored in secondary forests (Don et al., 2011). World deforestation has reduced over the past decade but continues at a high rate in many countries. Globally, around 13 Mha of forests were converted to other uses or lost through natural causes each year between 2000 and 2010 compared to around 16 Mha yr^{-1} during the 1990s (FRA, 2010), accounting for about 20% of global GHG emissions (Olander et al., 2008). Additionally, forest degradation, particularly selective logging, is responsible for 15-19% higher C emissions than reported from deforestation alone (Huang and G.P. Asner, 2010). Forest degradation include impacts of large-scale and open forest fires, collection of fuelwood and non-timber forest products and production of charcoal, grazing, sub-canopy fires, and shifting cultivation. On average, one percent of all forests are reported by FAO to be significantly affected each year by forest fires (FRA, 2010). Present global carbon emissions from wildfires estimated to be about 2.0 Gt C yr^{-1} during 1997–2001 (with range 2.8 Gt C yr^{-1} in 1998 and 1.6 Gt C yr^{-1} in 2001) and around 2.1 Gt C yr^{-1} during 2002–2007, before declining in 2008 (1.7 Gt C yr^{-1}) and 2009 (1.5 Gt C yr^{-1}) partly due to lower deforestation fire emissions in South America and tropical Asia (GR van der Werf et al., 2010). Data available from the Global Fire Emissions Database (http://globalfiredata.org) show that global emissions from all types of fires in different ecosystems in 2010 were as high as 2.2 Gt C. Within that number, grassland and open savanna fires had a major contribution of 0.8 Gt C and forest fires contributed about 0.3 PgC. Fires from deforestation and degradation increased in 2010 by almost three times compared to previous years, with 0.7 Pg C resulting from high emissions in South America and Southeast Asia. The contribution of peat fires from deforestation is estimated to be in the range from 0.1 to 0.3 Gt C yr^{-1} in recent years (RA Houghton, 2010). Additionally biomass burning (forest fires and agricultural burning) could contribute up to 42-52% of global black carbon emissions (CATF, 2009)**;** (AMAP, 2011)**;** Lamarque et al., 2010), and comprise as high as 2600 Mt of black carbon per year (Van Der Werf et al., 2006). Spring agricultural fires in the Northern Hemisphere alone (average for 2004-2007) emitted annually about 47.7 Mt of black carbon, with major contributions from Eastern Europe, southern and Siberian Russia, Northeastern China and the northern part of North America's grain belt (CATF, 2009). Agricultural fires account for 11% of China's total black carbon output (Cao et al., 2008).

Croplands: The global carbon balance on permanent croplands is characterized by net emissions of 0.6 – 0.9 Gt C yr^{-1} for 1990-1999 (Shevliakova et al., 2009). However, regional data suggest inconsistent trends within regions (e.g. some studies suggest that croplands in Europe have a negative C balance (Ceschia et al., 2010), whilst others suggest a small C sink; (Philippe Ciais et al., 2010), and different trends in different regions (e.g. average soil C stocks of US croplands are estimated to have increased by 4 Mt C yr^{-1} during 1982-1997 (Lokupitiya et al., 2010).

Grasslands: The current GHG budget of the world's grasslands is still highly uncertain. There are only a few modelling estimates on continental scale, primarily focused on the CO_2 component of GHG budget of grasslands. For the period 1990-1999 the global annual C flux from pastures varied from a source of 0.37 to a sink of 0.15 Gt C yr^{-1} (Shevliakova et al., 2009). A number of studies suggest that grasslands predominantly act as a sink for atmospheric CO_2 (Conant et al., 2001; Follett et al., 2001; Soussana et al., 2007; R. Lal, 2011), but a significant C release may occur in organic rich soils, or under grazing and heat stress during single years. For example, (Gilmanov et al., 2007) found that the annual net ecosystem CO_2 exchange of European grasslands varies from a significant uptake of more than 2400 g CO_2 $m^{-2}yr^{-1}$ to emissions of 600 g CO_2 $m^{-2}yr^{-1}$, though 80% of sites investigated were a net sink. On-site N_2O and CH_4 emissions from grassland may not outweigh the atmospheric CO_2 sink activity (Soussana et al., 2007). Worldwide, significant C sequestration potential has been estimated for permanent pastures in the range of 0.01-0.3 Gt C yr^{-1} (R. Lal, 2011) but the estimates are uncertain.

Wetlands: While CH_4 release from wetlands is largely part of natural C cycling, the drainage of peat soils results in enhanced CO_2 and N_2O emissions. Globally these emissions can be as high as 2-3 Gt CO_2-eq / yr (Couwenberg et al., 2010; Joosten, 2010). Worldwide estimates of GHG emission trends from drained and native wetlands are lacking in the peer-reviewed literature, though data from (Joosten, 2010) shows that the CO_2 emissions from more of 500,000 km^2 of drained peatlands in the world have increased from 1.1 Gt CO_2 yr^{-1} in 1990 to 1.3 Gt CO_2 yr^{-1} in 2008 (an increase of more than 20%). This increase has taken place particularly in developing countries (e.g. Central Asia region). Additionally, about 0.4 Gt CO_2-eq yr^{-1} was emitted due to peat fires in the South-East Asia (Couwenberg et al., 2010; Hooijer et al., 2010). Significant peat fires regularly occur in Russia, Belarus and sounding territories. For developed countries, the trend in emissions since 1990 is decreasing due to natural and artificial rewetting of peatlands though wetlands are still responsible for emissions of more than 0.5 Gt CO_2 yr^{-1} (Joosten, 2010). Future GHG fluxes and resulting C accumulation of peatlands may be affected in different directions in different regions of the world, due to differences in annual temperature, precipitation regime and water levels in wetlands (Saarnio et al., 2009); (Beilman et al., 2009).

It is critical to include the C budget of other ecosystems, such as lakes and mangrove forests, in estimates of current and future global C fluxes. The literature results assess global mangrove primary production of 218±72 Mt C yr^{-1}, and additional C sink due to organic C export, sediment burial and mineralization as high as 112±85 Mt C yr^{-1} (Bouillon et al., 2008). The results obtained by FAO (FAO, 2007) indicate that the global mangrove area is currently about 15.2 Mha, with the largest areas found in Asia and Africa, followed by North and Central America. An estimated 3.6 Mha (20% of the area) of mangroves have been lost since 1980. More recently, the rate of net loss appears to have slowed down, although it is still high. About 185 kha were lost every year in the 1980s; this figure dropped to some 118.5 kha yr^{-1} in the 1990s and to 102 kha yr^{-1} (–0.66%) during the 2000–2005 period, reflecting an increased awareness of the value of mangrove ecosystems. Potential changes of the C budget of lakes may be of global importance, while directions and the magnitude of possible changes depend on changes in precipitation and evaporation. (Cardille et al., 2009) found that regional C flux from lakes of North USA might be 31% higher for a future "wet" scenario and 45% lower in a "dry" scenario compared to present climate. Increased warming may increase CO_2 emissions from the surface of cool lakes (Kosten et al., 2010). Saline lakes play a significant role in the global C cycle and tend to emit more CO_2 than freshwater reservoirs. Globally this flux estimated as 0.11-0.15 Gt C yr^{-1} (Duarte et al., 2008).

11.2.3 Trends of non-CO_2 GHG emissions from agriculture

[AUTHORS: Section will be updated to 2010 data for SOD – 2010 data not yet available] At present, cumulative GHG emissions (both CO2 and non-CO2) from agriculture comprise about 12% of global anthropogenic emissions (Linquist et al., 2012). In total 76% of GHG emissions on croplands comes from the application of fertilizers and 7.6% - from field operations (Ceschia et al., 2010). Between 1990 and 2005 global emissions of CH4 and N2O grew by 10%, from 9909 to 10928 Mt CO2-eq (MtCO2-eq) (U.S. EPA, 2011). The agricultural sector is the largest contributor to global non-CO2 GHGs, accounting for 56% of emissions in 2005 (6211 Mt CO2-eq). N2O emissions from agricultural soils and CH4 emissions from enteric fermentation are dominant sources, which accounted for 32% and 30%, respectively, of agricultural emissions in 2005 (U.S. EPA, 2011). Rice cultivation (11%), biomass burning (12%), and manure management (7%) constitute the remaining non-CO2 emissions from the agricultural sector. Rice cultivation is one of the major sources of global CH4 emissions, which was estimated for 2000 from 708.3 (EPA, 2011) to 716.8 Mt CO2-eq (414.4 – 1167.6) (X Yan et al., 2009).

In the regions of East Asia, Middle East and North Africa, Caucasus and Central Asia, Western Europe, Central and Eastern Europe, OECD North America, N2O emissions from soils were the main source of GHGs in the agricultural sector. Between 1990 and 2005, N2O emissions from agricultural soil management have increased 10%, from 1804 to 1984 Mt CO2-eq (U.S. EPA, 2011). This was largely driven by increasing crop production and increasing use of fertilizer and other nitrogen sources such as crop residues. For the remaining regions, CH4 emissions from rice cultivation (South Asia) and enteric fermentation (Sub-Saharan Africa, Latin America and the Caribbean, and OECD Pacific) comprised the greatest contribution (U.S. EPA, 2011). Global CH4 emissions from enteric fermentation increased by 6% between 1990 and 2005, from 1755 to 1864 Mt CO2-eq (U.S. EPA, 2011). Historical trends in enteric fermentation follow the production cycle of animal numbers, which is largely driven by beef, dairy and buffalo. Emissions from rice cultivation have increased 6% between 1990 and 2005, from 670 to 710 Mt CO2-eq, due to the increase of harvest rice (U.S. EPA, 2011). Between 1990 and 2005, CH4 and N2O emissions from manure management decreased by 5%, from 408 to 389 MtCO2-eq (U.S. EPA, 2011), while emissions from burning increased 12% (from 177 to 198 Mt CO2-eq) and 17% (from 41 to 47 Mt CO2-eq) for CH4 and N2O respectively.

Between 1990 and 2005, total non-CO2 emissions grew from South Asia, East Asia, Sub-Saharan Africa, Latin America and the Caribbean, Middle East and North Africa, OECD Pacific, and OECD North America, while falling from the Caucasus and Central Asia, and Western Europe.

11.3 Mitigation technology options and practices, and behavioural aspects

Greenhouse gases can be reduced by production-side mitigation measures (i.e. by reducing GHG emissions per unit of land or per unit of product), or by demand-side options (i.e. by reducing demand for food and fibre products). IPCC AR4 WGIII chapters 7 and 8 (Nabuurs et al., 2007; P. Smith, Martino, Cai, Gwary, HH Janzen, et al., 2007) focussed on production-side measures; here we consider both production- and demand-side measures, in sections 11.3.1 and 11.3.2, respectively.

11.3.1 Production-side mitigation measures

Production-side mitigation options were described in detail in IPCC AR4 WGIII chapters 7 and 8 (Nabuurs et al., 2007; P. Smith, Martino, Cai, Gwary, HH Janzen, et al., 2007). Per-area and per-animal mitigation potentials for agricultural mitigation options were given in (P. Smith, Martino, Cai, Gwary, HH Janzen, et al., 2007; P. Smith et al., 2008). All measures are summarised in Table 11.2. Measures described in detail in AR4 are not decribed further; additional practices, not considered in AR4 (i.e. bioenergy related measures and biochar), are described in more detail in section 11.3.1.1.

Table 11.2 Summary of production-side mitigation options in the AFOLU sector

Option	Description	References
Forestry		
Reducing deforestation and forest degradation	REDD (Existing forest areas with demonstrable risk of land-use change or reduced carbon storage are conserved, resulting in the avoidance of a business-as-usual scenario that would have produced higher emissions; emissions reductions occur primarily through avoided emissions.)	(Gibbs, Brown et al. 2007; Saatchi, Harris et al. 2011; Mbow, C. et al. 2012)
Afforestation / Reforestation	Afforestration: Establishment of forest plantations on land that, until then, was not classified as forest. Implies a transformation from non-forest to forest. Reforestation: Establishment of forest plantations on temporarily unstocked lands that are considered as forest. Emission reductions occur primarily through additional sequestration.	(Gifford, R.M. et al. 2001; Ravindranath, N.H. et al. 2001; Siyanbola, W.O. et al. 2002; Mendis, M. et al. 2004)
Improved Forest Management	Existing forest areas are managed to increase carbon storage and/or to reduce carbon losses from harvesting or other silvicultural treatments; emissions reductions may occur through additional sequestration and/or avoided emissions and manipulating rotation length.	(Madon and G. 2001; Nabuurs, G.J. et al. 2001; Houghton and R.A. 2002; Karsenty, A. et al. 2002; Mund, M. et al. 2002; Fern and Sinkswatch 2003; Lippke, Garcia et al. 2003; Monserud and R.A. 2003; Zheng, D. et al. 2004; Lehtonen and A. 2005; Merganicova, K. et al. 2005; Robledo, C. et al. 2005)
Forest management in plantations	Planted forest are managed to improve productivity for wood fuel, timber, fruits including cocoa, coffee, wild fruits and NTFP such as gum, resins, rubber etc	(Stigter, Mohammed et al. 2002; Thenkabail, P.S. et al. 2002; Oke and Odebiyi 2007; Rice 2008; Méndez, Castro-Tanzi et al. 2012; Souza, Goede et al. 2012)
Sustainable management in native forest	This includes traditional conservation techniques through protected forest and community forests. Conservation is the major strategy for this activity	(Chokor, B.A. et al. 1994; Hellier, A. et al. 1999; Hardner, J.J. et al. 2000; Ravindranath, N.H. et al. 2001; Arnalds and A. 2004; May, P.H. et al. 2004; Toit, J.T. et al. 2004)

Land-based Agriculture		
Croplands – agronomy	High input carbon practices and those that conserve carbon, e.g. improved crop varieties, crop rotation, use of cover crops, conservation agriculture, agricultural biotechnology	(Powell, J.M. et al. 1996; Perez, P. et al. 1997; Metting, F.B. et al. 2001; Batjes and N.H. 2003; Levy, P.E. et al. 2004) Godfray et al. 2010; (Jennifer A. Burney et al., 2010).
Croplands – nutrient management	Integrated nutrient management, e.g. improved use of N fertilizers (application rate, fertiliser type, timing, precision application), reduction of leaching; , fertilizer input to increase yields causes GHG emissions but reduces land conversion pressures and increases residue for recirculation to soils (esp. important in low-yielding agriculture)	(Altieri, M. et al. 1999; Drechsel, P. et al. 2001; Neupane and Thapa 2001; Manlay, R.J. et al. 2004; Dezzeo, N. et al. 2005; Gray and K.M. 2005)
Croplands – tillage/residues	Improved tillage, e.g. reduced soil disturbance, incorporating crop residues and soil organic matter; retaining crop residues	(Meerman, F. et al. 1996; West, T.O. et al. 2003; Zhao, W.Z. et al. 2004; Farage, P.K. et al. 2007); Powlson et al., 2011; Smith 2012.
Croplands – water management	Improved water avaialability in cropland including water harvesting and application water harvesting techniques including improved SOM for improved water holding capacities of soils	(Meerman, F. et al. 1996; Jackson, Wallace et al. 2000; Dregne and H.E. 2002; Lott, Khan et al. 2003; Evrendilek, F. et al. 2004; Muchena, F.N. et al. 2004; Bayala, Heng et al. 2008)
Croplands – rice management	Riceland management, usually through improved water management (e.g. dryland rice, mid-season paddy drainage)	Yagi *et al.*, 1997; Wassmann *et al.*, 2000; Aulakh *et al.*, 2001; Li et al. 2005b; Sass and Fisher 1997; Cai *et al.*, 2000 2003; Kang *et al.*, 2002; Xu *et al.*, 2003; Pan *et al.*, 2006
Croplands – set-aside & LUC	Long term fallows and community forestry. This includes holly forest and other traditional conservation methods	(Hellier, A. et al. 1999; Todd, S.W. et al. 1999; Bassett, T.J. et al. 2000; Dahlberg and A.C. 2000; Adger, W.N. et al. 2003; Harris, F.M.A. et al. 2003; Lambin, E. et al. 2003; Reenberg, A. et al. 2003; Toit, J.T. et al. 2004; Skutsch and M.M. 2005; Seaquist, W. et al. 2008; Mbow, C. et al. 2010; Assogbadjo, Kakaï et al. 2012)
Biochar	Biochar is a soil amendment that possibly increase biomass productivity, and sequester C from source biomass	(Singh et al. 2010; Taghizadeh-Toosi et al. 2011; (Woolf et al., 2010); Lehmann et al. 2003)
Grasslands – management	Improved grass varieties / sward composition, e.g. deep rooting grasses, inceased productivity and nutrient management	Bosch et al. 2008; Conant et al. 2003; Lynch et al. 2005; Dalal *et al.*, 2003; (Follett et al., 2001); Conant *et al.*, 2005; Liebig et al. 2010c; Lynch et al. 2005; Mortenson et al. 2004
Grasslands – grazing	Appropriate stocking densities, carrying capacity management, fodder banks and improved grazing management, fodder production and fodder diversification	(Conant et al., 2001); Freibauer *et al.*, 2004; Conant and Paustian, 2002; Reeder *et al.*, 2004 Franzluebbers and Stuedemann 2009; Conant *et al.*,2005
Grassslands- fire mgt	Improved use of fire for sustainable grassland management. Fire prevention	(Ehrlich, D. et al. 1997; Ayoub and A.T. 1998; Fearnside and P.M. 2000; Mbow, C. et al.

	and improved prescribed burning	2000; Murdiyarso, D. et al. 2002; Haugaasen, T. et al. 2003; Saarnak, C. et al. 2003; Zhang, Y.H. et al. 2003; Barbosa, R.I. et al. 2005; Ito and A. 2005)
Organic soils – restoration	Soil carbon restoration on peatlands; and avoided net soil carbon emissions using improved land management	(Smith and Wollenberg 2012)
Degraded soils – restoration	Land reclamation (afforestation, soil fertility reduction, water conservation soil nutrients enhancement, improved fallow, etc.)	(Hardner, J.J. et al. 2000; Batjes and N.H. 2003; Sands, R.D. et al. 2003; Arnalds and A. 2004; May, P.H. et al. 2004; Zhao, W.Z. et al. 2004)
Biosolid applications	Use of animal manures and other biosolids for improved managment of nitrogen; integrated livestock agriculture techniques	(Powell, J.M. et al. 1996; Manlay, R.J. et al. 2004; Vagen, T-G. et al. 2005; Farage, P.K. et al. 2007)
Livestock		
Livestock – feeding	Improved feed and dietary additives to reduce emissions from enteric fermentation; including improved forage, dietary additives (bioactive compounds, fats), ionophores / antibiotics, propionate enhancers, archaea inhibitors, nitrate and sulphate supplements	(CJ Newbold et al., 2002; Machmuller et al., 2003; Odongo et al., 2007; RC Anderson et al., 2008; Beauchemin et al., 2008; Martin et al., 2008; Waghorn, 2008; Grainger et al., 2008, 2010; PA Foley et al., 2009; Nolan et al., 2010; Van Zijderveld et al., 2010; Ding et al., 2010; Mao et al., 2010; EG Brown et al., 2011; Eugene et al., 2011); Waghorn *et al*., 2007; Kumar, 2011; Wood *et al*., 2006; Van Zijderveld *et al*., 2011
Livestock – breeding and other long term management	Improved breeds with higher productivity (so lower emissions per unit of product) or with reduced emissions from enteric fermentation; microbial technology such as archaeal vaccines, methanotrophs, acetogens, defaunation of the rumen, bacteriophages and probiotics	(Boadi et al., 2004; Alford et al., 2006; Nkrumah et al., 2006; RS Hegarty et al., 2007; Attwood and CS McSweeney, 2008; SR Cook et al., 2008; Morgavi et al., 2008; Janssen and Kirs, 2008; Chagunda et al., 2009; YJ Williams et al., 2009; Wedlock et al., 2010; T Yan et al., 2010) Emma et al., 2010; Newbold and Rode, 2006
Manure management	Management of manure to reduce methane and nitrous oxide emissions including composting, covering manure storage facilities, livestock diets to reduce GHG emissions from manure	(Powell, J.M. et al. 1996; Manlay, R.J. et al. 2004; Vagen, T-G. et al. 2005; Farage, P.K. et al. 2007) (Berg et al., 2006; Clemens et al., 2006; Hindrichsen et al., 2006; Shiraishi et al., 2006; Hao et al., 2011; Osada et al., 2011; Park et al., 2011) Ahh *et al*. 2011

Integrated Systems		
Agroforestry (including agropastoral and agrosilvopastoral systems)	Agro-forestry is the production of livestock or food crops on land that also grows trees for timber, firewood, or other tree products. It includes shelter belts and riparian zones/buffer strips with woody species. Incorporating trees into cropland management by switching to short rotation woody crops (SRWCs) or by establishing agroforestry could serve both agricultural and carbon sequestration objectives	(Vagen, T-G. et al. 2005; Oke and Odebiyi 2007; Rice 2008; Takimoto, A. et al. 2008; Lott, Ong et al. 2009; Sood and Mitchell 2011; Assogbadjo, Kakaï et al. 2012; Semroc, Schroth et al. 2012; Souza, Goede et al. 2012; Wollenberg, E. et al. 2012)
Other mixed biomass production systems	Mixed production systems such as double-cropping systems and mixed crop-livestock systems can increase land productivity and efficiency in the use of water and other resources as well as serve carbon sequestration objectives. Grasses can in the same way as woody plants be cultivated in shelter belts and riparian zones/buffer strips provide environmental services	Heggenstaller et al., 2008; Herrero et al., 2010
Integration of biomass production with subsequent processing in food and bioenergy sectors	Integrating feedstock production with conversion, typically producing animal feed, that can reduce demand for cultivated feed such as soy and corn and can also reduce grazing requirements.	Dale et al., 2009, 2010; (Sparovek et al., 2007)
Bioenergy		
Bioenergy from forestry residues	Biomass from silvicultural thinning and logging, and wood processing residues such as sawdust, bark and black liquor. Dead wood from natural disturbances, such as storms and insect outbreaks, represents a second category..Environmental effects of primary residue removal depend on land management practice and local conditions, and removal rates need to be controlled considering local ecosystem, climate, topography, and soil factors.	(Chum et al., 2011); Näslund and Gustavsson 2008; Eriksson and Gustavsson 2010; Lattimore et al. 2009;
Bioenergy from forest unutilized forest growth	Biomass from growth occurring in forests judged as being available for wood extraction, which is above the projected biomass demand in the forest industry. Includes both biomass suitable for, e.g., pulp and paper production and biomass that is not traditionally used by the forest industry.	(Chum et al., 2011); Alam et al. 2012; (Sathre et al., 2010; Routa et al., 2012); Berg et al. 2005; Pyörälä et al 2012; Poudel et al. 2012
Bioenergy from forest plantations and agroforestry	Includes biomass from woody plants grown in short-rotation coppice or single stem plantations (e.g., willow, poplar, eucalyptus, pine). Both monoculture plantations and mixed production systems including agroforestry are included.	(Kursten 2000; Tamubula and Sinden 2000; Ravindranath, N.H. et al. 2001; Rice 2008; Sood and Mitchell 2011)

Bioenergy from crop residues	Use of crop residues for Bioenergy; Use of by-products associated with crop production and processing, both primary (e.g., cereal straw from harvesting) and secondary residues (e.g., rice husks from rice milling) to produce bioenergy.	(Rogner et al., 2012), Hakala K, Kontturi M, Pahkala K: Field biomass as global energy source. Agric Food Sci 2009, 18:347-365. (to be put in Zotero) (H. Haberl et al., 2010); (Chum et al., 2011), (Gregg and Steven J. Smith, 2010)
Bioenergy from dedicated crops	Cultivation of high yielding crops specifically designed for energy end use. Includes cultivation of both conventional agriculture crops and bioenergy feedstock plants such as oil crops (e.g., Jatropha), grasses (e.g., switchgrass, Miscanthus).	(Chum et al., 2011);(Sims et al., 2006; H. Haberl, K.-H. Erb, et al., 2011; T. Beringer et al., 2011); (A. Popp, J.P. Dietrich, et al., 2011); (Karl-Heinz Erb et al., 2012a)
Bioenergy from manure mgt (Biogas)	Animal dung from confined livestock production. Currently dung is often burned directly as a cooking fuel in many developing countries. Dung can be converted to biogas in biodigesters.	(Rogner et al., 2012) (H. Haberl et al., 2010); (Chum et al., 2011); (B Amon et al., 2006); Börjesson and Berglund 2006; Möller 2009
Bioenergy from Organic Wastes	A heterogeneous category that can include, e.g., organic waste from households and restaurants, discarded wood products such as paper and demolition wood, and wastewaters suitable for anaerobic biogas production.	(Chum et al., 2011); (Rogner et al., 2012)

11.3.1.1 Production-side mitigation measures not considered in the agriculture and forestry chapters in AR4

Biochar

Biomass stabilisation can be an alternative or enhancement to bioenergy in a land-based mitigation strategy. Heating biomass with exclusion of air / oxygen (pyrolysis) eliminates H and O preferentially over C, producing in addition to energy-containing volatiles and gases, a stable C-rich co-product (char). Added to soil as ‘biochar’, a system is created that has greater abatement potential than typical bioenergy (Woolf et al., 2010) and probably highest where efficient bioenergy (with use of waste heat) might be constrained by a remote, seasonal or diffuse biomass resource (Shackley et al., 2012). The relative benefit of pyrolysis–biochar systems (PBS) is increased if assumptions are made for the durability of positive effects of biochar on crop (and thus biomass) productivity and impacts on soil-based emission of trace gases (N_2O and CH_4). Using assumptions based on emerging understanding Woolf et al. (2010) calculated a “maximum sustainable technical potential” for 1.8 GtCe/yr abatement from 2.27 Gt biomass C. With competition for virgin non-waste biomass this was lower (1.0 GtCe/yr from 1.01 GtC) and the accrual of 66–130 Pg abatement over 100 y, with favourable adoption rates. Meta-analysis of short-term data supports plant productivity is typically enhanced by ca. 15% over the short-term, but with a wide range that probably relates to pre-existing soil constraints (Jeffery et al., 2011). Loosening by one-half the feedback from 0–90% productivity increase assumed by (Woolf et al., 2010), abatement estimates decreased 10%. Decreasing the assumed 25% suppression on soil N_2O flux similarly had a smaller effect. Although the interaction of biochar and the soil N cycle are not fully understood (mineralisation, nitrification, immobilisation and sorption are variously affected over periods of days to years) the occasionally dramatic and explainable suppression of soil N_2O flux is not predictable, especially long-term. The potential to enhance mitigation by tackling gaseous emissions from organic fertiliser before as well as after application to soil (Steiner et al., 2010) – and spatial strategies to maximise the effect – have been barely explored). However, the abatement potential for PBS remains most sensitive to the absolute stability of C stored in biochar, for which estimates of ‘half-life’ inferred from wildfire charcoal

(Lehmann et al., 2008) or extrapolation of direct short-term observation range from <50 to >10,000 y (Spokas, 2010). The (Woolf et al., 2010) analysis makes optimistic assumptions on the yield of stabilised carbon (biochar) and energy product from biomass pyrolysis that would require efficient as well as clean technology and access to energy infrastructure. Most importantly, the economic factors that currently constrain PBS are not considered in a technical, sustainable potential; currently the feasibility of meeting the breakeven cost of biochar production (location specific) depends on a predictable return on benefits to crop production – and this will remain the case until stabilised C can be monetised.

Bioenergy

Climate change mitigation from bioenergy

Production and use of bioenergy influences the climate through (i) emissions of CO_2 and other GHG emissions from fossil fuels associated with the biomass production and conversion to secondary energy carriers; (ii) GHG emissions or CO_2 sequestration associated with changes in biospheric C stocks often caused by associated direct and indirect land-use change (dLUC and iLUC); (iii) climate forcing not related to GHG emissions including particulate and black carbon emissions from small-scale bioenergy use, aerosol emissions associated with forests, and changes in surface albedo; and (iv) effects of other changes resulting from bioenergy use, such as price effects on petroleum influencing consumption levels (Chum et al., 2011). The net effect of harnessing the bioenergy potential on climate change mitigation is the difference between total climate forcing of the bioenergy system and that of the energy system displaced. The displaced system may be based on fossil fuels or other energy sources.

Bioenergy systems deliver large GHG savings if they replace fossil-based energy causing high GHG emissions and if the bioenergy production emissions – including those arising due to LUC– are kept low (Chum et al., 2011). Alternative methods of quantification lead to variation in estimates of GHG savings and the precise quantification of GHG savings for specific systems is often hampered by lack of reliable empirical data. Efficient fertilizer management that minimizes emissions of N_2O from agricultural production and the minimization of GHG emissions from the conversion process of feedstocks to final energy carriers are essential to achieve large mitigation per unit energy (A. Popp, H. Lotze-Campen, et al., 2011). However, GHG emissions from LUC of some bioenergy schemes can be large, in some cases more than a hundred times larger than the annual GHG savings from the fossil fuel displacement (Göran Berndes, 2012)**;** (Holly K Gibbs et al., 2008; Chum et al., 2011); hence, bioenergy-related policies and regulations may fail to reach their stated objective of climate change mitigation if they fail to take the full GHG effects of bioenergy into account (Helmut Haberl et al., 2012).

In regions with seasonal snow cover or a seasonal dry period (e.g. savannahs), reduction in albedo due to the introduction of perennial green vegetative cover can counteract the climate change mitigation benefit of establishing bioenergy plantations (Gibbard et al., 2005); Betts et al. 2007; Loaire et al. 2011). Conversely, albedo increases associated with LUC can counter the warming effect of C emissions, for instance when forests are converted to croplands, pastures, or other more reflective land cover (Brovkin et al. 2004; (Bala et al., 2007; Bernier et al., 2011) Kirchbaum et al. 2011). Similarly, the net climate outcome of forest bioenergy is influenced by the way associated changes in forest management affect albedo (PJ Lawrence et al., 2012); Otto et al. 2012; Bright et al. 2012). The integration of climate change effects associated with albedo and C stock changes is still in its infancy and several challenges remain (Bright et al. 2011; Pongratz et al. 2010). The combined effects are particularly sensitive to the true albedo change – including atmospheric effects and clouds – and this is often not measured (Schwaiger and D Bird, 2010).

Bioenergy feedstock supply potentials and associated land use

The main biomass resources are: a) Primary and secondary residues in the agriculture and forestry sectors, and tertiary residues including the organic fraction of MSW and wastewaters suitable for anaerobic biogas production); b) Unutilized forest growth including both biomass suitable for, e.g., pulp and paper production and biomass that is not traditionally used by the forest industry; and c) Biomass from cropping systems (annual and perennials) established on lands ranging from prime cropland to marginal lands including lands that have become degraded due to unsustainable land use. Table 11.3 describes these resources.

The global biomass supply potentials of these resources are difficult to estimate as they depend on a number of biophysical, technical, and socio-economic factors. Important determinants include population and economic/technology development and how these translate into fiber, fodder and food demand (especially share and type of animal food products in diets) and how these demands are further translated into demand for land, water and other resources depending on performance in the food and forestry sectors (e.g., yields, water use efficiency, livestock feeding efficiency). Trade patterns are also important by determining the links between supply and demand. Development and innovation in feedstock production (e.g., higher yields and adaptation to specific growing conditions) and conversion (notably to allow biofuels production based on lignocellulosic resources) may also open new possibilities. The potential also depends on the priority given to bioenergy products versus other products obtained from the land, and on how much total biomass can be mobilized in agriculture and forestry. This in turn depends on natural conditions (climate, soils, topography), how societies understand and prioritize nature conservation and soil/water/biodiversity protection, and on how agronomic and forestry practices are shaped to reflect these priorities (Karl-Heinz Erb et al., 2012b)**;** (Chum et al., 2011)**;** (H. Haberl, K.-H. Erb, et al., 2011)**;** (Creutzig et al., 2012).

The full fuel-cycle GHG emissions of all types of biofuels are uncertain. The marginal change in global GHG emissions induced by biofuel production depends on many factors and has not been comprehensively or reliably estimated (McKone et al. 2010; Delucchi, 2010; (Lapola et al., 2010). Where unregulated, production of some types of biofuels in some locations could cause deforestation resulting in large net GHG emissions (Marshall Wise et al., 2009). Even biofuel expansion accompanied with ambitious forest protection programmes may cause significant net emissions (Melillo et al., 2009; (Creutzig et al., 2012).

Many studies use a ‘food/fiber first principle’, applied with the objective of quantifying biomass resource potentials under the condition that specific requirements (e.g., food and fiber supply; soil and water protection) are prioritized (Chum et al., 2011; Coelho et al., 2012). Integrated Assessment Models (IAM) allows better capturing of the dynamics of competing demands for land and other resources and can be expected to help governance of bioenergy by advancing the understanding of trade-offs, possibilities and risks associated with bioenergy expansion, including GHG emissions or CO2 sequestration associated with LUC (see, e.g., (J Fischer et al., 2008; D.P. van Vuuren et al., 2009)**;** (H. Lotze-Campen et al., 2010)**;** Melillo et al., 2009; Wise et al., 2009; **;** (A. Popp, J.P. Dietrich, et al., 2011)**;** (T. Beringer et al., 2011). Existing and emerging guiding principles and sustainability certification systems support sensible utilization of biomass resources (Stupak, I., Lattimore, B., Titus, B., Smith, C.T., 2011; (van Dam et al., 2010) but the resource potential implications of complying with these are little researched.

The IPCC Special Report on Renewable Energy (SRREN) estimates that potential deployment levels of biomass for energy by 2050 could be in the range of 100 to 300 EJ yr^{-1} (Chum et al., 2011), noting that studies have reported both lower and higher lower/upper bounds. Other assessments report 50-500 EJ yr^{-1} (Veronika Dornburg et al., 2010) and 160-270 EJ yr^{-1} (Rogner et al., 2012). The potential of specific biomass resource categories are described below.

Bioenergy from organic waste and residues from forestry and agriculture

Organic waste and residue flows in the agriculture and forestry sectors represent a potential with few technical constraints on rapid ramp-up for several categories such as dung, straw, wood processing by-flows. Resource use (e.g., land and water) associated with harnessing this resource is low given that residues are by-flows of other production. Energy inputs (including for nutrient loss compensation) are commonly below 10% of energy in the extracted biomass and associated GHG emissions correspondingly low, but methane emissions from wood chip storage may in some situations be important (Eriksson and Gustavsson 2010; Wiersaari, M. 2005; Cherubini and Ulgiati 2010). Environmental effects of primary residue removal depend on land management practice and local conditions, and removal rates need to be controlled considering local ecosystem, climate, topography, and soil factors (Lattimore et al 2010; Gabrielle, B., Gagnaire, N., 2008; (Chum et al., 2011). iLUC effects are mostly negligible but may arise if earlier uses (e.g., animal feeding) are displaced or if soil productivity losses require compensating extended/intensified cultivation. There is a near term trade-off in that organic matter retains organic carbon for longer if they are left on the ground instead of being used for energy, although the longer term soil C tradeoff may be less than previously believed (see also Section "Forest Mitigation Options").

Table 11.3 shows the estimated supply potential disaggregated by main geographical regions. For comparison, (Chum et al., 2011) reported ranges for the global technical potential in 2050 at 15-70 EJ/yr (primary and secondary residues in agriculture, excluding dung); 5-50 EJ yr^{-1} (dung); 5-50 EJ yr^{-1} (organic wastes). Forest residue flows were not reported explicitly but grouped with potential supply from non-utilized forest growth (0-110 EJ yr^{-1}).

Forest biomass from natural and managed forests

This category refers to the potential use of unutilized forest growth, i.e., the net annual increment in forests available for biomass supply that is not needed for the production of conventional forest products (e.g., paper and sawnwood). Estimates of the supply potential range from 0 to 100 EJ/yr by 2050 (Chum et al., 2011). Realizing higher-end potentials for this category implies increasing the forest output to several times the present global industrial roundwood production, drastically extending the share of global forests that is managed for high biomass output. This requires handling of trade-offs in relation to timing of C flows, biodiversity conservation and other environmental objectives, and also aesthetic/recreation values.

The climate mitigation outcome of increasing the energetic use of forest biomass depends on how the forest C stock and albedo, but also non-CO_2 GHG emissions, are affected by the changes in forest management and harvest that occur in response to increasing forest biomass demand for energy. Specifically, the outcome for forest C stocks depends on soil and climate factors, the forest management history, and on which specific changes in management and harvest regime that are introduced (Hudiburg et al., 2011). *Ceteris paribus*, forest management to promote growth (e.g., fertilization, site preparation, and restocking to higher densities) increases forest C stocks (Alam et al. 2010, 2012; (Sathre et al., 2010; Routa et al., 2011, 2012) while shortened forest rotation period and increased removal of residues from felling and silvicultural treatments decreases forest C stocks (Marland and B. Schlamadinger, 1997; Cherubini et al., 2011). Modelling and assessment methodology also influences results (Antón-Fernandez et al., 2012; (Lippke et al., 2011; Göran Berndes, 2012; Galik and Abt, 2012).

Active forest management can promote increases in growing stocks – and net annual increment – allowing increased forest biomass output without draining the forest resource and C stocks over time. However, the inertia of long-rotation forestry makes this a longer- term option. Specifically, forest C losses associated with the conversion of old-growth forests to planted production forests may not be compensated by forest growth in other parts of the forest landscape in a situation of rapid and extensive forest conversion.

Biomass from cropping systems

This category includes annual and perennial plants including trees (see Table 11.3) grown on currently used or abandoned agricultural land, and on other lands including also lands under native vegetation. The potential critically depends on land availability – which in turn depends on competing land demand (infrastructure, food, feed and fiber production) and restrictions (e.g., water scarcity, high C content in soils and existing vegetation, biodiversity conservation) – and on what yield levels that can be achieved on available lands now and in the future. This last depends on both the quality of available land (climate, soil, topography) and the land use/technology practices that are implemented. Some studies (Monique Hoogwijk et al., 2003; M. Hoogwijk et al., 2005; EMW Smeets et al., 2007) exploring wider variations for critical determinants report wide ranges (zero to above 1000 EJ / yr in 2050) while other studies (D.P. van Vuuren et al., 2009; T. Beringer et al., 2011)(Beringer et al. 2011; Van Vuuren et al 2009; report more narrow ranges with the higher end for the potential below 300 EJ / yr.

Insufficient data and resolution can prevent identification of unsuitable land parcels (e.g., steep slopes) and also makes it difficult to assess whether land is already used (N. Ramankutty et al., 2002; Coelho et al., 2012). Especially land use for animal production is difficult to assess given the widespread and highly varying intensity of animal grazing (K.-H. Erb et al., 2007). These uncertainties can lead to both over- and underestimation, depending on how such uncertainties are treated in the modelling. The parameterization to reflect various considerations (e.g. protection of natural ecosystems or limitations due to water availability or high C content in soils and existing vegetation) is hampered by lack of data and knowledge, and it involves judgments of impact risks and priority among objectives and resource uses that can be based on norms and value judgments rather than objective data.

Table 11.3 Supply potential[1] for the main biomass categories, year 2050 if not indicated otherwise

	Biomass categories (Potential, EJ)							
	Waste	**Agriculture crop residues**	**Dung**	**Forest residues**	**Unutilized forest growth**	**Plantations**		**Total**
						Surplus agricultural land/ unspecified	**Marginal/ degraded land**	
Africa	1	5.5 12-20 2.3-2.4 5 2.2	4	2.5 0 0.6 0-1	1.8	69 31-317(SSAfr)) 0 5-48 15-24 10-137(SSAfr) 10-23 21		
Australia & NZ (Pacific OECD)	1	0.8 2-5(Oceania) 0.6-0.7 1 0,4	2	0.5 0 (Oceania) 0.6 1-2	0.3	17 38-102(Oceania) 6-12 17-32(Oceania) 6-10(Australia) 30-55(oceania) 3-8 2		

Canada & USA (NAm)	1	6.7 4-9(NAm) 6.1-6.4 4 6	4	3.6 10(NAm) 6.2 6-12	4.9	19 20-174(NAm) 8-30 27-58 12-33 45-71 6-21 10		
Canada		0.9-1.0				2-3.5 9-14 12-18		
USA		2.3/ <2.2 (2030) 4.4/ <2.8 (2030) 4.8/ <3.3 (2030) 5.2-5.4		1.5/ <2.2 (2030) 1.7/ <2.8 (2030) 1.8/ <3.3 (2030)		6-26 0.6/ <2.2(2030) 3.8/ <2.8(2030) 7.2/ <3.3(2030) 18-46 33-53		
Latin America	2	7.4 9-11 6.7-7.1 11 2.4	8	3.7 3(incl. Carib) 1.4(incl. Carib) 2-4	21.7	45 47-221(incl.Carib) 2-25 2-66 18-34 28-104 11-34 22		
Europe & Russia	1	8.2 5-7 6.0-6.4 6 5.5	6	2.9 8 4.1 7-13	34.5	17 3-4 65-115 6-16 53-255 90-150 6-20 12		
Europe	1	6.3 1-2 4.1-4.3 3 (2030) 0.6 3 4 4.5	4	1.8 5 2.7 1.4 (2030) 1.7-2.2 3.8-4.9 5-9	1.3 (2030) 2.8	12.3-18.3 8-56 17-24 4-11 17-23 11-14 11-18 3-11 5		
Former Soviet Union (Russia)	0	1.9 2-3 (C.I.S.+Baltic States) 1.9-2.1 2 1	2	1.1 3(C.I.S.+Baltics) 1.4(C.I.S.+Baltics) 2-4	31.7	45-199 (C.I.S.+Baltics) 47-97 2-5 68-127 3-9 7		

Middle East (ME& NAfr)	1	0.6 0-1 0.9-1.0 2 1	2	0.2 0 0.3 0	0	0.2 0 2-4 0-4 1-31 5-18(ME&NAfr) 1-3 0		
S&E Asia	4	11-14 16.6-17.6 24 10	14	9.2 7 4.1 2-4	0.8	4 0 11-92 7-28 26-172 44-144 8-25 11		
China		10.9 6.2-6.5		2.4		3-10		
India		7.9 4.8-5.1		2.9				
Japan & Korea (group without China)		0.3 0.2		3.3				
SE Asia		10.8 5.4-5.8		0.6		4-12		
Global	1-3 11	59.1 38-41 46-66 28 49	9-25 39	22.6 28 30 17.1	74 64	171 215-1272 6-70 130-410 (abandoned) 35-245 (restland) 0-988 44-133 77	8-110	105 163-268 350-450

[1] Category-specific cost-supply curves scalingfrom farm to the regional level are needed to account for possible large-scaledeployment scenario effects where the costs increase as total biomassproduction increases. Source for technical potentials: Gregg and Smith (2010); Data for costs adapted from Chum et al., 2011, Table 2.4 pp.34-35. [AUTHORS: The table will be completed for the SOD, using ranges instead of specific values for each region]

Despite uncertainties it can be concluded that: (i) intensification in agriculture for food/feed production, diets, and efficiency in the use of biomass are key aspects since they determine land requirements for food, biomaterials and bioenergy (Popp et al. 2011; (E. Stehfest et al., 2009) Wirsenius et al. 2010). Especially the share of animal food products in human diets is a critical determinant, given the large land requirements and often low productivity land use associated with livestock production (both cropland and grazing land); (ii) There exists large areas of marginal and degraded land (often subject to extensive grazing), and also currently unprotected grasslands, woodlands and forests that are biophysically suitable for producing biomass for energy. However, their utilization is in many places subject to serious trade-offs concerning, e.g., biodiversity, water impacts and also climate change mitigation due to large GHG emissions associated with converting such lands to bioenergy cultivations - including iLUC emissions where existing land uses are displaced (Karl-Heinz Erb et al., 2012b); Berndes 2002; Molden 2007; (Chum et al., 2011; Creutzig et al., 2012); (iii) Investment in agricultural research, development and deployment could produce a considerable increase in land and water productivity (Rost et al. 2009; Herrero et al. 2010; (H. Lotze-Campen et al., 2010) as well as improve robustness of plant varieties (Reynolds and Borlaug 2006; Ahrens et al. 2010). Integrated and multi-functional land use providing multiple ecosystem services represent alternatives to conventional intensification (IAASTD, 2009) Folke et al. 2004, 2009) represent and the integration of bioenergy systems into agricultural landscapes can contribute to multiple environmental and socioeconomic objectives, including the reclaimation of degraded lands and development of farming systems and landscape structures that are beneficial for the conservation of biodiversity (Berndes et al. 2008; Vandermeer and Perfecto 2006).

11.3.2 Demand-side options for reducing GHG emissions from AFOLU

Changes in demand for food and fibre can reduce GHG emissions in the production chain. With regard to food, this is a sensitive issue, given that currently approximately one in seven people do not have sufficient access to food in terms of protein and food calories (Godfray et al., 2010). Nevertheless, there are great opportunities in both, developing and industrialized countries today which may get even more important for currently developing and emerging regions if they take a path for consuming food comparably to industrialized regions in the future.

Two options exist to reduce GHG emissions through changes in food demand without jeopardizing health and well-being:

(1) Reduction of losses and wastes of food in the supply chain (FSC) as well as during final consumption (e.g. food bought and wasted during preparation or not consumed at all).

(2) Changes in diet towards less resource-intensive food, i.e. less animal products, substituted by appropriate plant-based food in order to avoid lack of protein supply, as well as reduction of overconsumption in regions where this is prevalent.

This section also discusses demand-side options related to forestry products and socioeconomic C stocks. Demand-side options are summarised in table 11.4.

Reductions of losses in the food supply chain - Globally, it has been estimated that approximately 30-40% of all food production is lost in the supply chain from harvest to final consumers (Godfray et al., 2010). In developing countries, losses of up to 40% occur on farm or during distribution as an effect of poor storage, distribution and conservation technologies and procedures. In developed countries, losses of food on farm or during distribution are smaller, but substantial amounts (up to 40%) are lost in services sectors and at the consumer level (J. A. Foley et al., 2005); Godfray et al., 2010; Parfitt et al., 2010; Gustavsson et al., 2011; Hodges et al., 2011).

Not all of these losses are ‘avoidable’ or ‘potentially avoidable’; for example, losses in households also include parts of products not deemed ‘edible’ under normal circumstances (Parfitt et al., 2010). In the UK, 18% of the food waste was classified as ‘unavoidable’, the same amount as ‘potentially avoidable’ and 64% as ‘avoidable’ (Parfitt et al., 2010). The review of Parfitt et al. (2010) compared recent data for industrialized countries (Austria, Netherlands, Turkey, UK, USA) that found food wastes at the household level of 150-300 kg food per household per year (Parfitt et al., 2010).

A mass-flow modelling study based on FAO commodity balances that covered the whole food supply chain (FSC) but excluded non-edible fractions found per-capita food loss values ranging from 120-170 kg/cap/yr in Subsaharan Africa to 280-300 kg/cap/yr in Europe and North-America (J Gustavsson et al., 2011). Calculated losses ranged from 20% in Subsaharan Africa to >30% in the industrialized regions. The study authors highlight that their results include substantial uncertainties and call for more research to close data gaps.

Most of these studies suggest a range of measures to reduce wastes throughout the FSC, including investments into harvesting, processing and storage technologies primarily in the developing countries as well as awareness raising, taxation or retail-sector measures targeted at reduction of retail and consumer-related losses primarily in the developed countries. However, none of the reviewed studies presents detailed, comprehensive bottom-up estimates of saving potentials, although the potential are likely quite substantial (Reay et al., 2012). Global food-related GHG emissions in 2050 in a 'business as usual' scenario are estimated to be approximately 12.1 Gt CO_2eq / yr (E. Stehfest et al., 2009). If one assumes that 25% of the produced food would be wasted in the FSC (J Gustavsson et al., 2011) and a quarter respectively half of the wasted food could be saved (Parfitt et al., 2010), this would amount to a GHG saving potential on the order of 0.76-1.5 Gt CO_2eq / yr [Popp et al. paper in preparation].

Table 11.4 Summary of consumption-side mitigation options in the AFOLU sector

Change in diet	Reduced consumption of food derived from agricultural products with high greenhouse gas emissions per unit product, e.g. livestock products	(E. Stehfest et al., 2009); (A. Popp et al., 2010); Smith 2012 (Annika Carlsson-Kanyama and Alejandro D González, 2009), (Alejandro D. González et al., 2011).
Reduced food loss	Reduced losses in the food supply chain as well as in final consumption	(Godfray et al., 2010) (J Gustavsson et al., 2011) (Hodges et al., 2011) (Parfitt et al., 2010).
Change Consumption of Wood Products	By changing habits to conserve wood and using alternative and recycled fibers to substitute for wood in various products, wood consumption could be reduced and then conserving existing carbon pools in the forest. Consumers can also promote forest protection by buying wood products, if they are made from "certified sustainable wood." Sustainable wood comes from the practice of "sustainable forestry" which ensures that the rate of timber harvest does not exceed the rate of timber growth.	[AUTHORS: References will be added]
Substitution of wood for carbon intensive products	By using forest products as substitutes for fossil fuels or non-renewable materials, emissions from fossil C sources can be displaced. The efficiency of emissions displacement depends on the product, its lifecycle and the fossil-fuel based reference system that is substituted. The obtained emission reductions per unit of biomass are generally higher if harvested biomass can be used both for material and energy substitution; and possibly even higher if it can be materially recycled during its lifetime and only finally used for energy.	(K. Pingoud et al., 2010)
Increased C stocks in Wood Products	Carbon in wood and paper products remains sequestered and is emitted to varying degrees depending on how products are made, used, and disposed. Sequestration in products and uses can be increased by altered processing methods, shifts in products used, end-use durability, and landfill management. Sequestration in forests and products can be maximized by coordinated understanding of forest ecosystems and product utilization.	(Laturi et al., 2008)

Changes in diets - Bottom-up studies, based on Life-Cycle Analysis methods, consistently show much lower GHG emissions for most plant-based food than for animal products, with the exception of vegetables grown in heated greenhouses or transported via airfreight (A. Carlsson-Kanyama and A.D. González, 2009). This also holds for GHG emissions per unit of protein when animal-based and plant-based protein supply is compared (Alejandro D. González et al., 2011). A comparison of three meals served in Sweden with similar calorie and protein content based on (1) soy, wheat, carrots and apples, (2) pork, potatoes, green beans and oranges, and (3) beef, rice, cooked frozen vegetables and tropical fruits revealed GHG emissions from 0.42 kgCO_2eq for the first option, 1.3 kgCO_2eq for the second and 4.7 kgCO_2eq for the third, i.e. a factor of >10 for nutritionally comparable meals (A. Carlsson-Kanyama and A.D. González, 2009). Such LCA studies have so far not considered emissions related to land-use change deriving from food production and consumption. In a recent study aimed at exploring the magnitude of land-related GHG emissions of food, the foregone C sequestration potential of land required for food production in Life Cycle Analyses (LCA) of beef, lamb, calf, pork, chicken and milk was found to be 25%-470% of the GHG emissions considered in conventional accounts. The land-related GHG emissions depended on product and time horizon (30-100 yr) (Schmidinger and Elke Stehfest, 2012). iLUC-related GHG emissions are particularly high for beef produced in tropical regions if cattle production contributes to deforestation (C. Cederberg et al., 2011). Such findings underline the large importance of dietary choices for GHG emissions related with food supply chains (Reay et al., 2012).

Top-down modelling studies show that changes in future diets can have a significant impact on GHG emissions from food production. Using a coupled model system comprising the land use allocation model MAgPIE and the dynamic global vegetation model LPJmL (A. Popp et al., 2010) calculate several scenarios: In a 'constant diet' scenario that considers only population growth, agricultural non-CO_2 emissions (CH_4 and N_2O) would rise from 5.3 GtCO_2-eq/yr in 1995 to 8.7 GtCO_2-eq/yr in 2055. If current dietary trends (increased consumption of animal-related food) were to continue, emissions were projected to rise to 15.3 GtCO_2-eq/yr, while the GHG emissions of a 'decreased livestock product scenario' were estimated to be 4.3 GtCO_2-eq/yr in 2055. A combination of increased consumption of livestock products and implementation of technical mitigation measures reduced emissions compared to the scenario with increased consumption of livestock products, but emissions in 2055 were still higher than in the 'constant diet' scenario (9.8 GtCO_2-eq/yr), whereas the emissions could be reduced to 2.5 GtCO_2-eq/yr in 2055 in a 'reduced meat plus technical mitigation' scenario. Popp et al. concluded that the potential to reduce GHG emissions through changes in consumption was substantially higher than that of technical GHG mitigation measures.

Stehfest et al. (2009) discuss effects of changes in diets on GHG emissions based on IMAGE model runs; their study includes CO_2, CH_4 and N_2O. They estimate that land-use related GHG emissions (including C sequestration in ecosystems) will rise to 3.2 GtC-eq/yr (i.e. 11.9 GtCO_2-eq/yr) in the year 2050 in a scenario largely based on FAO projections FAO, 2006). They investigate several other diets (1) no ruminant meat – here all ruminant meat is substited by proteins derived from plant products, (2) no meat – all meat substituted by plant products (3) no animal products – all animal products, including eggs and milk substituted by plant products and (4) a 'healty diet' based on recommendations of the Harvard Medical School – this diet implies reductions of animal product intake in countries with rich diets but increases in countries with poor, protein-deficient diets. Their findings show a huge range of future emissions with changes in diets resulting in GHG emissions compared to business-as-usual ranging from 36-66% (see Table 11.5). Depending on scenario, CO_2 contributed 44-67% to the total emission reduction, CH_4 28-47% and N_2O 6-11%. Stehfest et al. also analyzed the effects of the adoption/non-adoption of dietary change had on abatement costs required to reach a predefined GHG concentration target (450 ppm CO2eq). They found that a global adoption of the 'healthy diet' would reduce global GHG abatement costs by about 50% compared to the reference case.

Table 11.5 Food-supply chain related GHG mitigation potentials in 2050

	Global GHG reduction potential compared to 'business as usual' scenario [Gt CO_2-eq/yr]	Sources
Reduction of FSC losses and wastes	0.76-1.5[1]	Extrapolation from (J Gustavsson et al., 2011) and (E. Stehfest et al., 2009) – Popp et al (in prep.)
Switch to a 'no ruminant meat' diet	5.8[2]	(E. Stehfest et al., 2009)
Switch to a 'no meat' diet	6.4[2]	(E. Stehfest et al., 2009)
Switch to a purely plant-based diet	7.8[2]	(E. Stehfest et al., 2009)
Switch to a 'healty' diet (Harvard Medical School)	4.3[2]	(E. Stehfest et al., 2009)

[1] very uncertain estimate (see text); more studies needed

[2] Original values are given in C-eq and were converted to CO2-eq by multiplication with 3.66667.

Demand-side options related to wood and forestry – Global socioeconomic carbon stocks in long-lived products were approximately 2.3 GtC in 1900 and increased to 10.1 GtC in 2008. Per-capita C stocks remained about constant at ~1.4 t C / capita with a falling share of wood products (68% in 2008) and a rising share of plastics and bitumen. The rate of C sequestered in socioeconomic stocks increased from 17 Mt C / yr in 1900 to a maximum of 188 MtC / yr in 2007. The net amount of C sequestered annually (C-inflows minus C outflows of socioeconomic C stocks) in long-lived wood products in the last decades was variable and ranged from 50-80 MtC / yr (Christian Lauk et al., 2012). If inflows would rise through increased use of long-lived wood products, C sequestration in wood-based products could be enhanced, thus contributing to GHG mitigation.

Analyses of the net CO_2 emissions over a 100 year lifetime of buildings showed that buildings constructed with wood frames have lower emissions than buildings with steel and concrete frames (L Gustavsson et al., 2006). The analysis included changes in C stocks in forests and buildings as well as fossil-fuel inputs of construction. Construction of buildings with a larger share of wood instead of more energy- and emissions-intensive materials such as steel and concrete (L Gustavsson and Sathre, 2011) reduces GHG emissions and sequesters C in the buildings. The largest part of the emissions reductions stems from use of the logging and wood manufacture by-products resulting from increased wood use to replace fossil fuels.

A scenario analysis with an integrated modelling framework showed that construction of one million flats per year in the next 23 years would reduce GHG emissions in the EU-27 by 0.2-0.5% (Eriksson et al., 2012). A study for the US (Upton et al., 2008) also found substantial GHG benefits of substituting concrete or steel frames with wood; however, this study warned that the results were quite sensitive to assumptions on the alternative use of land (e.g., for C sequestration) not required for wood production if concrete or steel were used instead of wood ('land-use leakage'). (Nässén et al., 2012) confirmed that buildings with wood frames have lower GHG emissions than those with concrete frames under current conditions, but if stringent GHG reduction policies are implemented in the energy sector, the advantage of wood as construction material is reduced or even non-existent, except if the wood wastes resulting from demolishion of the building after its 100 year lifetime are burned with CCS. Hence, (Nässén et al., 2012) question whether promotion of wood as construction material is an efficient strategy to reduce GHG emissions in the construction sector.

11.3.3 Mitigation effectiveness (non-permanence: saturation, human and natural impacts, displacement)

Since soil and vegetation carbon sequestration forms a lage proportion of the mitigation potential in the AFOLU sector, this section considers the factors affecting the mitigation effectiveness of carbon sequestration compared to avoided GHG emissions.

Non-permanence / reversibility. Reversals are the release of previously sequestered carbon, which negates some or all of the benefits from previous years. This issue is sometimes referred to as “permanence” (Smith et al., 2005): while other types (e.g., forestry, agricultural soil C) have an inherent risk of future reversals of sequestered C that must be mitigated through some mechanism (e.g. buffer pool, insurance) to compensate for reversals that occur. Most activities that reverse carbon sequestration are relatively easy to track visually: a ploughed field with residue removed, the removal of trees etc. There are relatively few data on how much carbon is lost when reversals occur. Certain types of mitigation activites (e.g. avoided N_2O from fertilizer, emission reductions from changed diet patterns or reduced food-chain losses) are effectively permanent since the emissions, once avoided, cannot be re-emitted. Unintentional reversals are usually caused by natural events. The natural events that affect yields (e.g. frost damage, pest infestation) will affect the annual increment of C sequestration or N_2O flux, but the resulting change is not a reversal. With respect to annual crops, wildfire would only affect the current year’s carbon storage, unless it burns into the organic soil layer. However, wildfire in systems with tree or shrub crops or windbreaks could see substantial loss of aboveground stored carbon. The permanence of a soil carbon sink is defined as the longevity of the sink, i.e. how long it continues to remove carbon from the atmosphere. The permanence of the soil carbon stock relates to the longevity of the stock, i.e. how long the increased carbon stock remains in the soil or vegetation, and is linked to consideration of the reversibility of the increased carbon stock (Smith et al., 2005).

Saturation. Avoided emissions can continue in perpetuity but carbon sequestered in soils or vegetation cannot continue indefinitely. The carbon stored in trees and vegetation reaches a new equilibrium (as the trees mature or as the soil carbon stock saturates). As the soils / vegetation approach the new equilibrium, the annual removal (sometimes referred to as the sink strength) decreases until it becomes zero at equilibrium. This process is called saturation (Smith, 2005; (Körner, 2006, 2009).

Human and natural impacts. Soil and vegetation carbon sinks can be impacted upon by direct human induced, indirect human induced and natural change (Smith, 2005). Direct human induced changes are deliberate management practices, designed to influence the land. All of the mitigation practices dicussed in section 11.3.1 are direct human induced changes. Sinks can also be affected by natural changes, for example, carbon stocks could be affected by future changes in climate. Between the direct human-induced changes and the natural changes are indirect human-induced. These changes can impact carbon sinks and are induced by human activity, but are not directly related to management of that piece of land; an example being atmospheric nitrogen deposition. Natural changes that threaten to impact the efficacy of mitigation measures are discussed in section 11.5.

Displacement / leakage. If reducing emissions in one place leads to increased emissions elsewhere, the emissions no net resuction in emissions occurs; the emissions are simply displaced (T Kastner, M Kastner, et al., 2011; T Kastner, Karl-Heinz Erb, et al., 2011). Displacement / leakage can occur within or across national boundaries. Trade statistic give information on net imports and exports of agricultural products and timber (and other forest products) and can be used as a proxy for possible emission displacement. Indirect land use change (iLUC) is an important compoment to consider for displaced emissions, and can be considerable (T. Searchinger et al., 2008). The efficacy of mitigation practices must consider the potential for displacement of emissions.

11.4 Infrastructure and systemic perspectives

11.4.1 Land: a complex, integrated system

Climate-change mitigation activities in the AFOLU sector are embedded in the complex interrelations between natural and socioeconomic factors that simultaneously affect patterns, processes and dynamics of land systems (BL Turner et al., 2007). At present, more than half of the earth's land is used – more or less intensively – for human purposes; less than one quarter is classified as 'wild' (Ellis et al., 2010), (K.-H. Erb et al., 2007). Approximately one quarter of global terrestrial net primary production is 'appropriated' by humans, i.e. either foregone due to land-use related losses in NPP or harvested for human purposes (H. Haberl et al., 2007). This and many other indicators demonstrate the extent to which land systems are meanwhile dominated by human activities (Vitousek et al., 1997). Human domination of terrestrial ecosystems has been growing rapidly in the past centuries (Ellis et al., 2010), driven by the ongoing population growth and socio-ecological transition from agrarian to industrial society (Fischer-Kowalski and H. Haberl, 2007), (H. Haberl, Fischer-Kowalski, et al., 2011),(T Kastner et al., 2012) . Success in influencing this trajectory critically depends on identifying points in space and time when this currently evolving trajectories may be more easily influenced (Fischer-Kowalski, 2011; WBGU, 2011). in global resource use patterns are increasingly affecting competition for land and hence feedbacks in the land system (see Figure 11.5, (Mark Harvey and Sarah Pilgrim, 2011).

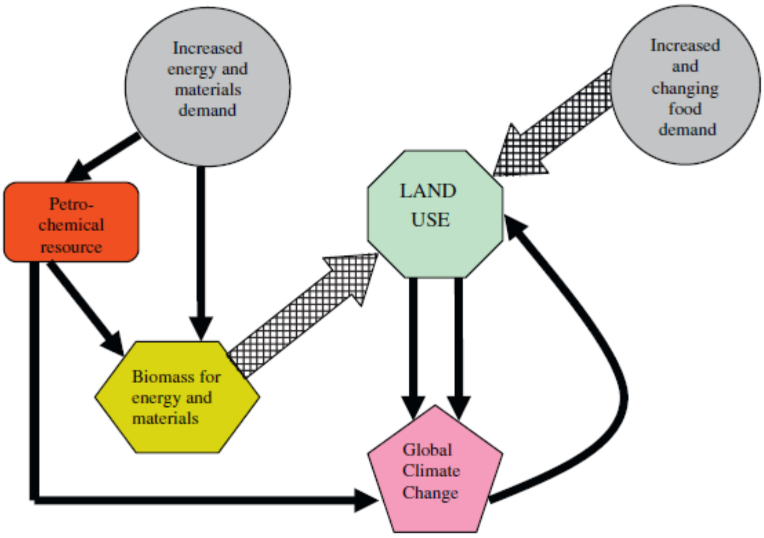

Figure 11.5 Interactions and feedbacks affecting land demand as global resource flows are changing. Source: (Mark Harvey and Sarah Pilgrim, 2011)

Due to the character of land systems as coupled socio-ecological (or human-environment) systems, most GHG mitigation activities in the AFOLU sector affect land use and/or land cover and therefore both socioeconomic as well as ecological aspects of land systems (R. Madlener et al., 2006) (H. Lotze-Campen et al., 2010) – often several at the same time. Such feedbacks may include impacts on food provision and food security, agricultural labour, livelihoods or other crucial socioeconomic factors just as well as important ecological aspects such as biodiversity, ecosystem functions and services, water systems – and also changes in sources and sinks of GHG (CO_2, CH_4, N_2O, etc.) beyond a measure's intended GHG benefits (B. Schlamadinger et al., 2007).

Human societies critically depend on the continuous delivery of ecosystem services (Daily et al., 2009; (Power, 2010) which include not only provisioning services such as the provision of food, fibre or bioenergy production, but also vital regulating, supporting and cultural services such as climate regulation, carbon sequestration, water retention, pollination, recreation, etc.. In many cases, there are trade-offs and synergies between different services. For example, maximization of provisioning services (e.g. food production) may result in losses of other services such as climate regulation or water retention (MEA, 2005). AFOLU mitigation options may simultaneously affect several ecosystem services, positively or negatively (e.g., (Chum et al., 2011).

Hence, successful implementation of mitigation measures in AFOLU hinges on the ability to anticipate systemic feedbacks in order to exploit synergies, reduce detrimental side-effects and optimize trade-offs between different social goals (R. Madlener et al., 2006). Considering feedbacks, synergies and trade-offs renders the implementation of AFOLU mitigation options a complex, multiple-objective optimization exercise along social/institutional, economic and environmental goals. Social issues includes the clarification of the relevant social actors and their relationships, social processes, social values (e.g. equity of participation) and social capital in terms of capacities and skills ((M.K. Macauley and R.A. Sedjo, 2011); (Laitner et al., 2000). Objectives defined in the social / economic / ecological dimensions may be in line with each other, neutral, or diametrically opposed, depending on the respective situation (R. Madlener et al., 2006). Climate change mitigation in the AFOLU sector therefore faces a complex set of interrelated challenges:

- GHG reduction measures need to be evaluated in terms of their full GHG impacts, including those resulting from feedbacks (‘indirect effects’); e.g. indirect land-use change effects of bioenergy (Timothy Searchinger et al., 2008).
- Leakage has to be avoided, i.e. it must be ascertained that emissions are not merely shifted from one region to another.
- GHG reduction must not jeopardize critical functions of land systems such as livelihoods of poor populations, provision of sufficient food and the maintenance of healthy ecosystems and biodiversity.
- Mitigation activities in AFOLU need to be based on sustainable land management aiming to maximize synergies and to minimize trade-offs, i.e. they face a multi-dimensional optimization problem involving social, economic and ecological criteria.

Compliance with these socioeconomic and ecological criteria needs to be judged at different spatial scales, because many of these phenomena are scale-dependent and processes may proceed with different speed, or perhaps even move in different directions, at different scales.

11.4.2 Competition for land and water

In recent years, land-use change has been recognized as a pervasive driver of global environmental change, associated with a multitude of - positive and negative - effects (J. A. Foley et al., 2005; Jonathan A. Foley et al., 2011). Land is used for a variety of purposes, including housing and infrastructure, production of goods and services through agriculture and forestry and absorption or deposition of wastes and emissions (Dunlap and Catton, Jr., 2002). Agriculture and forestry are important for rural livelihoods and employment (Coelho et al., 2012). Driven by economic and population growth, changing consumption patterns and increased demand for bioenergy, the competition for scarce land and water resources is expected to intensify (P. Smith et al., 2010); (Jeremy Woods et al., 2010).

Mitigation activities in the AFOLU sector can reduce climate forcing in different ways:

- Reductions in CH_4 or N_2O emissions from cropping and animal husbandry systems.
- Reductions of direct (e.g. tractors) or indirect (e.g. production of fertilizers) emissions resulting from fossil energy use in agriculture or forestry or from production of inputs.
- Reductions of carbon losses from biota and soils, e.g. through management changes within the same land-use type (e.g. switch from tillage to no-till cropping, removal of factors such as N or P deficiency that limit soil carbon) or through reductions in the loss of carbon-rich ecosystems, e.g. reduced deforestation.

- Enhancement of carbon sequestration in biota and soils through increases in the area of carbon-rich ecosystems such as forests (afforestation, reforestation), or through increased carbon storage per unit area, e.g. increased stocking density in forests.
- Changes in albedo that increase reflection of visible light.
- Provision of bioenergy with low GHG emissions that can replace high-GHG energy (e.g. fossil fuels) in the energy, industry and transport sectors, thereby reducing their GHG emissions.

Most of these mitigation activities can result from (1) changes in land management practices and technology, (2) changes in the consumption of land-based resources (e.g. diets) both of which may be stimulated by the governance of natural resources such as sectoral policies or tenure regulation. In other words, one may discern demand-side and supply-side measures with considerably different potential for feedbacks such as synergies and trade-offs.

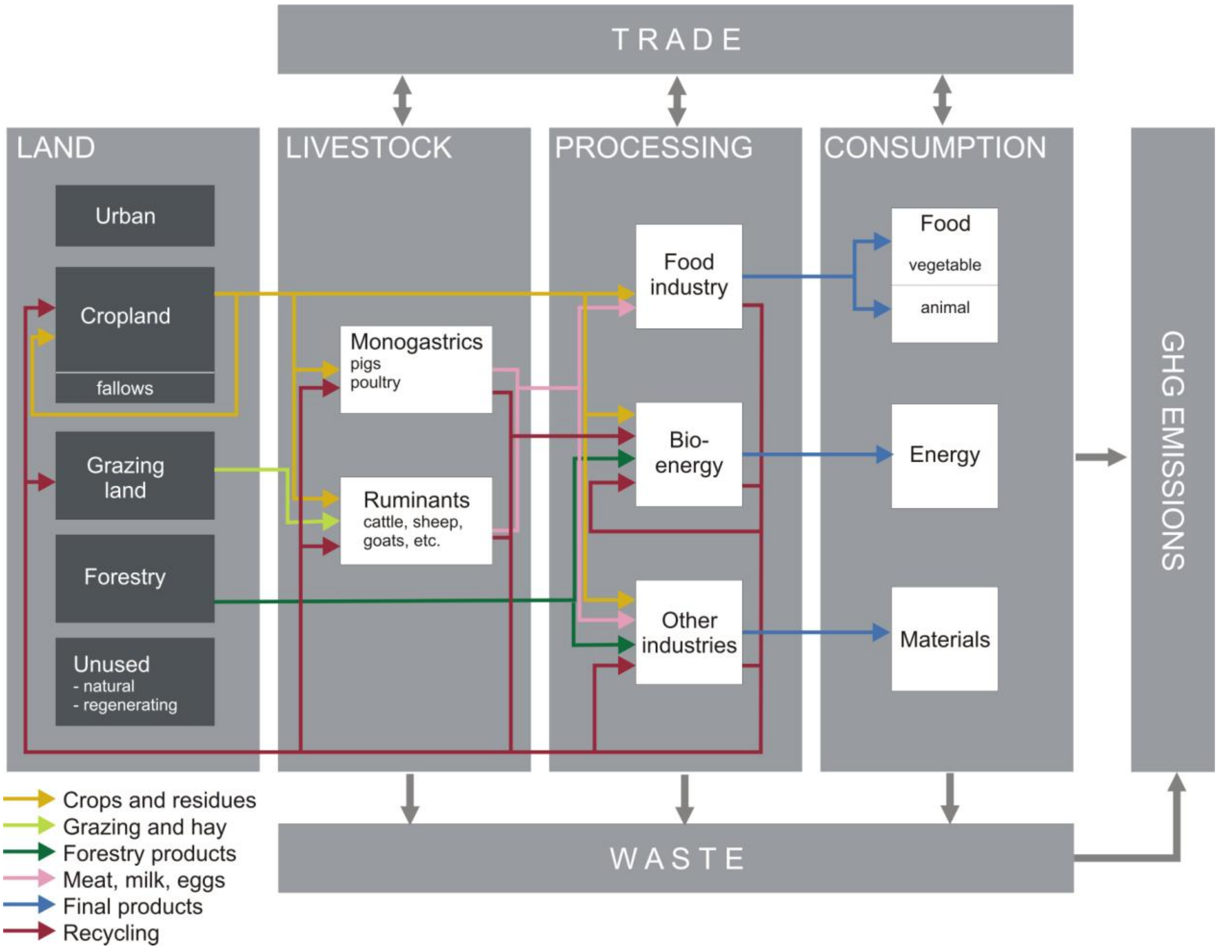

Figure 11.6 Global land use and biomass flows from the cradle to the grave. Concept graph developed based on (H. Haberl et al., 2007, 2010; K.-H. Erb et al., 2007; F. Krausmann et al., 2008) (H. Haberl, K.-H. Erb, et al., 2011; K.-H. Erb et al., 2012).

Figure 11.6 demonstrates why these synergies and trade-offs are different for demand-side and supply-side measures. Demand-side measures save GHG emissions through two mechanisms (i) by reducing the use of inputs required during production (e.g. CH_4 from enteric fermentation, N_2O from fertilizers or CO_2 from tractor fuels) and (ii) by reducing land demand, i.e. making areas available for other uses, e.g. afforestation or biofuels, or allowing adoption of less intensive cultivation technologies such as organic agriculture (E. Stehfest et al., 2009), (K.-H. Erb et al., 2012);(Karl-Heinz Erb et al., 2012b); (A. Popp et al., 2010). That is, their ecological feedbacks are generally beneficial, as they reduce pressure on the land system in terms of competition for land and other resources such as water. Health impacts are also deemed positive, as the studies considered here generally assume a switch to healthier diets (see section 11.4.3). A study for Europe based on an environmentally extended input-output model confirmed that dietary change can have beneficial effects on GHG emissions. Dietary switches towards healthier food tended to result in lower consumer spendings on food. GHG reductions prevailed even when rebound effects (increased consumption of other products resulting expenditure savings) were considered (Tukker et al., 2011).

This is different for supply-side measures, as some – not all – of them may intensify competition for land and other resources. Based on Figure 11.6 one may distinguish several cases:

- **Optimization of biomass-flow cascades** through use of residues and by-products, recycling and energetic use of wastes (Helmut Haberl and Geissler, 2000); (Helmut Haberl et al., 2003); (WBGU, 2009). As such measures increase the efficiency of resource use, they will be generally positive, but there may be trade-offs as well. For example, using crop residues for bioenergy or roughage supply may leave less C in the cropland ecosystem and may have detrimental effects on soil quality or C balance of the cropland (e.g. see Blanco-Canqui and Lal, 2009 and (Ceschia et al., 2010).
- **Land-sparing measures** such as increases in yields in croplands (Jennifer A. Burney et al., 2010); (D. Tilman et al., 2011), grazing land or forestry or increases in the efficiency of biomass conversion processes such as livestock feeding (Steinfeld et al., 2010), (Thornton and Herrero, 2010). These measures also reduce competition for land, but there may be trade-offs with other ecological, social and economic costs (IAASTD, 2009) that need to, and can at least to some extent, be mitigated (D. Tilman et al., 2011). Moreover, increases in yields may increase consumption that result in rebound effects (E.F. Lambin and Meyfroidt, 2011), (Karl-Heinz Erb, 2012).
- **Land-demanding measures** that harness the production potential of the land for either C sequestration, maintenance of C stocks, or production of dedicated energy crops. These options result in competition for land (and sometimes also other resources such as water) that may have substantial social, economic and ecological effects (positive or negative) that need to be managed sustainably (Chum et al., 2011); (Coelho et al., 2012); (WBGU, 2009); (UNEP, 2009). Such measures may result in pressures on forests and GHG emissions related to iLUC and dLUC, either directly or indirectly, contribute to price increases of agricultural products or negatively affect livelihoods of poor people that need to be balanced against possible positive effects such as GHG reduction or job creation (Chum et al., 2011); (Coelho et al., 2012).
- **Competing uses of biomass** such as the use of grains for food, feed and as feedstock for biofuels, or the use of wood residues for chipboards, paper and bioenergy, may also result in increased land demand with the above-mentioned effects.

Therefore, an integrated energy/agriculture/land-use approach for mitigation in AFOLU has to be implemented in order to optimize synergies and mitigate negative effects(A. Popp, H. Lotze-Campen, et al., 2011); (Creutzig et al., 2012); (P. Smith, 2011).

11.4.3 Feedbacks of additional land demand

In 2004, the area occupied by dedicated bioenergy crops and its by-products was only 1% of global cropped area worldwide (IEA 2006; (P. Smith, 2011). In 2050, energy crops might occupy 1.3-9.9 M km^2 (9-65% of current cropland which amounts to 15.2 mio. km^2) if ambitious bioenergy strategies are pursued (Coelho et al., 2012), (H. Haberl et al., 2010). Hence, policies for climate change mitigation may increase the pressure on the land system, not only due to bioenergy, but also when afforestation and avoided deforestation claim land or at least restrict farmland expansion (Murtaugh and Schlax, 2009) and (Wackernagel et al., 1999); (A. Popp, J.P. Dietrich, et al., 2011). Feedbacks such as GHG emissions from land expansion or agricultural intensification, higher prices of agricultural products, reduced food consumption, displacement of food production to other regions and consequent land clearing and higher yields of food crops may result (RJ Plevin et al., 2010), (TD Searchinger, 2010), (Havlik et al., 2011), (Alexander Popp et al., 2012), (Marshall Wise et al., 2009).

Additional land demand for GHG mitigation affects the availability of land for other purposes and affects the GHG balance of ecosystems. Land use change (LUC) effects on the GHG balance of bioenergy can be low or beneficial if energy crops such as perennial grasses or short-rotation coppice are used that build up soil carbon stocks (David Tilman et al., 2006), (R. J. Harper et al., 2009), (Stanley J. Sochacki et al., 2012), if degraded or low-carbon land is converted to energy crops (H.K. Gibbs et al., 2008), (Sterner and Fritsche, 2011) or afforestation and reforestation takes place. Most second-generation energy crops build up carbon stocks while delivering bioenergy when planted on land previously used to grow food crops (Cherubini et al., 2009). However, LUC-related GHG emissions may also substantially surpass those of fossil fuels for decades or even centuries if carbon-rich ecosystems such as wetlands or forests are converted to energy crop plantations, either directly if the energy crops replace C rich vegetation, or indirectly if they replace food crops that in turn are grown somewhere else and thereby cause C loss (H.K. Gibbs et al., 2008), (UNEP, 2009), (Chum et al., 2011). GHG emissions from LUC depend on future systemic feedbacks between population numbers, diets, agricultural technology, livestock feeding efficiency, climate impacts, as well as on bioenergy production levels (Chum et al., 2011). For example, (RJ Plevin et al., 2010) suggest a ‘plausible’ range of LUC-related GHG emissions for US corn ethanol of 21-142 g CO_2 eq / MJ (gasoline 90-100 g CO2 eq / MJ). A critical factor is the ‘displacement factor’, i.e. the fraction of the energy crop plantation area that is replaced by crop production somewhere else (RJ Plevin et al., 2010). A recent study suggests that LUC emissions alone (without any process-chain emissions) reach or surpass 100 g CO2 eq / MJ at displacement factors of approximately 50% for cropland-grown biofuels derived from jatropha, rape, wheat or corn (Sterner and Fritsche, 2011). Higher dietary requirements, lower agricultural yields and livestock feeding efficiencies, stronger climate impacts and higher energy crop production levels result in higher LUC-related GHG emissions and vice versa (Chum et al., 2011). A clear message from recent integrated assessment work is hence that avoidance of deforestation is a critical factor to ensure low LUC-related GHG emissions of bioenergy deployment (Havlik et al., 2011), (Alexander Popp et al., 2012), (A. Popp, J.P. Dietrich, et al., 2011), (Marshall Wise et al., 2009)(JM Melillo et al., 2009).

However, restrictions of agricultural expansion resulting from avoided deforestation, expansion of energy crop areas, afforestation and reforestation are expected to increase food and feed prices and costs of agricultural production. Integrated assessments of land use based mitigation options indicate that conserving natural vegetation with high carbon content (such as tropical forests) increase food prices by a factor of 1.75 until 2100 due to limitations of land available for cropland expansion, even in the absence of additional energy crop production (M. Wise et al., 2009). Impacts on food prices increase strongly if large scale bioenergy deployment is combined with forest conservation regimes. Regional aggregated food price indices, i.e. the average of all crop and livestock products weighted with their average share in total food demand, are forecast to rise most prominently in Africa (+82%), Latin America (+73%) and Pacific Asia (+52%) until 2100, compared to a reference scenario without forest conservation and bioenergy (A. Popp, J.P. Dietrich, et al., 2011).

If more land is to be taken out of food and feed production, intensity on the remaining land has to be increased in order to raise yields. (A. Popp, J.P. Dietrich, et al., 2011)showed that reducing the land available for agricultural use due to forest conservation can partially be compensated through higher agricultural yield increases. While increases in yields achieved through agricultural innovation can help to save land, thereby reducing competition for land and alleviating environmental pressures (P. Smith et al., 2010; J.A. Burney et al., 2010), agricultural intensification incurs economic costs (H. Lotze-Campen et al., 2010) and may also create a host of social and environmental problems such as nutrient leaching, soil degradation, toxic effects of pesticides and many more (IAASTD, 2009). Maintaining yield growth while reducing negative environmental effects of agricultural intensification is therefore a central challenge (R. DeFries and Rosenzweig, 2010). Both increased land-use intensity and land expansion into new areas may entail higher greenhouse gas emissions from the agricultural sector and result in increased water use for irrigation (IAASTD, 2009). Negative impacts such as increases in flows of reactive nitrogen can be mitigated through a strategy of technology dissemination to developing countries that focuses efforts of intensification in regions with the highest yield gaps (D. Tilman et al., 2011).

Large-scale bioenergy production may affect water scarcity and quality, which are highly dependent on particular crop needs (Gerbens-Leenes et al., 2009). In many regions, additional irrigation of energy crops will further intensify existing pressures on water resources. Worldwide, agriculture accounts for roughly 70% of global freshwater use (Kummu et al., 2010)Shiklomanov and Rodda, 2003), but in the future a growing amount of water will be needed for industrial and household uses. (A. Popp, J.P. Dietrich, et al., 2011), applying the integrated assessment model ReMIND/MAgPIE, to assess the impact of land use based mitigation options (bioenergy deployment and forest conservation) on regional water price indices, i.e. changes in shadow prices of irrigation water relative to a reference scenario without land-based mitigation measures. Large-scale energy crop cultivation alone increases the water price index in Latin America by +210%, in the Former Soviet Union by +170% and in Pacific Asia by +130% in 2100. In this case, energy crops compete directly for irrigation water with other agricultural activities. If, in addition to bioenergy, intact forests are excluded from available land for future cropland expansion, shadow prices of irrigation water rise even more (460% in Latin America, 390% in Sub-Sahara Africa and 330% in Pacific Asia), because less land is available for rain-fed agriculture, and energy crop cultivation results in higher evapotranspiration, which reduces water availability in regions where water is already scarce (A. Popp, J.P. Dietrich, et al., 2011). In turn, (D.P. van Vuuren et al., 2009) indicated that an exclusion of sever water scarce areas for bioenergy production (mainly to be found in the Middle East, parts of Asia and western USA) would reduce global bioenergy potentials by 17 % until 2050 (D.P. van Vuuren et al., 2009).

Additional land demand may also put pressures on biodiversity, as land-use change is one of the most important drivers of biodiversity loss (Sala et al., 2000). Large-scale bioenergy may therefore negatively affect biodiversity (Groom et al., 2008) which is a key prerequisite for the resilience of ecosystems, i.e. for their ability to adapt to changes such as climate change and to continue delivering indispensible ecosystem services in the future (Díaz et al., 2006); (Landis et al., 2008). Biodiversity conservation is therefore a necessity, in particular in the face of future climate change, but exclusion of nature conservation and high biodiversity areas may reduce area and hence energy potentials of energy crops by 9-32% in 2050 (Erb et al., 2012; (Detlef P. van Vuuren et al., 2009).

Changes in food demand – which may be influenced through options such as reduced losses and changes in diets – can significantly affect the strength of these feedbacks. Adoption of diets richer in animal products has been shown to massively reduce the area available for energy crops, resulting considerably higher energy crop potentials in scenarios with less rich diets and vice versa (H. Haberl, K.-H. Erb, et al., 2011), (Karl-Heinz Erb et al., 2012a), (E. Stehfest et al., 2009). (E. Stehfest et al., 2009) also show that adoption of more vegetarian diets reduces the overall costs of achieving certain climate-change mitigation targets due to synergies in the coupled land/energy/economy systems.

An additional strategy to reduce trade-offs of increased land demand may be multifunctional use of the land. If used appropriately, land can often generate more than one type of product or service such as food, feed, energy or materials, the protection of the soil, wastewater treatment, recreation, or nature protection – an observation usually denoted as “multifunctionality” or multiple use (de Groot, 2006); (R. DeFries and Rosenzweig, 2010). Appropriate land management based on multiple use can alleviate trade-offs or even turn them into synergies and therefore enhance biomass production while reducing environmental pressures, in particular when combined with ecological zoning approaches (Coelho et al., 2012).

11.4.4 Sustainable development and behavioural aspects

The dual relation between sustainable development and climate change was widely discussed in the AR4 as well as in chapter 4 of the AR5 (IPCC, 2007a). This section focuses on the specific relation between AFOLU and sustainable development as well as on the considerations of behavioural aspects for a sustainable future. The development context in a given region can be understood as the dynamic relation between social and human framework, natural assets, state of infrastructure and technology, economic factors and institutional arrangements (see table 11.6).

Table 11.6 Issues related to AFOLU mitigation options and sustainable development

Dimensions	**Issues**
Social and human framework	Population growth and migration, level of education, human capacity, existence and forms of social organization, indigenous knowledge and cultural background, equity and food security
Natural assets	Availability of natural resources (land, forest, water, agricultural land, minerals, fauna, etc), GHG balance, ecosystem integrity, biodiversity conservation, ecosystem services, ecosystem productive capacity, climate change resilience and vulnerability
State of infrastructure and technology	Availability of infrastructure and technology, technology development, appropriateness, acceptance
Economic factors	Credit capacity, employment creation, income, wealth distribution/distribution mechanisms, carbon finance
Institutional arrangements	Land tenure and land use rights, participation and decision making mechanisms, sectoral and cross-sectoral policies

Based on (Pretty, 2008) (Sneddon et al., 2006a) (M.K. Macauley and R.A. Sedjo, 2011), (R. Madlener et al., 2006),(Steinfeld et al., 2010)

The development context defines the enabling conditions and thus determines the feasibility of the AFOLU mitigation options (see Figure 11.7). For example the existence of local capacities is highly relevant for implementing and monitoring the reduction of deforestation (Herold, 2009). On the other hand, planning and implementing AFOLU mitigation options have an impact on the development context; for example promoting agroforestry plantations can have an impact on improving food security besides the carbon sequestration effect (Nair et al., 2008) (Calfapietra et al., 2010). In developing and less developed countries this dual relation between AFOLU mitigation options and the development can be considered when proposing measures aimed at achieving long term development goals as articulated for example in the Millennium Development Goals to allow AFOLU mitigation options to become a means for sustainable development.

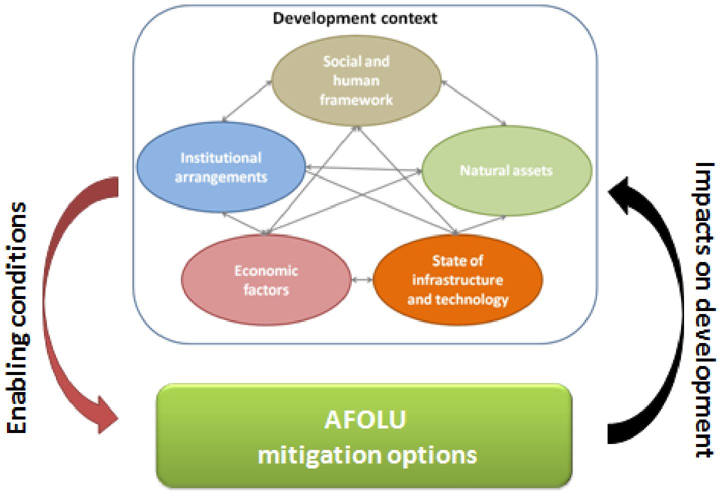

Figure 11.7 Dynamic relation between the development context and AFOLU mitigation options

Table 11.7 Potential impacts of AFOLU mitigation options on sustainable development

	Potential Sustainable Development Implications			
	Forestry	**Bioenergy**	**Cropland management a)**	**Livestock and manure a)**
Social and human framework	Recognition of the relevance of indigenous knowledge in managing natural forest. Protection of cultural habitat, especially in natural forests Increase capacities at the local level for conserving and/or sustainable using forest resources According to the specific type of management can promote or prevent from migration and displacement of activities Some type of plantations can secure basic needs (e.g. building materials, firewood, heating material, etc) Agro-forestry as well as forest management activities can have an impact on food security	Potential competition with food production/food security. This may increase as population continues to grow, except for bioenergy options derived from residues, wastes or by-products (energy demand vs. food demand) Impacts of setting up energy crop plantations on small scale producers and/or agri-pastoralists need to be understood in a case by case basis. These can be positive (e.g. promoting local organizations, job creation in rural areas) or negative (e.g. displacing small-scale producers, jeopardizing livelihoods of agri-pastoralists) Impacts on discrimination, displacement and/or marginalization of local stakeholders along the value chain need to be analyzed Biofuel production can promote an improvement on local skills through capacity building	Impacts on traditional practices need to be analyzed according to the specific development context Impacts on food security are uncertain as changes in productivity per ha can occur Agroforestry seems to have a series of social positive impacts including use of traditional knowledge and improvements in food security Impacts on small scale producers need to be analyzed according to the development context Impacts on discrimination, displacement and/or marginalization of local stakeholders along the value chain need to be analyzed	Impacts on traditional practices need to be analyzed according to the specific development context Impacts on food security are uncertain due to behavioral aspects (e.g. consumption/demand of meat and other animal protein)as well as to changes in productivity, especially in developing and less developed countries per ha can occur Equity issues are special relevant for pastoralist and nomadic communities (e.g. in Africa) Impacts on small-scale producers need to be analyzed according to the development context
Natural assets	Activities related to conservation and sustainable forest management of natural forest as well as agroforestry have an impact on conserving biodiversity and securing ecosystem services including soil and watershed protection. GHG emissions from forests for rural energy (firewood) are high relevant in developing countries → link also to food security Sustainable management of plantations and natural forest is expected to prevent from degradation and to keep or even increase resilience of communities to climate change events. Plantations, especially of extended monocultures can have negative impacts on biodiversity conservation and other ecosystem services, including impacts on soil properties, water availability. Risk of leakage of GHG emissions due to displacement of people or activities Vulnerability of forest ecosystems to climate change needs to be better understood	Large scale monocultures have impacts on biodiversity and soil quality as well as on environmental services Biofuels/bioenergy plantations can displace natural ecosystems, including forests, causing leakages and other environmental damages Potential increases in GHG emissions due to direct and indirect land use changes Biofuels and vulnerability???	Sustainable practices, including tillage or organic agriculture can have positive impacts on soil fertility and other environmental services. Water management can have a positive impact on the overall water cycle Increasing productivity would have an impact on the area required for food security per region and product Large scale monocultures can have an impact on ecosystem services including conserving biodiversity or soil quality; as well as on displacement of people or activities. Large scale agro-industry needs to analyze environmental impacts according to the development context Agriculture is highly vulnerable to climate change, especially in developing and less developed countries.	Changes in livestock management can have a relevant impact on availability of land as well as on fodder requirements (i.e. impacts on cropland production and management) Silvopastoral activities have an impact on biodiversity, especially when replacing degraded grassland Impacts on environmental services depend on the specific management practice Potential displacement of activities (GHG emissions) due to manure management need to be analyzed especially in developing and less developed countries Livestock management is highly vulnerable to climate change, especially in developing and less developed countries.

State of infrastructure and technology	Production and availability of vegetal material that is adequate under long term climate consideration is key for any forest mitigation option There is still lack of knowledge on forest management strategies under future climate scenarios New forestry systems need to be checked in terms of acceptability by local stakeholders before being promoted as mitigation options	Availability of infrastructure in the same area where biofuels crops are produced can increase the development benefits Lack of (access to) infrastructure can increase social misbalance in some developing countries Location of areas suitable for energy crop plantations in nations with insufficient political stability can reduce or prevent investments and, in effect, make these areas unavailable for energy crop production.	Availability of infrastructure in the same area where agricultural crops are produced can increase the development benefits Lack of (access to) infrastructure can increase social misbalance in some developing countries Availability of infrastructure and technology for food processing in developing countries can increase the development impact	Uncertainty on the acceptability of some livestock management due to societal and cultural values Availability of infrastructure and technology for food processing in developing countries can increase the development impact Feasibility of high-tech practices need to be checked according to the development context
Economic factors	Some activities are dependant of high investments in advance Conservation and sustainable forest management activities can create additional income through non-timber forest products (NTFP) and/or through Payment for Ecosystem Services (PES) There is a lot of debate on the minimum carbon price required per forest mitigation activity for promoting sustainable development in different regions Employment creation (when less intense land use is replaced)	Provides new economic opportunities for farmers and local economies. May contribute to the increase of the price of feedstock used for food and feed. May promote concentration of income and increase poverty Feasibility depends on investment in advance	Impacts on economic factors is highly related to changes in productivity and to extend of cultivated area Certification processes can increase competitiveness of sustainable cropland management Distribution of economic benefits are closely related to the place where processing of agricultural products takes place Feasibility depends on investment in advance	Impacts on economic factors is highly related to changes in productivity Distribution of economic benefits are closely related to the place where processing of livestock products takes place Feasibility depends on investment in advance
Institutional agreements	Clarification of land tenure and use rights is key in all AFOLU mitigation options, impacts can be positive or negative for local stakeholders Harmonization/Conflict with customary rights Increase/decrease in participation of local stakeholders in planning, implementing and monitoring forest mitigation options Cross-sectoral coordination at the level of policies and land use planning is key, including forestry, agriculture, energy and mining Mechanisms for sharing benefits and liabilities need to be clarified with all relevant stakeholders at various levels (including local, provincial/departmental and national) There is a need to create incentives for AFOLU mitigation options in land use policies, including forestry agriculture, energy and mining Govenrance issues in rural areas are highly relevant for realizing the mitigation potential in the AFOLU sector, especially in developing and less developed contries			

Notes: a) There is less (reported/validated) experience with livestock and manure management and cropland management as AFOLU mitigation option in developing countries, especially in less developed countries. This can be as a consequence of the fact that these activities are not widely included in existing carbon markets

Sources: (Trabucco et al., 2008), (Steinfeld et al., 2010)(P Gerber et al., 2010)(Sikor et al., 2010)(Rosemary, 2011)(Pettenella and Brotto, 2011) (Gasparatos et al., 2011a)(Corbera and Schroeder, 2011a)(Carol J. Pierce, 2011a)(Blom et al., 2010)(Halsnæs and Verhagen, 2007)(AM Larson, 2011)(Batjes, 2011)(AJ Van Bodegom et al., 2009)(Thompson et al., 2011)(Graham-Rowe, 2011)(J. Fargione et al., 2008)(Helmut Haberl et al., 2004)(Godfray et al., 2010)(J Foley et al., 2009a)(Halsnæs, 1996)(Reinhard Madlener et al., 2006)(Brooks et al., 2009)(Josep G Canadell and Michael R. Raupach, 2008)(Pretty, 2008)(Sneddon et al., 2006b)(Molly K. Macauley and Roger A. Sedjo, 2011)(Timothy Searchinger et al., 2008).

Table 11.7 summarizes the findings on potential impacts of AFOLU mitigation options and the development context. Future interactions between AFOLU mitigation options and the development context under the transformation pathways are discussed in subsection 11.10.

Understanding the links between sustainable development and AFOLU mitigation options needs to go beyond the implications on these five categories. Considerations of the temporal and spatial scales of the implementation of AFOLU mitigation options, and on human behavior and behavioral change, need to be included too. These dimensions need to be considered when making decisions on how to balance development goals with mitigation goals in different regions.

The scale of the implementation of an AFOLU mitigation option is highly relevant for understanding its impact on sustainable development. The scale of the intervention includes the geographical size (i.e. area), as well as the size of interactions among social groups and between human and natural systems(Trabucco et al., 2008); (Reinhard Madlener et al., 2006) (Pretty, 2008) . These interactions tend to become more complex the bigger the scale used. One can identify a "social scale-line" that goes from individuals to the global scale. Intermediate scales would be e.g. family – neighborhood – community – village – province – country – region – global. Impacts on sustainable development are different along this scale-line. For example, of bio-fuels has been identified as one interesting option for substituting fossil fuels as a global scale (see section 11.3). However, the development impacts of bio-fuel plantations on a specific region, including land-use competition, water and soil pollution, air emissions, food security, labor conditions or social responsibility of biofuels producers can bring negative impacts at the village or community levels (Gallardo and A Bond, 2011) (Alves Finco and Doppler, 2010a). Not adequately implemented the large-scale expansion of many of the AFOLU options may exacerbate social and environmental and social problems. Thus considering the impacts of AFOLU mitigation options at various scales seems relevant for understanding the implications for sustainable development.

The discussion regarding the time frame in the context of AFOLU and sustainable development brings some systemic challenges. Understanding development concerns for 20 years has a different outcome than considering development for 50 or 100 years. Further the impact of AFOLU mitigation options can be at different moments: e.g. while reducing deforestation has an immediate impact on GHG emissions, plantations will have an increasing impact on the C sequestration over time. In section 11.10 we discuss the AFOLU mitigation options in different future scenarios and under consideration of key input parameters as e.g. population growth.

Finally the discussion on sustainable development needs to include behavioral aspects. Past and current human decisions on land use have an influence on climate change. The type of use and management given to a certain land depends upon cultural values, perceptions and priorities of individuals, specific social groups (e.g. indigenous peoples or settlers) and states (Swanwick, 2009) (Gilg, 2009). Changes in behavioral patterns including type of food, food preparation and consumption or energy consumption patterns can increase or decrease GHG emissions from land use and have an impact on resilience and adaptive capacity of nature and social groups (A. Popp et al., 2010).

Sustainable management of agriculture, forests, and other land uses –either natural or man-made, such as plantations- is essential to achieving sustainable development. To do so, synergies among the different uses need to be maximized - including the maximization of the mitigation effect -while acknowledging and working to minimize trade-offs (World Bank, 2006). Adequately implemented, forestry and agriculture mitigation options provide effective means to reduce poverty, create local employment and economic opportunities, provide food, feed and energy, reduce deforestation, halt the loss of forest biodiversity, and reduce land and resource degradation, at the same time contributing to climate change mitigation (Nabuurs et al., 2007). Additional costs and human capacities as well as the need for creating enabling conditions needs to be considered according the specific development context in a given area.

11.5 Climate change feedback and interaction with adaptation (includes vulnerability)

Natural resources are increasingly being recognized for their importance in mitigating climate change. Reducing emissions from land-use changes and enhancing the capacity of natural systems to sequester and store carbon is considered a cost effective way to mitigate global climate change (Eliasch, 2008) Stern 2008, (McKinsey and Company, 2009), World Bank 2010). At the same time these natural systems can also play an important role in adapting to climate change by buffering against certain climate hazards and strengthening resilience to climate variability and change (Locatelli et al, 2008). Mitigation and adaptation in natural ecosystems are closely interlinked through a web of feedbacks, synergies and tradeoffs (see section 11.8).

When reviewing the interlinkages between climate change mitigation and adaptation within the natural resource space the following issues need to be considered: (i) the impact of climate change on the mitigation potential of a particular sector (e.g. forestry and agricultural soils) over time, (ii) potential trade-offs/synergies within a land-use sector between mitigation and adaptation objectives, and (iii) potential trade-offs across sectors between mitigation and adaptation objectives. This discussion needs to be further placed within the broader development context in recognition of relevance of natural resources for many livelihoods and economies. This also implies that trade-offs/synergies associated with land-use choices need to be considered across different scales in their economic, social and environmental consequences.

11.5.1 Feedbacks between land use and climate change

As an integral component of global carbon cycle, changes in land-use systems influence the carbon loading of the atmosphere and the increasing carbon in the atmosphere also impacts the carbon uptake efficacy of the landuse systems. Forests have been found to respond to rising atmospheric CO_2 through photosynthetic enhancement, and this “CO_2 fertilization” is a negative feedback to higher atmospheric CO_2 concentration. However, it is also reported that terrestrial carbon storage would decline with warming, due to effects like reduced growth and increases in stress and mortality due to the combined impacts of climate change and climate-driven changes in the dynamics of forest insects and pathogens and this would vary greatly. For example Wamelink et al. (2009), projected an increase in biomass accumulation all over Europe, with the growth rate varying between 0 and 100%. (Metsaranta et al., 2011) who designed 12 scenarios combining possible changes in tree growth rates, decay rates, and area burned by wildfire, depending on the scenario projects the cumulative GHG balance to range from a sink of - 4.5 Gt CO_2e (-67 t CO_2e / ha) for the most optimistic scenario, to a source of 4.5 Gt CO_2e (67 t CO_2e / ha) for the most pessimistic over the period 2010 to 2080. (G.B. Bonan, 2008) shows that the efficiency of the carbon cycle to store anthropogenic CO_2 in ocean and land is declining and is doing so at a greater extent than estimated by models. It further suggests that carbon cycle–climate feedbacks are projected to to increase atmospheric CO_2 at the end of the 21st century by 4 to 44%, equivalent to an additional 20 to 224 ppm.

Climate feed-backs of forests ecosystems differ from each other depending on the location and forest types. For example, tropical forests mitigate warming through evaporative cooling, but the low albedo of boreal forests is a positive climate forcing (G.B. Bonan, 2008). Deforestation in mid- to high latitudes is hypothesized to have the potential to cool the Earth’s surface by altering biophysical processes (Bala et al., 2007; G.B. Bonan, 2008). Several studies show that there will be an expansion of deciduous woodlands (Edwards et al., 2005; Peros et al., 2008). In this context, (Swann et al., 2010), suggest that the expansion of deciduous forest has a positive feedback on regional climate change. The study further suggests that vegetation changes create a positive feedback through albedo and transpiration and produce a strong warming if they act in combination with sea-ice processes.

11.5.1.1 Exposure, Sensitivity and Vulnerabilities to Climatic Changes

In general, how forests, agriculture or other land-use systems will respond to climate change depends on the exposure to climatic changes as well as the sensitivity of the ecosystem to these changes (Locatelli et al, 2008). Vulnerability is defined by the IPCC (TAR, AR4) as "the degree to which a system is susceptible to or unable to cope with adverse effects of climate change, including climate variability". (Allen et al., 2010) suggest that the forested ecosystems of the world already may be responding to climate change and raises concerns that forests may become increasingly vulnerable to higher background tree mortality rates and die-off in response to future warming, droughts, forest fires and pest incidence. The study further suggests risks to ecosystem services, including the loss of sequestered forest carbon and associated atmospheric feedbacks.

Future climatic changes may increase the exposure to climate related hazards, such as the incidence of droughts or fires in tropical forest ecosystems (see also section 11.5.3). Forest ecosystems may be exposed to higher risks under the climate change scenarios, as an altitudinal and poleward expansion and a lengthening of the growing season are expected for temperate and boreal forests (Burrows et al., 2011). And the pace of adaptation may not catch up with the pace of climate change (Zhu et al., 2011).

11.5.1.2 Compounding pressures

Furthermore, forests are subject to many other human influences, such as pollution, environmental degradation, and introduction of invasive species. These influences may further compound vulnerabilities to climate changes as well as impact the mitigation potential. For example, increased ground-level ozone and deposition could potentially affect future tree mortality rates and thus CO_2 emissions under a changing climate (Allen et al., 2010).The degradation of natural resources not only contributes to greenhouse gas emissions and constrains carbon sequestration (e.g.,DC Nepstad et al., 2008), it also undermines the ability of some systems to withstand change. There is evidence that natural ecosystems characterized by high biodiversity tend to be more resilient to change than degraded ecosystems or managed systems, characterized by low species diversity (Strassburger 2008, Leadley et al 2010).

11.5.1.3 Tipping points and ecological thresholds

Ecological thresholds and tipping points depend on the type of ecosystems, the level of change and compounding pressures it has exposed to. This has potential implications on the species composition within an ecosystem as well as its capacity to sequester and store carbon.

Assessing a range of biodiversity scenarios for the 21st century and associated implications for ecosystem services, Leadley et al. (2010) concluded that uncertainties for most terrestrial tipping points are high, but crossing these thresholds may have severe consequences. The large uncertainties in the assessment are explained by the complex interactions of a wide range of global change drivers. Die-back of the Amazon rainforest is cited as one tipping point with large negative impacts for the regional rainfall regime, biodiversity and global climate. Other studies express concern with regards to species and ecosystems' ability to respond to the rate and magnitude of future climate change (Gitay et al., 2002), Seppälä et al. 2009). Zhu et al (2011) demonstrate that climate change is expected to occur more rapidly than trees can adapt. The adaptive capacity of many natural and human systems is likely to be exceeded with global climatic changes of and above 4 °C with associated adverse consequences for biodiversity and ecosystem integrity, agricultural productivity, food security and development (Schneider et al. 2007, Stern 2008). This may also imply that mitigation options through natural systems may be diminished or no longer be available, as ecological thresholds are crossed and ecosystem structure and functioning is altered. For example, recent analysis suggests that the possibility of Amazon drying and die-back may previously have been underestimated (Philips et al. 2009).

11.5.2 Implications of climate change on forest carbon sinks and mitigation potential

While maintaining and enhancing forest carbon stocks represent an important mitigation option to date (Eliasch, 2008), progressive climate change too poses a threat to the mitigation potential of forests. Pervasive droughts, disturbances such as fire and insect outbreaks, exacerbated by climate extremes and climate change further put the mitigation benefits of the forests at risk (Swetnam and Betancourt, 1990; Kitzberger et al., 2001; B. Schlamadinger et al., 2007; IPCC, 2007b; J.G. Canadell and M.R. Raupach, 2008; OL Phillips et al., 2009; Herawati and H Santoso, 2011); van Nieuwstadt et al. 2005, Brando et al., 2008, Moraal et al., 2011; Netherer et al., 2010; Evangelista et al., 2011). Forest disturbances and climate extremes have associated carbon balance implications (Millar et al., 2007; M Zhao and Running, 2010; Potter et al., 2011, Davidson et al., 2011, (Kurz et al., 2008). Forest disturbances affect roughly 100 million ha of forests annually (FRA 2005). On average, 1% of all forests were reported to be significantly affected each year by forest fires alone (FRA, 2010). It is estimated that fires alone released approximately 0.6 Gt C in 2008 (GCP 2009)

Building on the AR4, the SREX (IPCC, 2012) provides further evidence that climate change is already affecting the exposure to a range of weather and climate extremes.These climatic changes interact and are superimposed on natural climate variability and other environmental or human induced disturbances, that already impact on forests (Mirzaei et al., 2008). At the same time, these disturbance events, when their severity is enhanced due to climate change, can have increased impacts on the regional carbon balance as well (Volney and Fleming, 2000; Logan et al., 2003; Shaw et al., 2005; e.g., Chambers et al., 2007; Beach et al., 2009; Lindroth et al., 2009; Penman and York, 2010; Seidl et al., 2011) (Kurz et al., 2008).

Arcidiacono-Bársony (2011) suggest a possibility that the mitigation benefits from deforestation reduction under REDD could be reversed due to increased fire events, and climate-induced feedbacks. While Gumperberger (2010) conclude that the protection of forests under the forest conservation (i.e REDD) programmes could increase carbon uptake in many tropical countries, mainly due to CO_2 fertilization effects, even under climate change conditions. (Ravindranath et al., 2011) too project an increase in forestry mitigation potential in India under the changed climate, primarily due to CO_2 fertilization, however this study does not consider the impact of increased fire and pest occurrences and nutrient deficiency on the mitigation potential. Carnicer et al (2011) suggest that climate change is increasing severe drought events in the Northern Hemisphere, and causing regional tree die-off events and global reduction of carbon sink efficiency of forests. Ma et al (2012) provide the observational evidence of the weakening of the terrestrial carbon sinks in the northern high latitude regions, based on observations from the long-term forest permanent sampling plots in Alberta, Saskachetwan and Manitoba. Globally Bergengren et al (2011) project 49% of the Earth's land surface area to undergo plant community change and 37% of the world's terrestrial ecosystems to undergo biome-scale changes by the end of the 21st century.

(Heimann and Reichstein, 2008) simulate the global terrestrial carbon uptake using 11 coupled carbon-cycle–climate models driven with carbon emissions from the SRES-A2 scenario. It suggests that for some models, the terrestrial carbon cycle even becomes a substantial source of atmospheric CO_2 and thus strongly amplifies global climate change (Figure 11.8).

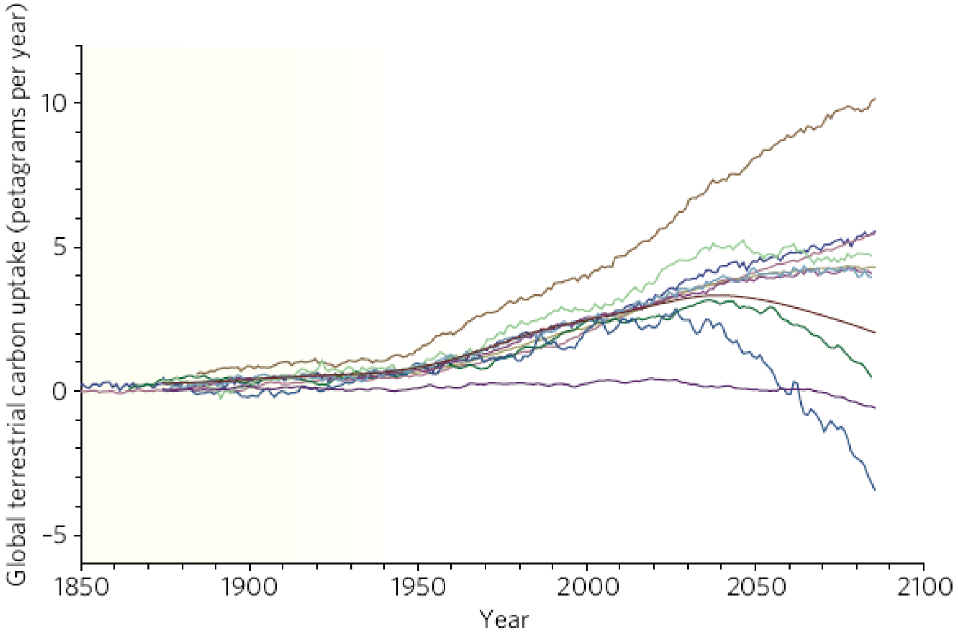

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Figure 11.8 Comparison of estimated global terrestrial carbon uptake in different models of the carbon-cycle–climate system: (Source: (Heimann and Reichstein, 2008).

11.5.3 Implications of climate change on soil carbon including peat lands, pastures/grasslands and rangelands

Wetlands, peatlands and permafrost soils contain higher carbon densities than mineral soils, and together they make up enormous stocks of carbon globally (E.A. Davidson and Janssens, 2006). The soil organic carbon stocks in forests according to FAO (2010), was estimated to be 363Gt C. Hopkins et al (2012) project accelerated soil organic carbon loss from forests with warming, losses are estimated to be high especially in the younger soil carbon that is years-to-decade old that comprises of large fraction of total soil carbon in forest soils globally. According to (Schuur et al., 2008), the thawing permafrost and the resulting microbial decomposition of previously frozen organic carbon (C) is one of the most significant potential feedbacks from terrestrial ecosystems to the atmosphere in a changing climate. The thawing of permafrost with warming occurs both gradually and catastrophically, exposing organic carbon to microbial decomposition. (E.A. Davidson and Janssens, 2006), further caution that extrapolation of decomposition rates into a future warmer world based on observations of current apparent temperature sensitivities is inadequate.

Peatlands cover approximately 3% of the earth's land area and are estimated to contain 350-550 Gt of carbon, roughly between 20 to 25% of the world's soil organic carbon stock (Gorham, 1991), Fenner et al., 2011). Thus peatlands represent a significant stock of carbon and play an important role in the global carbon cycle (Strack and Waddington, 2007). Peatlands can lose CO_2 through plant respiration and aerobic peat decomposition (Clair et al., 2002). Although peatlands have long been considered carbon sinks, however, with the onset of climate change, peatlands may become a source of CO2 (Koehler et al., 2010). A study by Fenner et al (2011) projects the impact of climate change on peatlands. The study suggests that climate change is expected to increase the frequency and severity of drought in many of the world's peatlands which, in turn, will release far more GHG emissions than thought previously. Climate change is projected to have a severe impact on the peatlands in northern regions where most of the perennially frozen peatlands are found (Tarnocai, 2006).

Grasslands, Pastures and Rangelands: Grassland as defined in IPCC Good Practice Guidance for LULUCF covers about one-quarter of the earth's land surface (Chuluun and Ojima et al., 1993) and span a range of climate conditions from arid to humid. Carbon stocks in permanent grassland are influenced by human activities and natural disturbances, including harvesting of woody biomass, rangeland degradation, grazing, fires, and rehabilitation, pasture management, etc.

The potential impacts of climate change on pastures would be declines in pasture/grass productivity, reduced forage quality, livestock heat stress, greater problems with some pests and weeds, more frequent droughts and intense rainfall events, and greater risks of soil erosion (Hennessy et al. 2007). The most important impacts of climate change on rangelands will likely be through changes in both pasture productivity and forage quality. Climate change may also affect grazing systems by altering species composition; for example, warming will favour tropical (C4) species over temperate (C3) species (SM Howden et al., 2008). Projected increases in rainfall intensity (Tebaldi et al. 2006; CSIRO 2007) are likely to increase the risks of soil erosion, leading to losses in carbon stocks from the grassland and rangelands.

11.5.4 Potential adaptation measures to minimize the impact of climate change on carbon stocks in forests

Forest adaptation practices aim to increase the resilience of natural systems such as forests to possible changes in climate conditions where this is likely to be feasible and cost effective. For example (Malhi et al., 2009) expect the climate of the Eastern Amazon to favour seasonal forests. In order to minimize the risk of a shift towards fire dominated, low biomass, forest, the authors highlight the importance of reducing compounding pressures, such as deforestation, degradation and habitat fragmentation. Without such adaptive actions, (Malhi et al., 2009) note the risk that a tipping point may be crossed beyond which rainforest in Eastern Amazonia may not be sustained. Adaptation practice is basically a framework for managing future climate risks and offers the potential of reducing future economic, social, and environmental costs (Murthy et al 2011). Forest ecosystems require the longer response time to adapt. For example a long gestation period is involved in developing and implementing adaptation strategies in the forest sector (R. Leemans and B. Eickhout, 2004; Ravindranath, 2007). Thus there is a need to develop and implement adaptation strategies. Some examples of the ‘win-win’ adaptation practices are as follows: (Murthy et al., 2011): anticipatory planting of species along latitude and altitude, assisted natural regeneration, mixed species forestry, species mix adapted to different temperature tolerance regimes, fire protection and management practices,thinning, sanitation and other silvicultural practices, in situ and ex situ conservation of genetic diversity, drought and pest resistance in commercial tree species, adoption of sustainable forest management practices, increase Protected Areas and link them wherever possible to promote migration of species, forests conservation and reduced forest fragmentation enabling species migration and energy efficient fuelwood cooking devices to reduce pressure on forests.

11.5.5 Potential adaptation measures to minimize the impact of climate change on carbon stocks in agricultural soils

Organic carbon levels in soils depend heavily on management practices that affect the inputs as well as removal of carbon, namely net primary production, quality of organic residues, residue management (e.g. burning, incorporation), soil management (e.g. tillage) and livestock management (KY Chan et al., 2008). The main cause of soil organic carbon (SOC) loss in agricultural soils is due to disturbance of soils with tillage, which results in increased decomposition rates (KY Chan et al., 2010).

(P. Smith et al., 2008) reviewed studies to estimate the average annual mitigation potential, accounting for changes in emissions of all GHGs, of agricultural practices globally. (P. Smith and Olesen, 2010) further examined these measures, and identified a number of synergies between measures that deliver climate migration in agriculture, and that also enhance resilience to fufutre climate change, the most prominent of which was enhancement of soil carbon stocks.

11.5.6 Mitigation and adaptation synergy and tradeoffs

Both mitigation and adaptation to climate change are essential and complementary. The mitigation potential itself may be affected by climate change and hence require adaptive responses. Mitigation policies and measures may exhibit synergies and trade-offs with adaptation (Bates et al., 2008). Examples which successfully combine forest-based adaptation with mitigation options include ecosystem-based adaptation policies and measures that conserve, (e.g., natural forests) and at the same time provide significant climate change mitigation benefits by maintaining existing carbon stocks and sequestration capacity, and by preventing future emissions from deforestation and forest degradation; adaptation projects that prevent fires and prevent release of GHG and restore degraded forest ecosystems also enhance carbon stocks (CBD and GiZ, 2011). Many strategies and practices developed to advance sustainable forest management (SFM) also help to achieve the objectives of climate change adaptation and mitigation (JA Van Bodegom et al., 2009). Similarly forest and biodiversity conservation, protected area formation and mixed species forestry based afforestation are practices that can help to maintain or enhance carbon stocks, while also providing adaptation options to reduce vulnerability of forest ecosystems to climate change (Ravindranath, 2007). In the agriculture sector cropland adaptation options that also contribute to mitigation are: soil management practices that reduce fertilizer use and increase crop diversification; promotion of legumes in crop rotations; increasing biodiversity, the availability of quality seeds and integrated crop/livestock systems; promotion of low energy production systems; improving the control of wildfires and avoiding burning of crop residues; and promoting efficient energy use by commercial agriculture and agro-industries (FAO 2008, FAO 2009a).

11.6 Costs and potentials

This section deals with economic costs and potentials within the AFOLU sector. Economic potentials are distinguished from technical or market potentials (IPCC 2007, pp.35, 140; Smith et al. 2011). Technical mitigation potentials represent ‘full’ biophysical potential of a mitigation measure. These estimates account for constraints and factors such as land availability and suitability (Smith et al. 2011) but not any associated costs (at least explicitly). By comparison, economic potential refers to mitigation potential that could be realised at a given carbon price over a specific period assuming that ‘all’ biophysical constraints were overcome but does not take into consideration any socio-cultural (for example, life-style choices) or institutional (for example, political, policy and informational) barriers to practice or technology adoption. Finally, market potential is the realised mitigation outcome under current or forecast market conditions encompassing biophysical, economic, socio-cultural and institutional barriers (for example, targeted policies) to technological and/or practice adoption specific to a sub-national, national or supra-national market for carbon. Figure 11.9 (Smith 2012) provides a schematic view of the three types of mitigation potentials.

Economic (as well as market) potentials tend to be context-specific and are likely to vary across spatial and temporal scales. Unless otherwise stated, in rest of this section, economic potentials are expressed in million tonnes (Mt) of GHG mitigation (reduction or sequestration) that can arise from an individual mitigation measure or from an AFOLU sub-sector at a given cost per tonne of carbon dioxide equivalent over a given period to 2030, which is ‘additional’ to the corresponding baseline or reference case levels.

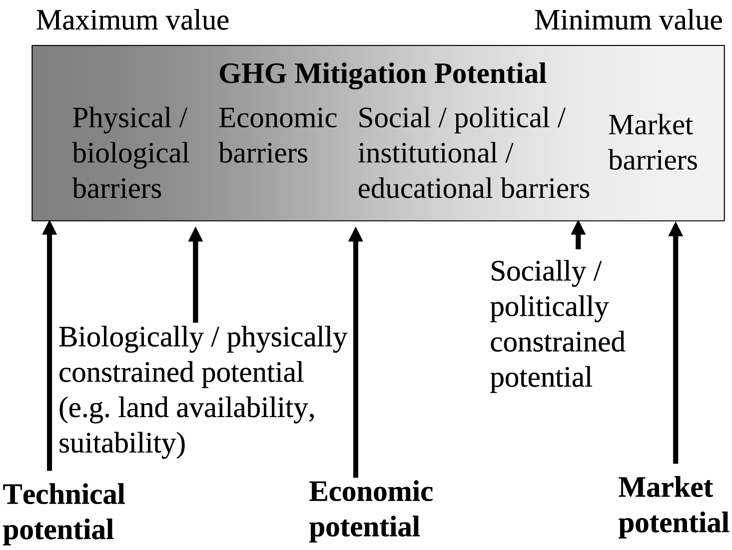


Figure 11.9 Relationship between technical, economic and market potential (after Smith, 2012)

11.6.1 Approaches to estimating economic mitigation potential

Bottom-up and top-down modelling approaches are used to estimate AFOLU mitigation potentials and costs. While both approaches provide useful estimates for mitigation costs and potentials, comparing bottom-up and top-down estimates is not straightforward.

Bottom-up estimates are typically derived for discrete abatement options in agriculture at specific location or time, and are often based on detailed technological, engineering and process information and data on individual technologies (for example USEPA 2006 described in (DeAngelo et al., 2006). These studies provide estimates of how much technical potential of particular agricultural mitigation options will become economically viable at certain carbon dioxide-equivalent prices. Bottom-up mitigation responses are typically restricted to input management (for example, changing practices with fertiliser application and livestock feeding) and mitigation costs estimates are considered ‘partial equilibrium’ in that the relevant input-output prices (and, sometimes, quantities such as acreage or production levels) are held fixed. As such, unless adjusted for potential overlaps and trade-offs across individual mitigation options, adding up various individual estimates to arrive at an aggregate for a particular landscape or at a particular point in time could be misleading.

With a 'systems' approach, top-down models typically take into account possible interactions between individual mitigation options. These models can be sectoral or economy-wide, and can vary across geographical scales—sub-national, national, regional and global. Top-down mitigation responses may include a broad range of management responses and practice changes (for example, moving from cropping to grazing or grazing to plantation) as well as changes in input-output prices (for example, land and commodity prices). Such models can be used to assess the cost competitiveness of various mitigation options and its implications across input-output markets, sectors, and regions over time for large-scale domestic or global adoption of mitigation strategies.

As such, the bottom-up estimates of mitigation potential for agricultural greenhouse gas emissions have enabled the top-down modelling of agricultural abatement in simulating long-term climate stabilisation scenario pathways. In such a top-down modeling exercise, a dynamic cost-effective portfolio of abatement strategies are identified incorporating the lowest cost combination of mitigation strategies over time from across sectors, including agricultural and other land-based sectors, across the world that achieve the climate stabilisation target (S.K. Rose et al., 2011).

In this context, it is important to recognise a somewhat subtle but important distinction (at least conceptually) between mitigation ‘supply’ curves and ‘projected’ mitigation contribution of the AFOLU sector. Both relate to carbon prices. A ‘supply’ curve of the particular mitigation option at a specific point in time is represented by a marginal abatement cost curve (MACC), which provides a schedule for GHG mitigation potential from a particular mitigation option under a range of carbon prices, all other things being unchanged. In other words, MACCs are based on a set of specific assumptions regarding input-output attributes and prices and, hence, tend to change their shapes and positions with changing policy settings, input-output prices and/or (actual or expected) opportunities for other mitigation options. Accordingly, various models —including sectoral optimization, computable general equilibrium (CGE) or integrated Assessment (IA), with embedded MACCs and/or relative costs for technologies or practices— tend to provide 'projected' mitigation potential under a particular policy setting or climate target, which may differ significantly from the corresponding MACC based 'supply' schedules. This distinction between 'supply' curves and 'projected' mitigation contribution will be important and more apparent while assessing AFOLU sector's mitigation under various transformation pathways encompassing certain 'stabilization' targets later in this chapter (Section 11.11).

In general, available top-down estimates of costs and potentials suggest that AFOLU mitigation will be an important part of a global cost-effective abatement strategy. However, some studies suggest that the relative contribution of agricultural abatement of rice and livestock methane (enteric and manure) and soil nitrous oxide could be more in early decades than during the rest of the century (S.K. Rose et al., 2011).

Providing consolidated estimates of economic potentials for GHG mitigation within the AFOLU sector as a whole is further complicated because of potential 'leakages' stemming from competing demands on land for various agricultural and forestry activities as well as for the provision of many ecosystem services (P. Smith, Bustamante, et al., 2013). While assessing the overall economic mitigation potentials of the AFOLU sector, studies which accounted for (explicitly or implicitly) competition for scarce resources including land are to be relied on. Otherwise, estimates of economic potentials are to be considered subject to the applicable context and caveats.

In view of the above, the following two sub-sections assess the economic AFOLU mitigation potentials under two broad sub-sectors: Forestry and Agriculture, followed by an assessment of economic potentials from the AFOLU sector. Studies undertaken since IPCC's last assessment —which are expected to present more up-to-date estimates of economic potentials, taking into account recent developments and information—are of particular interest for this assessment. However, for completeness, these recent estimates are presented together with the previous IPCC assessments (IPCC, 2007b); pp.516-9 and 551-63).

11.6.2 Forestry

The economic potentials of carbon mitigation from forestry including reduced deforestation, forest management, afforestation, and agro-forestry differ greatly by activity, regions, system boundaries and the time horizon over which the options are assessed (Nabuurs et al., 2007). In the short term, the economic potentials of carbon mitigation from reduced deforestation are expected to be greater than the economic potentials of afforestation. That is because deforestation is the single most important source of GHG emissions, with a net loss of forest area between 2000 and 2010 estimated at 5.2 million ha/yr (FAO 2012). Biomass from forestry can contribute 12-74 EJ/yr to energy consumption [AUTHORS: to be updated from the SRREN], with an estimated mitigation potential roughly equal to 0.4-4.4 GtCO2/yr depending on the assumption whether biomass replaces coal or gas in power plants (IPCC, 2007b); p.543; IPCC 2012).

Figure 11.10 presents global estimates for economic mitigation potentials in forestry at 2030 under various carbon prices. The range of global estimates at a given carbon price reflects uncertainty surrounding forestry mitigation potentials in the literature. Table 11.8 [AUTHORS: based on IPCC 2007; p. 559; to be updated] shows the economically viable mitigation potentials by key region and main mitigation option, estimated using global models.

Table 11.8 Potential of mitigation measures of global forestry activities. Global model results indicate annual amount sequestered or emissions avoided, above business as usual, in 2030 for carbon prices 100 US$/tCO2 and less.

	USA			Europe			OECD			Non-annex I East Asia			Countries in Transition		
Activity	**1 – 20 1)**	**20 – 50 2)**	**100 3)**	**1 - 20**	**20 – 50**	**100**	**1 - 20**	**20 - 50**	**100**	**1 - 20**	**20 - 50**	**100**	**1 - 20**	**20 - 50**	**100**
Afforestation	0.3	0.3	445	0.31	0.24	115	0.24	0.37	115	0.26	0.26	605	0.35	0.3	545
Reduced deforestation	0.2	0.3	10	0.17	0.27	10	0.48	0.25	30	0.35	0.29	110	0.37	0.22	85
Forest management	0.26	0.32	1,59	0.3	0.19	170	0.2	0.35	110	0.25	0.28	1,2	0.32	0.27	1,055
TOTAL	0.26	0.31	2,045	0.3	0.21	295	0.25	0.34	255	0.26	0.27	1,915	0.33	0.28	1,685

	Central and South America			Africa			Other Asia			Middle East			Total		
	1 - 20	**20 - 50**	**100**	**1 - 20**	**20 - 50**	**100**	**1 - 20**	**20 - 50**	**100**	**1 - 20**	**20 - 50**	**100**	**1 - 20**	**20 - 50**	**100**
Afforestation	0.39	0.33	750	0.7	0.16	665	0.39	0.31	745	0.5	0.26	60	0.4	0.28	4,045
Reduced deforestation	0.47	0.37	1,845	0.7	0.19	1,16	0.52	0.23	670	0.78	0.11	30	0.54	0.28	3,95
Forest management	0.43	0.35	550	0.65	0.19	100	0.54	0.19	960	0.5	0.25	45	0.34	0.28	5,78
TOTAL	0.44	0.36	3,145	0.7	0.18	1,925	0.49	0.24	2,375	0.57	0.22	135	0.42	0.28	13,775

1) Fraction in cost class: 1 – 20 US$/t$CO_2$

2) Fraction in cost class: 20 – 50 US$/t$CO_2$

3) Potencial at costs equal or less than 100 US$/tCO2, in Mt$CO_2$/yr in 2030*

* Results average activity estimates reported from three global forest sector models including GTM (Sohngen and R Sedjo, 2006), GCOMAP (Sathaye et al., 2006), and IIASA-DIMA (Benítez et al., 2007). For each model, output for different price scenarios has been published. The original authors were asked to provide data on carbon supply under various carbon prices. These were summed and resulted in the total carbon supply as given middle column above. Because carbon supply under various price scenarios was requested, fractionation was possible as well.

Two right columns represent the proportion available in the given cost class. None of the models reported mitigation available at negative costs. The column for the carbon supply fraction at costs between 50 and 100 US$/tCO2 can easily be derived as 1- sum of the two right hand columns

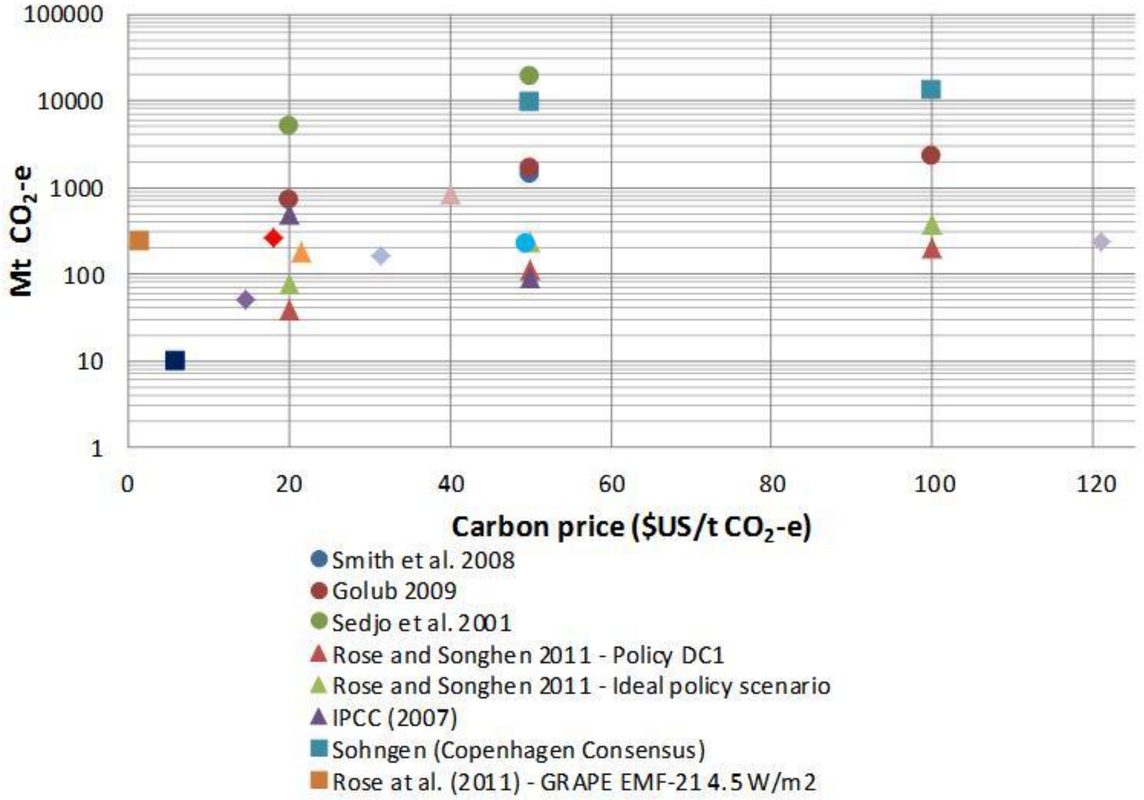


Figure 11.10 Global forestry mitigation potential in 2030

Table 11.8 [AUTHORS: to be updated], which presents global estimates (excluding bioenergy) with broad regional breakdowns under various broad modelling methodologies, also reflects the uncertainty surrounding forestry mitigation potentials in the literature. Bottom-up estimates of economically viable mitigation generally include numerous activities in one or more regions represented in detail. Top-down global modelling of sectoral mitigation potentials and of long-term climate stabilization scenario pathways generally includes fewer, simplified forest options, but allows competition across other sectors of the economy including agriculture to generate a portfolio of least-cost mitigation strategies. As discussed earlier, comparison of top-down and bottom-up modelling estimates is difficult. This stems from differences in how the two approaches represent mitigation options and costs, market dynamics, and the effects of market prices on model and sectoral inputs and outputs such as labour, capital, and land. One important reason that bottom-up results yield a lower potential consistently for every region is that this type of study takes into account (to some degree) barriers to implementation. Compared to the top-down estimates, the bottom-up estimates are expected to be closer to market potentials defined earlier, but the degree is unknown.

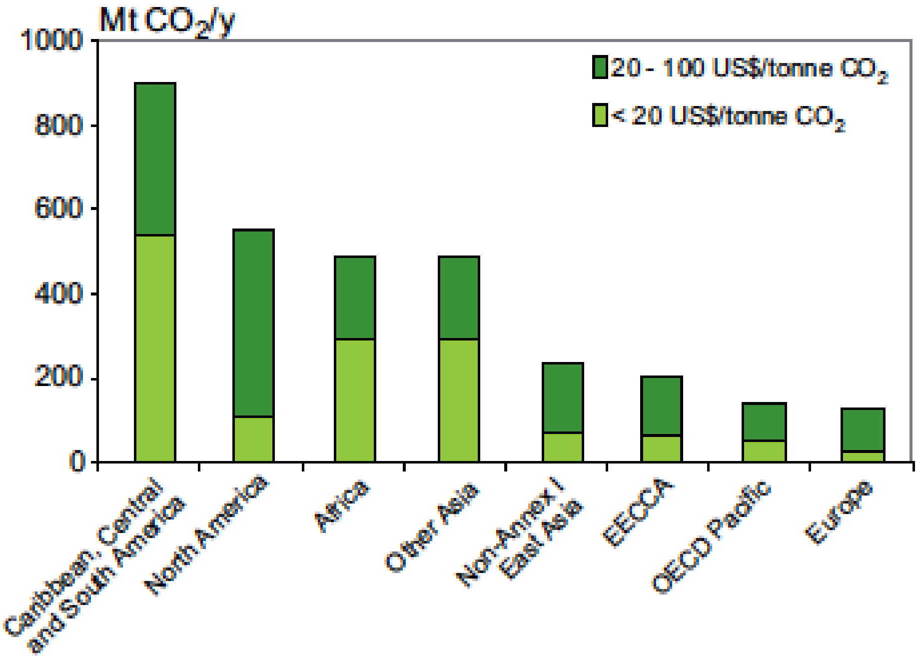
The uncertainty and differences behind the studies referred to, and the lack of baselines are reasons to be rather conservative with the final estimates for the forestry mitigation potentials. Therefore, mostly the bottom-up estimates are used for the final estimates. This stands apart from any preference for a certain type of study. Summarizing the collated results, forestry mitigation options are estimated to contribute between 1.27 and 4.23 Gt CO_2/yr [AUTHORS: to be updated] economically viable abatement in 2030 at carbon prices up to 100 US$ / tCO_2-eq. (Table 11.9). About 50% of the mean estimates are projected to occur at a cost under 20 US$/ tCO_2-eq. (= 1.55 Gt CO_2 / yr) (Figure 11.11; [AUTHORS: to be updated]). The combined effects of reduced deforestation and degradation, afforestation, forest management, agro-forestry and bio-energy have the potential to increase gradually from the present to 2030 and beyond. The carbon prices against which the potentials have been assessed should be seen as indicative only, as the information in the literature varies a lot. These analyses assume gradual implementation of mitigation activities starting from now.

Table 11.9 Economicmitigtaion potential by world region in forestry sector, excluding bioenergy. Values are in Mt CO2 / yr for at prices up to 100 US$ t CO2 / yr for 2030.

	Regional bottom-up estimate			**Global forest sector models**	**Global integrated assessment models**
	Mean	**Low**	**High**		
OECD	700	420	980	2,730	
Economies in transition	150	90	210	3,600	
Non-OECD	1,900	760	3,040	7,445	
Global	2,750[a]	1,270	4,230	13,775	700

[a] Excluding bio-energy. Including the emission reduction effect of the economic potential of biomass for bio-energy would yield a total mean emission reduction potential (based on bottom up) of 3140 MtCO$_2$/yr in 2030.

About 65% of the estimated sink enhancement/emission avoidance is expected to occurin the tropics; mainly in above-ground biomass; and with about 10% achievable through bio- energy. In the short term, this potential is much smaller, with 11XX Mt CO$_2$ / yr [AUTHORS: to be updated] in 2015. Uncertainty from this estimate arises from the variety of studies used, the different assumptions, the different measures taken into account, and not taking into account possible leakage between continents.



Note: EECCA=Countries of Eastern Europe, the Caucasus and Central Asia.

Figure 11.11 Annual economic mitigation potential in the forestry sector by world region and cost class in 2030

A recent report from UNEP suggests that forestry could deliver a mitigation potential of 1.3-4.2 Gt CO_2 / yr in achieving climate stabilization at +2º C [AUTHORS: to be updated].

11.6.3 Agriculture

Figure 11.12 presents global estimates for economic mitigation potentials in agriculture at 2030 under various carbon prices and stabilisation scenario pathways. Global economic mitigation potentials at 2030 are estimated to be up to 1600, 2700, and 4300 Mt CO_2-eq / yr at carbon prices of up to US$20, US$50 and US$100 a tonne of CO_2-eq, respectively. The change in global economic mitigation potential with increasing carbon price for each practice is shown in Figure 11.12.

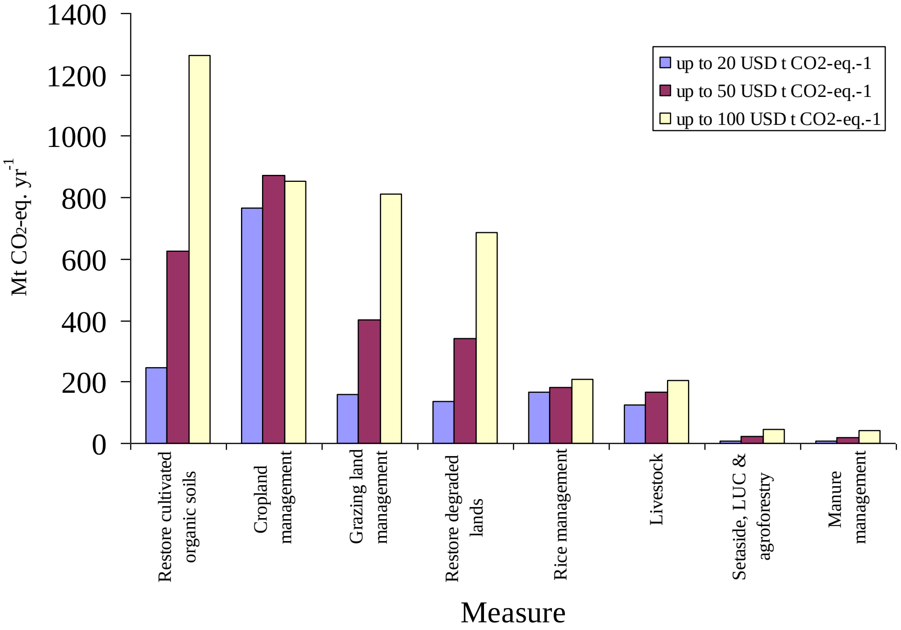


Figure 11.12 Economic potential for GHG agricultural mitigation at a range of prices of CO2-eq. Note: Based on B2 scenario, although the pattern is similar for all SRES scenarios. Source: Drawn from data in (P. Smith, Martino, Cai, Gwary, HH Janzen, et al., 2007).

As can be seen from these figures, a large proportion of the estimated economic potentials (at carbon prices of up to US$100 a tonne of CO_2-e and excluding bioenergy) is expected to arise from soil carbon sequestration, which is may be affected by climate change in the long run (upsetting any policy requirement for permanent sequestration). However, the direction and magnitude of climate change impacts on soil carbon sequestration are both uncertain (P. Smith, 2011).

In an assessment across all sectors, (McKinsey and Company, 2009) used a bottom-up approach similar to that used by (P. Smith et al., 2008), but made different assumptions about the baseline projections for GHG emissions in agriculture and the policy levers for encouraging mitigation. In that assessment, new global MACCs were derived, and the global potential was somewhat larger than that estimated in the IPCC Fourth Assessment Report at 4.6 Gt CO_2-eq. / yr in 2030, and was estimated to be possible at lower cost (<70 US$ / t CO_2-eq.). A recent report from UNEP suggests that agriculture could deliver a mitigation potential of 1.1-4.3 Gt CO_2 / yr in achieving climate stabilization at +2º C [AUTHORS: to be updated].

Table 11.10 shows the economically viable mitigation opportunities in agriculture at 2030 by broad region and by main mitigation option under carbon prices of up to US$100 a tonne of CO_2-eq. At carbon prices of around $100 a tonne of CO2-eq, restoration of organic soils appear to be most promising among all options, followed by cropland management and grazing land management. At a price of around US$20 a tonne of CO_2-eq, cropland management seems to hold highest economic mitigation potential. In other words, the composition of the agricultural mitigation portfolio varies with the carbon price (Smith 2012a). A comparison of estimates of economic mitigation potential in agriculture published since AR4 are shown in Figure 11.13.

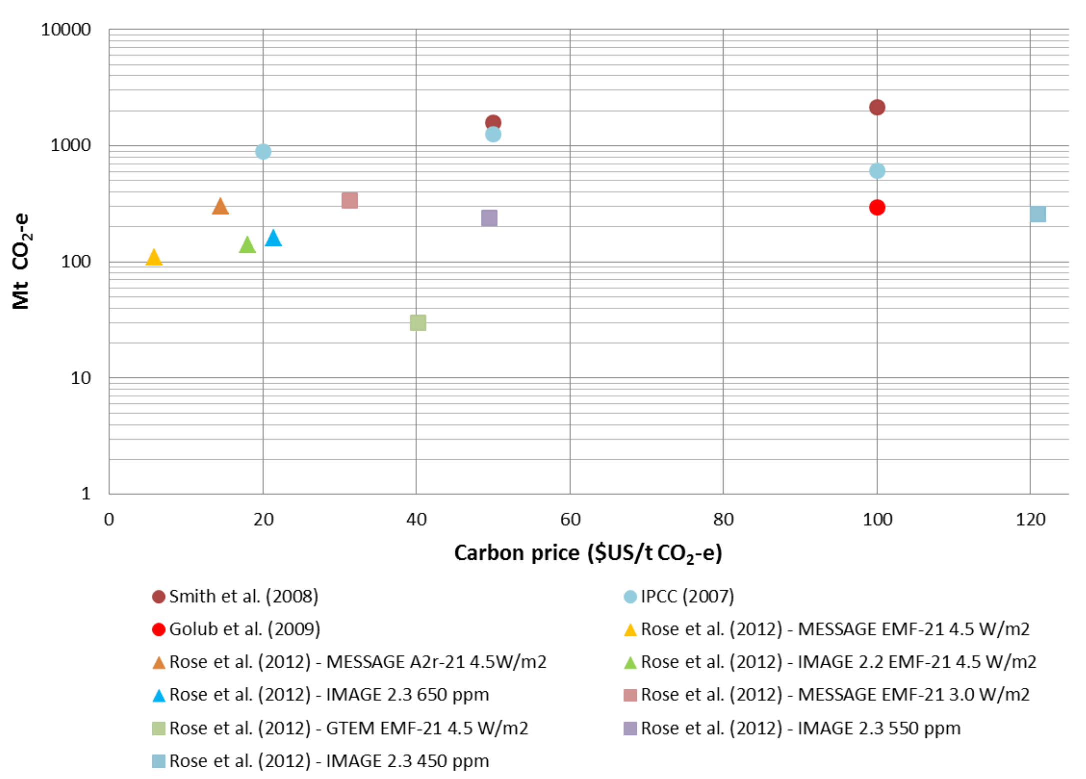


Figure 11.13 Global agricultural mitigation potential in 2030

Table 11.10 Economic mitigation potential in agriculture by option under different carbon prices (P. Smith, Martino, Cai, Gwary, HH Janzen, et al., 2007).

Option	**Regional Potential (Mt CO_2-eq. yr^{-1}) in 2030)**								
	OECD			**Non-OECD**			**Total**		
	<20 USD t CO_2-eq.$^{-1}$	<50 USD t CO_2-eq.$^{-1}$	<100 USD t CO_2-eq.$^{-1}$	<20 USD t CO_2-eq.$^{-1}$	<50 USD t CO_2-eq.$^{-1}$	<100 USD t CO_2-eq.$^{-1}$	<20 USD t CO_2-eq.$^{-1}$	<50 USD t CO_2-eq.$^{-1}$	<100 USD t CO_2-eq.$^{-1}$
Cropland management	168 (7-260)	145 (73-232)	89 (43-151)	602 (-11-982)	723 (343-1193)	746 (352-1234)	770 (-4-1242)	868 (416-1425)	835 (395-1386)
Grazing land management	18 (-12-33)	44 (7-82)	89 (13-1650	152 (-8-234)	385 (179-591)	776 (360-1191)	170 (-19-266)	430 (185-673)	865 (374-1356)
Restore cultivated organic soils	75 (8-100)	189 (103-253)	381 (208-510)	173 (18-239)	438 (238-605)	883 (480-1219)	248 (26-340)	628 (341-858)	1264 (688-1729)
Restore degraded lands	25 (0-37)	63 (30-95)	126 (61-191)	110 (-8-171)	278 (126-432)	562 (253-870)	135 (-9-208)	341 (156-526)	688 (314-1060)
Rice management	3	4	5	165	179	205	168	182	210
Set-aside, LUC, agro-forestry	0	0	0	7 (1-11)	26 (15-37)	47 (28-67)	7 (1-11)	26 (15-37)	47 (28-67)
Livestock	32	54	82	99	125	141	131	178	223
Manure application to land	3	8	15	5	13	27	8	21	42

11.7 Co-benefits, risks and uncertainties, and spill-over effects

This section focuses on the following elements: co-benefits, risks, uncertainties and potential spillovers of AFOLU mitigation options. We consider socio-economic effects, environmental and health effects, technological considerations and public perception.

The implementation of the AFOLU mitigation options (Section 11.3) will result in a range of other outcomes, some being beneficial (co-benefits). There are also potential detrimental or poorly understood effects (risks and uncertainties). Apart from considering activities in terms of net greenhouse gas mitigation benefit, other outcomes that can be considered include profitability (Sandor et al., 2002), energy use, biodiversity (Koziell and Swingland, 2002; Venter et al., 2009), water (R.B. Jackson et al., 2005), aspects of social amenity and social cost. Some of these factors can be quantified, whereas metrics for others are less clear. Modelling frameworks are being developed which allow an integrated assessment of multiple outcomes (PV Townsend et al., 2011) at project to national scales.

11.7.1 Co-benefits

In several cases the implementation of AFOLU mitigation measures may result in an improvement in land management. There are many examples where existing land management is sub-optimal, resulting in various forms of desertification or degradation including wind and water erosion, rising groundwater levels, groundwater contamination, eutrophication of rivers and groundwater or loss of biodiversity. Management of these impacts is implicit in the United Nations Convention to Combat Desertification (UNCCD, 2011) and Convention on Biological Diversity (CBD) and thus mitigation action may contribute to a broader global sustainability agenda.

11.7.1.1 Socio-economic

AFOLU mitigation options can promote increases in food and fibre production including increases in food yields and timber production, such as within agroforestry systems, or the conversion of agriculture to forestry. Economic activity can increase through an increase in the overall capital available in particular systems and thus intensification. Examples include the capital costs of mitigation systems that involve the reforestation or revegetation of agricultural land, and the consequent increase in demand for labor and other inputs. In some situations, several co-benefits can be sold (e.g. timber, water) thus providing additional cash-flow for land-holders. An emerging area is the payment for several environmental services from reforestation (Deal and White, 2012; Deal et al., 2012). Similarly, mitigation payments can fulfil the gap for a sustainable production of non-timber forest products (NTFP), further diversifying income at the local level (PP Singh, 2008). Further considerations on economic co-benefits are related to the access to carbon payments either within or outside the UNFCCC agreements. Several recent studies have examined carbon markets, their potentials and constrains as means for promoting AFOLU mitigation options in developed and developing countries (P. Combes Motel et al., 2009; Alig et al., 2010; Asante et al., 2011; Asante and Armstrong, 2012). An increased income or income diversification are often mentioned as important potential co-benefits. The realisation of these economic co-benefits seems to be related to the design of the specific mechanisms (Corbera and Katrina Brown, 2008). Especially important seems to be a) if the payments are done *ex-ante* or *ex-post*, b) how high are these payments i.e. what the payments cover and c) to whom the payments are made (Margaret Skutsch et al., 2011).

Deforestation can become a rational choice under circumstances of insecure property rights (Araujo et al., 2009). Conversely, improvements in land tenure and land use rights can facilitate a reduction of deforestation and provide the conditions for promoting forestry activities that maintain or increase carbon stocks (Sunderlin et al., 2005; A. Chhatre and A. Agrawal, 2009; Blom et al., 2010; Sikor et al., 2010; Rosendal and Andresen, 2011). Improvements on institutional agreements, especially those regarding tenure and use rights, and considering local stakeholders' rights, can be seen either as enabling condition (see 11.8) or as a co-benefit of AFOLU activities. Improvements in land tenure and use rights has been seen as a potential co-benefit of A/R CDM, tenure issues are obligatory and where improvements of rights can be considered as an additionality factor.

Several of these co-benefits may result in additional payment streams – and thus impact on the nett cost of mitigation. Examples include reforestation schemes that also produce timber. Other co-benefits may not be easily valued

11.7.1.2 Environmental and health effects

Climate benefits of reforestation in the tropics are enhanced by positive biophysical changes such as cloud formation, which further reflects sunlight. These patterns of full radiative forcing reinforce the large potential of tropical regions in climate mitigation, discourage major land use changes in boreal regions, and suggest avoiding large albedo changes in temperate regions to maximize the climate benefits of carbon sequestration.

Multi-process practices (diversified crop rotations and organic N sources) significantly improved total N retention compared to three common single-process strategies (reduced N rates, nitrification inhibitors, and changing chemical forms of fertilizer) (Gardner and Drinkwater, 2009). Integrated systems can be an alternative to reduce leaching. A forest plantation and an open pasture showed a potential to leach up below 1.2 m soil depth about 88% and 55% higher, respectively, than an integrated forestry-pasture system due to root interaction between grasses and pine trees. This interaction could result in higher take up N from soil profile reducing the contamination of groundwater by nitrate (Bambo et al., 2009).

At any given level of demand for agricultural products, intensification increases output per unit area and year and would therefore, under ceteris paribus conditions, allow to reduce farmland area which would set free land for C sequestration and/or bioenergy production. For example, a recent study calculated impressive GHG reductions from global agricultural intensification by comparing the past trajectory of agriculture (with substantial yield improvements) with a hypothetical trajectory with constant technology (J.A. Burney et al., 2010). An empirical long-term study for Austria 1830-2000 also suggested that increased agricultural yields contributed to the emergence of a substantial terrestrial carbon sink in biota and soils (e.g.,K -H. Erb et al., 2008).

AFOLU mitigation options can promote conservation of biological diversity. Biodiversity conservation can be improved both by reducing deforestation, and by using reforestation/afforestation to restore biodiverse communities on previously developed farmland (R.J. Harper et al., 2007). Reforestation may also provide a mechanism to fund translocation of biodiverse communities in response to climate change. Further, increases in water yield and quality can become additional co-benefits. Water yield and quality can be affected by land management and surface cover in particular (Calder, 2005). Reducing deforestation can reduce water quality impacts, such as turbidity and salinity. Watershed restoration by reforestation can result in an array of other benefits including improvements in water quality (PV Townsend et al., 2011), biodiversity (Swingland et al., 2002), shading induced water temperature reductions (Deal et al., 2012) and improvements in amenity.

It should be also mentioned that stubble retention and minimum tillage may also increase crop yields and reduce the amount of wind and water erosion due to an increase in surface cover (R. Lal, 2001); agroforestry systems will reduce wind erosion by acting as wind breaks and may increase crop production, and reforestation or bioenergy systems can be used to restore degraded or abandoned land (Yamada et al., 1999; Wicke et al., 2011; Stanley J. Sochacki et al., 2012).

Reduced emissions from agriculture and forestry may also improve air, soil and water quality (P. Smith, Ashmore, et al., 2013), thereby indirectly providing benefits to human health and well being. Demand-side measures to reduce livestock product consumption in the diet are also known to be associated with multiple health benefits (E. Stehfest et al., 2009).

11.7.1.3 Technological considerations

AFOLU mitigation options can promote innovation and many technological production-side mitigation options, outlined in section 11.3, also increase agriclultual and silvicultural efficiency. Since many agricultural GHG emissions constitute inefficiencies (e.g. nitrogen lost as N_2O from soils is not available as fertilizer, CH_4 emitted from enteric fermentation constutes lost livestock productivity), measures to reduce GHG emissions often improve productivity and profitability.

Improvements on local resilience to climate change, which are further potential co-benefits of AFOLU mitigation options are discussed in section 11.5.

11.7.1.4 Public perception

AFOLU mitigation practices have potential positive impacts on land tenure, land use rights and governance (see section 11.4.4). Mitigation measures which support sustainable development are likely to be viewed positively in terms of public perception, but a large scale drive toward mitigation without inclusion of the key stakeholder communities involved would likely not be greated favourably (P. Smith and E Wollenberg, 2012).

11.7.2 Risks and uncertainties

11.7.2.1 Socio-economic

Some mitigation measures may result in a decrease in the amount of land available for food production (e.g. reforestation of farmland to sequester carbon or produce bioenergy), decrease yields (e.g. competition between trees and crops, reduced yields with reduced fertilizer inputs), or directly compete for food materials as a bioenergy feedstock (e.g. conversion of sugar or maize to ethanol). Further, agricultural profitability often relies on land-holders being able to switch between crops. Mitigation projects may have rules that require the mitigation activity to be in place for 70-100 years; this can reduce future flexibility in land-use. Similarly, land-holders have to consider the marginal spread of carbon prices between when they sell and wish to repurchase carbon credits. Assessments on the perceived risks of AFOLU mitigation options include socio-economic as well as environmental risks. Perceived socio-economic risks cover from the possibility to further promote corruption or to jeopardize the decentralisation efforts made in the last decades, or to increase land rents and food prices due to reduction in land availability for agriculture in developing countries. Further there is a preoccupation that land based mitigation options could increase land conflicts or marginalize small scale farm/forests owners due to elevated transaction costs of the AFOLU mitigation options (Huettner, 2012).

11.7.2.2 Environmental and health effects

The impacts of greenhouse gas mitigation in the AFOLU sector on other climate drivers (such as albedo and water balance) are discussed in detail in section 11.5 so are not discussed further here. In addition to potential climate impacts, land-use intensity drives the three main fractionating N loss pathways (nitrate leaching, denitrification and ammonia volatilization) and typical N balances for each land use indicate that total N loss also increase with increasing land-use intensity (Stevenson et al. 2010). Leakages from N cycle can cause air (e.g. NH_3, NO_x), soil (nitrate) and water pollution (e.g. eutrophication) and agricultural intensification can lead to a variety of other adverse environmental impacts, as described in (P. Smith, Ashmore, et al., 2013; P. Smith, Bustamante, et al., 2013).

In a synthesis of global data, (R.B. Jackson et al., 2005) documented several effects of afforestation/ reforestation on the environment. Stream flow decreased within a few years of planting and 13% of streams dried up completely for at least 1 year, with eucalyptus more likely to dry up streams than pines. The reduction percentage of runoff is higher at drier regions (< 1000 mm mean annual precipitation – Farley et al., 2005). Plantations not only have greater water demands than grasslands, shrublands, or croplands, they typically have increase nutrient demand, which change soil chemistry in ways that affect fertility and sustainability. Afforestation of grasslands or shrublands significantly increased Na concentrations, exchangeable sodium percentage, and soil acidity and decreased base saturation, suggesting potential soil salinization. The release of organic acids in the process of decomposition of litter causes acidification of the topsoil. Leachates from the canopy are also identified as substances liable to decrease the pH of the soil in forestry. Agroforestry crops, using high yields such as short rotation forestry, have been used. Besides the benefits, there is a risk of increased release into the atmosphere of volatile organic compounds (VOC) emitted in large amounts by most of the species commonly used (Calfapietra et al., 2010). Forestry projects can result in reduced water yields (R.B. Jackson et al., 2005) in either groundwater or surface catchments, or where irrigation water is used to produce bioenergy crops. There is considerable literature on the effects of plantation establishment on water yield (Calder et al., 1993; Calder, 2005). Where a mitigation project involves land use change, biodiversity can be impacted (P. Smith, Ashmore, et al., 2013).

11.7.2.3 Technological considerations

Since a large proportion of the mitigation potential in the AFOLU sector arised from carbon sequestration in soils and vegetation, there are significant risks associated with the future maintenance of the C stocks, which may be affected by management (see section 11.3.3 for discussion of non-permanence / reversal) or by natural factors (see section 11.5 for discussion of future climate impacts on C sinks / stocks). A number of the technologies also present apparent risks; certain types of biotechnology and animal feed additives, for example, are banned in parts of the the world.

11.7.2.4 Public perception

In public perception there are concerns about competition between food and AFOLU outcomes either because of an increasing use of land for biofuel plantations (J. Fargione et al., 2008; Alves Finco and Doppler, 2010b) or due to blocking transformation of forest land into agricultural land (M. Harvey and S. Pilgrim, 2011). Further, lack of clarity regarding the architecture of an international climate regime that includes and promote a sustainable use of the AFOLU mitigation options beyond 2015 is perceived as a potential threat for long-term planning and long-term investments. As noted in section 11.7.2.3, certain types of biotechnology and animal feed additives are banned in parts of the the world due to perceived health and/or environmental risks. Public perception is often as/ more important than scientific evidence of hazard / risk in considering government policy regarding such technologies (Royal Society, 2009).

11.7.3 Spillovers

The section on systemic perspectives largely deals with spill over effects so the details will not be repeated here. There are two additional socio-economic spilloovers however that should be mentioned.

Ecosystem markets - In some jurisdictions ecosystem markets are developing (Engel et al., 2008; Wünscher and Engel, 2012); (MEA, 2005); (Deal and White, 2012) and these allow valuation of various components of land-use changes, in addition to carbon mitigation (Mayrand and Paquin, 2004; Barbier, 2007). Different approaches are used; in some cases the individual components (both co-benefits and tradeoffs) are considered singly (bundled), in other situations they are considered *in toto* (stacked). Ecosystem market approaches provide a framework to value the overall merits of mitigation actions at both project, regional and national scales (J Farley and Costanza, 2010). The ecosystem market approach also provides specific methodologies for valuing the individual components (e.g. water quality response to reforestation, timber yield) however for some types of ecosystem services (e.g. biodiversity, social amenity) these methodologies are less well developed.

Scale of impacts - It is also important to consider the scale of any impacts. The co-benefits and trade-offs from mitigation measures will be largely scale dependent – thus if the uptake of mitigation is poor, then the co-benefits and trade-offs will be likewise poor, whereas large scale carbon mitigation investment may result in large-scale landscape change. Where this displaces other commodities, there are likely to be impacts on markets. Such analyses will also need to consider the impacts of climate change on mitigation and associated co-benefits and trade-offs.

Co-benefits, risks and uncertainties, and spill-overs in the AFOLU sector are summarised in Table 11.11.

Table 11.11 Summary of co-benefits, risks and uncertainties, and spillovers from mitigation measures in the AFOLU sector

	CO-BENEFITS, RISKS AND SPILLOVERS			
	Outcomes-impacts of the implementation			
	Risks	**Uncertainties**	**Co-benefits**	**Spill-overs**
Socio-economic effects	Competition with food availability: "fuel vs. Food" (22)	increments in productivity can induce higher consume of agricultural crops creating a rebound effect, ergo more GHG emissions (12)	Increases in food and fibre production (15)	Ecosystem markets (26)
	Impacts on existing conflicts or on social discomfort in fragile areas	Precluding other land-use options (25)	Increase in economic activity (19)	Scale of impacts (27)
		Competition between global benefits and local negative effects	Impacts on additional payment streams (20)	
			Increases in NTFP	
Environmental and health effects	impacts on N cycle in water due to activities in cropland, livestock and manure management (6)	Intensification of agriculture can have positive or negative impacts on GHG emissions depending on the impact on land availability/use (11)	positive impact of multi-process practices on N and P cycles (7)	Agricultural intensification should be considered as an element in a landscape system (14)
	Interactions with ozone in ecosystems (10)	Impacts of manure management on N cycle (4)	Increases in water yield and quality (16)	
	impacts of intensification on N cycle (3)	Risk of impacts on P and N in manure due to livestock management (5)	Improvements in biodiversity conservation (17)	
	Impacts of intensification on biodiversity, rain patterns and soil (13, 24)		Improvements in sustainable agriculture (18)	
	impacts on albedo and evaporation with further implications for radioactive force(1)		Additional carbon sequestration (21)	
	Monocultures can have negative impacts on water and nutrients' demand (8)		Positive biophysical changes like cloud formation (2)	
	Potential emissions of VOC by agroforestry systems (9)		Increases climate resilience	
	impacts on water availability (23)			
	Impacts of manure management on N cycle (4)			
	Risk of impacts on P and N in manure due to livestock management (5)			
Technological (risks)			AFOLU mitigation options can promote innovation through "the first of its art" (see at the additionality options of A/R CDM)	
Public perception	Potential (negative) impacts on land use /land tenure rights for poor communities / landless people		Potential (positive) impacts on land tenure, land use rights and governance	Successfully implemented AFOLU options will be copied

11.8 Barriers and opportunities

11.8.1 Socio-economic barriers and opportunities

There are some economic factors that could limit the use of AFOLU mitigation options. If financing or market mechanisms aimed at promoting these mitigation options fail to cover at least transaction and monitoring costs, the mechanisms themselves will become a limitation, because AFOLU financing will be less attractive than returns from other land uses. Additionally if land dependent people (e.g. agriculturalist, pastoralist or forest dependent communities) have not access to the financing/marketing mechanisms of AFOLU they will not be used (Carol J. Pierce, 2011b). Thus market limitations and limited access to financial or market mechanisms for AFOLU mitigation options can become barriers for realising the mitigation potential in the sector. Conversely, the UNFCCC can create economic incentives for AFOLU mitigation options, thus improving their feasibility (Huettner, 2012).

Poverty, as characterized not only by reduced income but also reduced access to decision making can become a barrier, especially when forest users are affected. Other characteristics of social groups affected by poverty, including lack of skills or reduced social organization can limit the use of AFOLU mitigation options too. Balancing development priorities can prevent to make full use of the AFOLU potential, because land, as a finite good, cannot be used only for mitigating climate change but also for other development priorities. This is especial relevant when keeping forest land is competing with other development strategies e.g. increasing agricultural land or promoting some types of mining (Forneri et al., 2006) or when a full use of biofuels can compromise food security (Nonhebel, 2005).

Further, institutional agreements and good governance are basic for promoting the use of AFOLU mitigation options. This includes the need to have clear land tenure and land use regulations and that these regulations are enforced. Countries and regions, where land tenure and use rights are clear and governance agreements between the civil society, the public and the private sector are enforced will provide better enabling conditions for fully use the mitigation potential of the AFOLU sector (Pettenella and Brotto; Ezzine-de-Blas et al., 2011; Kanowski et al., 2011; Markus, 2011). Development impacts for the poor can play an important role here as transfer of ownership over larger forest commons patches to local communities, coupled with payments for improved carbon storage seems to be an option for contributing to climate change mitigation without adversely affecting local livelihoods (Ashwihi Chhatre and Arun Agrawal, 2009). (P. Smith, Martino, Cai, Gwary, H Janzen, et al., 2007)(P. Smith and Trines, 2006; P. Smith and E Wollenberg, 2012) review some of the barriers to implementation of agricultural mitigation options.

11.8.2 Ecological barriers and opportunities

Human activities now appropriate nearly one-third to one-half of global ecosystem production, and as development and population pressures continue to mount, so could the pressures on the bio-sphere. Modern land-use practices, while increasing the short-term supplies of material goods, may undermine many ecosystem services in the long run, even on regional and global scales (J Foley et al., 2009b). Availability of land and water for different uses need to be balanced considering short and long term priorities. Consequently land use competition can become an ecological barrier at the global level in the sense that land is a finite good and the decision of how to use it needs to balance ecological integrity and societal expectations (T Jackson, 2009).

At the local level, the specific soil conditions and water availability as well as natural variability and resilience to the specific systems will determine the size of the potential by each AFOLU mitigation option. Desertification processes and extending droughts in Africa as well as changes in the hydrological cycle in Central and South America seem to be important variables defining the specific regional potential (Rotenberg and Yakir, 2010)(Bradley et al., 2006). It needs also to be highlighted, that well implemented AFOLU mitigation options can have a supplementary character as they can provide mitigation and adaptation benefits, while improving the living conditions of the local population (D.P. van Vuuren et al., 2009)(C. Robledo et al., 2011) (Guariguata et al., 2008)

11.8.3 Technological barriers and opportunities

Some mitigation technologies are already applied now (e.g. afforestation, cropland and grazing land management, improved livestock breeds and diets) so for these there are no technological barriers, but others (e.g. some livestock dietary additives, crop trait manipulation) are still in the development stage. Such future developments present opportunities for additional mitigation to be realised in the future. Potential barriers to such developments include private and public sector commitments to research and development, market failures, policy failures and lack of practitioner or public acceptance of the new technologies. These issues are discussed in full in section 11.7.

11.8.4 Public perception

The willingness of a social group to improve the enabling conditions in favour of AFOLU mitigation options is highly determined by the perception of benefits, risks and uncertainties. This is relevant for all social groups including public and private sectors as well as civil society (Reinhard Madlener et al., 2006). Changes in institutional agreements regarding land use, including changes in land tenure and use regulation, changes in sectoral policies or creation of subsidies and other economic instruments have an impact on changing enabling conditions and thus on increasing opportunities or exacerbating barriers.

If social groups depending on, or regulating, agriculture, forest or livestock perceive that the agreements and mechanisms concerning AFOLU mitigation options jeopardize or reduce their participation in the benefits of these sectors, they will behave in such a way that makes the optimization of AFOLU difficult (Corbera and Katrina Brown, 2008; Corbera and Schroeder, 2011b). This is relevant for marginalized social groups as well as for non-marginalized, and has been documented especially for potential agreements on REDD+ and on biofuels (Carol J. Pierce, 2011b), (Killeen et al., 2011; Gasparatos et al., 2011b). On the other side if the agreements aimed at promoting AFOLU mitigation options create mechanisms to leverage the social benefits, and if these potential benefits are properly communicated, social groups can increase their willingness to adopt AFOLU activities.

Key examples of barriers and opportunities arising from mitigation actions in the AFOLU sector are summarised in table 11.12.

Table 11.12 Barriers and opportunities arising from mitigation actions in the AFOLU sector

	Barriers	**Opportunities**
Socio-economic	**Economic/financial**: Land competition, technology vs. effective mitigation; transaction costs, integrity vs. measurement; availability of financial capital, market failure, reduced access to markets (especially for the poor) (28)	Clear land tenure and use rights systems/ well enforced legislation
	Policy, institutional, legal: Contradictory policies, sectoral conflicts, lack of enforcement (already updated of ZOD)	Coordinated cross-sectoral policies
		Existence of participatory mechanisms that ensure stakeholders active participation
Environmental and health effects	**Physical:** saturation point, natural variability, uncertainty, reversibility, and permanence (30)	Available land
Technological	**Technological:** State of R&D, availability/acceptability of technologies (29)	
Public perception	Acceptability, sense of no-urgency, individual priorities vs. global priorities (already updated of ZOD), individual preferences, lack of knowledge	increasing desertification Clarification of land tenure and uses rights
		Recognition of customary rights
	Peoples perceptions of (new) rights and regulations, perception of (social) justice in legislations and mechanisms for AFOLU	

11.9 Sectoral implications of transformation pathways and sustainable development

[AUTHORS: data from Ch6 not yet available. Section to be written for SOD: 3 pages max]

11.9.1 Land use implications of transformation pathways

Uncertainty about reference AFOLU emissions is significant historically [AUTHORS: Reference will be added] and in projections (see section 6.2.8). Climate policy transformation projections of AFOLU emissions and land-use are defined by the reference scenario and abatement policy assumptions regarding eligible abatement options and regions covered. Most transformation scenarios assume immediate, global, and comprehensive availability of land related mitigation options. In these scenarios, the global landscape contributes to abatement with land-use CO_2 emissions in 2030 declining 0 to 3 Gt CO_2 yr^{-1} (Fischer et al., 2007) with up to 10 Gt CO_2 yr^{-1} estimated (M. Wise et al., 2009). In these cases, models are assuming an explicit terrestrial carbon stock incentive or a global forest protection policy. Bioenergy is also being deployed, with levels reaching as high as 100 EJ yr^{-1} in 2030 (see section 6.2.8). Bioenergy land use estimates vary widely, e.g. 50% (M. Wise et al., 2009) and 15-16% (Mellilo et al, 2012) due to variation in climate objective, modelling structure, land productivity, and options considered. The abatement role of individual land-related technologies is not generally reported in transformation pathway studies. In part, this is due to emphasis on the energy system, but also other factors (secton 6.2.8). An exception is (Steven K. Rose et al., 2012) who reported agriculture, forest carbon, and bioenergy abatement levels for various climate stabilization policies. Across scenarios, land-related strategies contributed 21 to 59% of cumulative abatement to 2030, with forest strategies contributing 0 to 25%, agricultural CH_4 - 1 to 7%, agricultural N_2O - 1 to 23%, and bioenergy - 2 to 26%. Over the century, bioenergy was the dominant strategy, followed by forestry, and then agriculture.

More recently, the literature has begun exploring more realistic fragmented policy contexts and identifies a number of policy coordination issues. There are many dimensions to policy coordination: technologies, regions, climate and non-climate policies, and timing. For instance, increased bioenergy incentives without terrestrial carbon stock incentives (M. Wise et al., 2009); Reilly et al., 2012) or global forest protection policy (A. Popp, J.P. Dietrich, et al., 2011), suggests a large potential for leakage with the use of energy crops. The leakage comes primarily in the form of displacement of pasture, grassland, and natural forest (see section 11.5). There is also food cropland conversion. However, providing bioenergy while protecting terrestrial carbon stocks could result in a significant increase in food prices (see illustrative figure 11.14).

[AUTHORS: Data from Ch6 not yet available. For SOD aim for: For each family of pathways / scenarios, describe global implications for cropland, forest, grassland and bioenergy areas. For each family of pathways / scenarios, describe implications for cropland, forest, grassland and bioenergy areas – focus on regional differences]

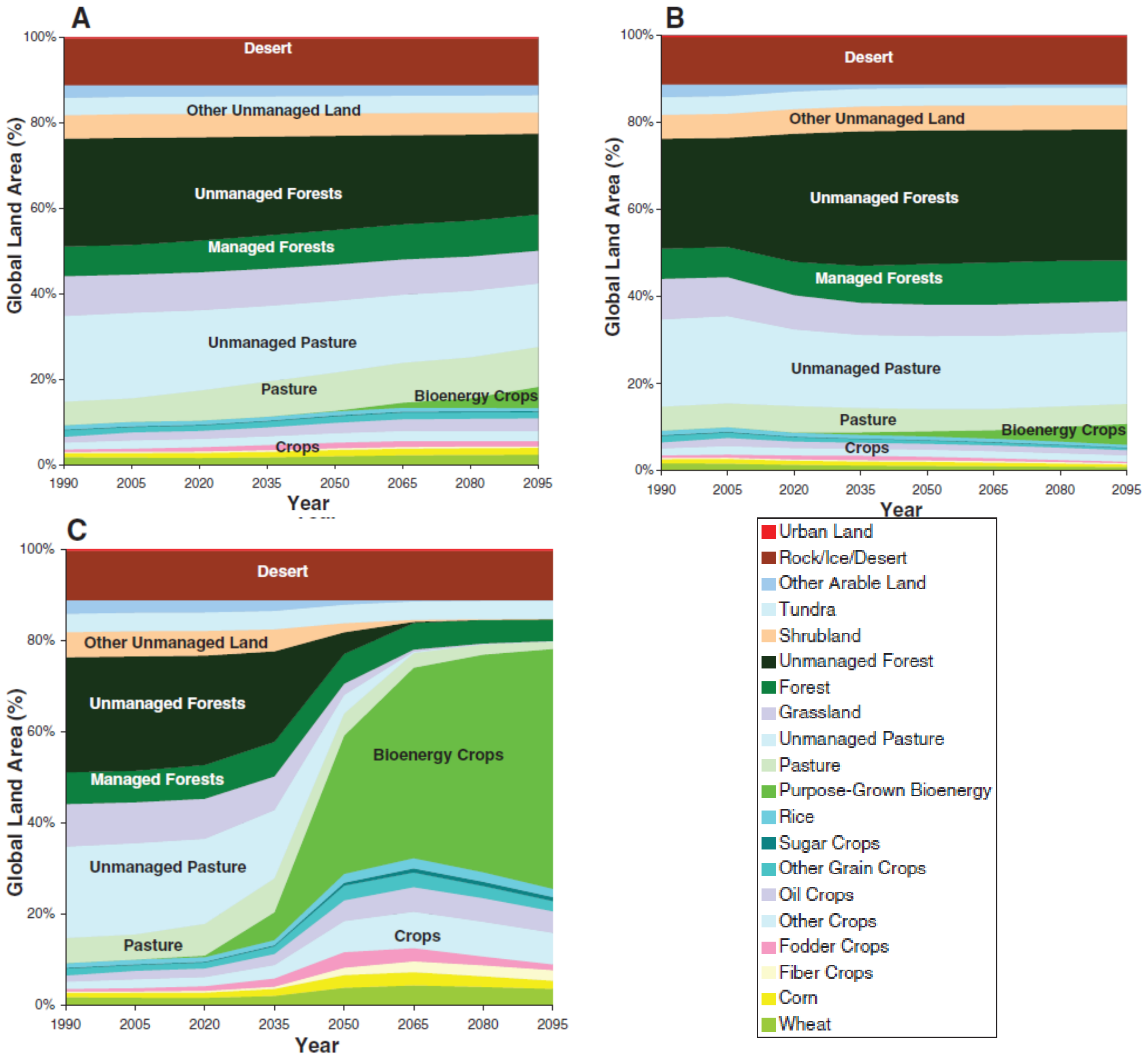


Figure 11.14 A comparison of global land use under different scenarios. (A) Land use along the reference pathway. (B) Land use under a UCT pathway defined to achieve a CO2 concentration target of 450 ppm, which limits fossil fuel, industrial, and terrestrial carbon emissions with a common carbon tax on emissions. (C) Land use along the corresponding FFICT scenario in which only fossil fuel and industrial emissions are controlled to achieve the same 450-ppm CO2 concentration. In the FFICT scenario, the substantial increase in demand for purpose-grown biomass (four times as much as the reference scenario in Year 2095) intensifies its competition with food and fiber crops for the best cropland, pushing crops and biomass growth beyond traditional croplands and into lands that are inherently less productive. As a result, the relative increase in land required for biomass and other crops exceeds the relative increase in demand. Illustrative figure showing how different climate policies (with and without terrestrial carbon emissions with a common carbon tax on emissions) could impact upon land use. If only fossil fuel and industrial emissions are controlled to reach a 450 ppm CO2 concentration target (C), purpose-grown biomass increases by 4 fold compared to the reference case, pushing crops and biomass beyond traditional croplands where they are less productive having an enormous impact on all land use, but unmanaged forests and pastures in particular. Source: (M. Wise et al., 2009)

11.9.2 Feasibility of mitigation from AFOLU sector from transformation pathways

[AUTHORS: Data from Ch6 not yet available. For SOD aim for: Refer to costs and potentials section for – a) comparison of the mitigation potential from transformation pathways with global bottom-up estimates, b) comparison of the mitigation potential from transformation pathways with regional bottom-up estimates]

11.9.3 Consequences of land use change under transformation pathways for sustainable development

[AUTHORS: Data from Ch6 not yet available. For SOD aim for: Refer to sustainable development sections for implications of changes in areas of for cropland, forest, grassland and bioenergy for sustainable development – try to look at potential positives and negatives – if implemented in way "x", bad for SD, but if implemented in way "y" then could benefit SD. Text: If high forest area, then implications for SD are…; if low forest area then…; If high cropland area, then implications for SD are…; if low cropland area then…; If high grassland area, then implications for SD are…; if low grassland area then…; If high bioenergy area, then implications for SD are…; if low bioenergy area then…; table of potential positive and potential negative SD impacts of above, depending on implementation (to summarise the section)]

11.9.4 Consequences of land use change under transformation pathways for other services delivered by the AFOLU sector

[AUTHORS: Data from Ch6 not yet available. For SOD aim for: Impact on biodiversity (depending on change in land use areas), impact on food security (depending on change in land use areas), impact on fibre / timber provision (depending on change in land use areas); impact on water availability (depending on change in land use areas); impact on other ecosystems services (table with references) – cross reference to the systemic perspective section – include multiple feedbacks]

11.10 Sectoral policies

Climate change is likely to influence and be influenced by the most diverse policy or management choices, due to the pervasive nature of its impacts for many important aspects of human life. This is particularly true for those interventions affecting agriculture and forests that are strongly dependent on climate phenomena, but also contribute to climate evolution being sources of and sinks for greenhouse gases (Golub et al., 2009). Regional variability is one of the main drawbacks to fully assess the cost-effectiveness of different measures. In the case of Europe, for example, agricultural and forestry sectors can potentially provide emissions reduction at a competitive cost, mainly with methane abatement in agriculture and carbon sequestration with appropriate forest management measures while afforestation, cropland management and bioenergy could be less economically viable measures due to competition with other land use (Povellato et al., 2007).

National and international agricultural and forest climate policies have the potential to redefine the opportunity costs of international land-use in ways that either complement or counteract the attainment of climate change mitigation goals. Additionally, adequate policies are needed for orienting practices in agriculture and in forest conservation and management to cope with mitigation and adaptation. Extreme events caused by climate change will affect not just production and the volatility of production but may also create new difficulties related to water quality, storage and related food safety issues.

Forests provide multiple benefits at local to global scales including carbon sequestration and contributions to livelihoods for more than half a billion users. Forest carbon stocks can be increased by increasing the biomass on existing forest acreage (the intensive margin – e.g. by delaying harvests or modifying management) or by expanding forest land (the extensive margin – e.g. by afforesting non-forested lands or preventing conversion of current forest lands). The role of tropical forests regulating global climate might be bigger than previously thought (Stephens et al., 2007) and will likely become even more important as alternative sinks become saturated (C. Le Quere et al., 2007) while forests can continue to act as sinks throughout a century of climate-change (Gullison et al., 2007). Public policies have had an impact by reducing deforestation rates in some countries (e.g. Brazil; www.obt.inpe.br/prodes).The most striking aspect of policies for the forest sector is the discussion of mechanisms associated with REDD and its variations (Santilli et al., 2005); (UNFCCC, 2006). The mechanism would offer incentives to countries to reduce their deforestation in comparison to a national reference level calculated from their deforestation rate in a recent timeframe (1990s, or early 2000s). The REDD-plus approach would finance not only forest conservation, but also sustainable forest management and enhancement of carbon stocks restoration / afforestation / reforestation) (UNFCCC, 2009). Some regional and global programs and partnerships address illegal logging, forest management and conservation and REDD are presented in Table 11.13.

There is a general consensus that REDD can be a very cost effective option for mitigation climate change. According to (Strassburg et al., 2007, 2009) incentives in the order of US$ 20 billion per year could curb 90% of global emissions from deforestation. The associated total cost per tonne of CO_2 of approximately US$ 8 is on the very low side of the UNFCCC estimates of mitigation options (US$ 100 t^{-1} of CO_2). The annual amount of CO_2 emissions reduced (3.2-6.4 Gt CO_2) would be four to eight times the annual target of the Kyoto Protocol. The large share of global abatement of emissions from land-use sector would be from the extensive margin of forestry, especially through avoided deforestation in tropical regions (Golub et al., 2009).

A growing body of academic literature has been analyzing different aspects related to the implementation, effectiveness and scale of REDD+ mechanisms as well as the interactions with other social and environmental co-benefits. One central aspect is related to forest governance as central governments own by far the greater proportion (~86%) of the world´s forests and wooded areas (FAO, 2005). Major features of contemporary forest governance include decentralization of forest management, logging concessions in public owned commercially valuable forests, and timber certification, primarily in temperate forests. Although a majority of forests continue to owned formally by governments, there are indications that the effectiveness of forest governance is increasingly independent of formal ownership. Growing and competing demands for food, biofuels, timber, and environmental services will pose several challenges to effective forest governance in the future, especially in conjunction with the direct and indirect impacts of climate change (A. Agrawal et al., 2008). Original data on 80 forest commons in 10 countries across Asia, Africa, and Latin America , showed that larger forest size and greater rule-making autonomy at the local level are associated with high carbon storage and livelihood benefits; differences in ownership of forest commons are associated with trade-offs between livelihood benefits and carbon storage (A. Chhatre and A. Agrawal, 2009). Additionally, it was argued that local communities restrict their consumption of forest products when they own forest commons, thereby increasing carbon storage. However, there are widespread concerns that REDD will increase costs on forest-dependent peoples and in this context, stakeholders rights, including rights to continue sustainable traditional land use practices, appear as a precondition for REDD development (Phelps et al., 2010).

Another key issue for the implementation of REDD is how to address the “leakage” of emissions (i.e. a reduction of deforestation in a target area being compensated for an increase in other areas) that characterized past initiatives (Santilli et al., 2005; UNFCCC, 2006; Nabuurs et al., 2007) UNFCCC, 2007a; (Strassburg et al., 2007, 2009). A mechanism operating at the national level would solve the leakage within each country, a major drawback of project-based approaches (M. Herold and M. Skutsch, 2011) although the threat of international leakage would remain. Still regarding the implementation, the two main multilateral readiness platforms for REDD, the UN-REDD Programme and the Forest Carbon Partnership Facility (FCPF) were established to advise REDD countries in successfully preparing for and implementing REDD. The UN-REDD Programme has taken the lead on providing its technical expertise to furthering methods and approaches on how to best meet country needs for carbon measurement, reporting and verification (MRV), while the FCPF leads in the area of economic analysis for REDD strategies. Nevertheless, it has been argued that these platforms do not yet identify communities or forest commons as relevant agents for managing forests to sequester carbon or derive livelihood benefits from forests (A. Chhatre and A. Agrawal, 2009).

At the COP13 of the UNFCC, parties adopted a series of decisions known as the “Bali Action Plan” (UNFCCC, 2008) that calls for verifiable nationally appropriate mitigation actions (NAMAs) by developing country parties in the context of sustainable development. Developing countries would submit climate plans (e.g. low carbon growth strategies) that list their intended NAMAs and associated requests for support. NAMAs can be individual actions or groups of actions and could be supported and enabled by verifiable technology financing, and capacity building support from developed countries. Actions or group of actions could include REDD+, agricultural or related activities as bioenergy and Clean Development Mechanism. Several developing countries have already communicated their NAMAs to the UNFCCC with the overall national objectives for reducing emissions and the specific mitigation actions to be implemented in order to meet those objectives. Among them are countries in South America, Africa and Asia with significant forest cover that included actions to reduce deforestation, restore degraded forests and implement sustainable forest management. Additionally in the context of sustainable development, the COP16 (2010) established the Green Climate Fund (GCF) aiming to promote low-emission and climate-resilient development pathways by providing support to developing countries to limit or reduce their greenhouse gas emissions and to adapt to the impacts of climate change. The Fund should be an operating entity of the financial mechanism of the UNFCCC. The GCF was designed by the Transitional Committee (TC) that reported at the COP 17 (Durban - 2011) but arrangements are not concluded yet.

Although the UNFCCC consider approaches that could be developed appropriate market-based instruments to support REDD+ activities, several issues (like environmental integrity risk of leakage, non-permanence and excess supply of credits) prevented so far the development of compensatory mechanisms in these activities supported under the Convention. Additionally, parties differ in their views on the use of private finance for forest related activities. While some countries prefer the use of both public and private funding sources and favor the market-based approaches, others differ, particularly in the use of offsets within market based approaches. Transactions of carbon credits from the forest sector amounted $ 133 million in 2010 (Peters-Stanley et al., 2011), 95% of them in voluntary markets. Afforestation / reforestation are the forestry activities in mandatory carbon markets linked to the Kyoto Protocol. This is the approach of the New Zealand emissions trading scheme (NZ-ETS), the Australian regional scheme (NSW Greenhouse Gas Reduction Scheme - GGAS) and the Clean Development Mechanism (CDM). In voluntary markets, different certification systems also consider other activities such as improvements in forest management, avoided deforestation and carbon uptake by regrowth, reforestation, agroforestry and sustainable agriculture. In general, the low level of disbursement in comparison to the total deposited in some of the funds presented in Table 11.13 is an indication of the still open issues related to the implementation of REDD+ initiatives.

Table 11.13 Some regional and global programs and partnerships related to illegal logging, forest management and conservation and REDD

Program	Institution	Context	Objectives and Strategies
Forest Law Enforcement and Governance (FLEG)	World Bank	Illegal logging and lack of appropriate forest governance are major obstacle to countries to alleviate poverty, to develop their natural resources and to protect global and local environmental services and values World	Support regional forest law enforcement and governance
Improving Forest Law Enforcement and Governance in the European Neighbourhood Policy East Countries and Russia (ENPI-FLEG)	European Union	Regional cooperation in the European Neighbourhood Policy Initiative East Countries (Armenia, Azerbaijan, Belarus, Georgia, Moldova and Ukraine), and Russia following up on the St Petersburg Declaration	Supports governments, civil society, and the private sector in participating countries in the development of sound and sustainable forest management practices, including reducing the incidence of illegal forestry activities
Forest Law Enforcement, Governance and Trade (FLEGT**)**	European Union	Illegal Logging has a devastating impact on some of the world's most valuable forests. It can have not only serious environmental, but also economic and social consequences	Exclude illegal timber from markets, to improve the supply of legal timber and to increase the demand for responsible wood products. Central element are trade accords with timber exporting countries (**Voluntary Partnership Agreements)** to ensure legal timber trade and support good forest governance in the partner countries and . the **EU Timber Regulation**. There is a number of countries in Africa, Asia, South and Central America currently negotiating FLEGT Voluntary Partnership Agreements (VPAs) with the European Union.
Program n Forests (PROFOR)	multiple donors including the European Union, European countries, Japan and the World Bank	Well-managed forests have the potential to reduce poverty, spur economic development and contribute to a healthy local and global environment	Provide in-depth analysis and technical assistance on key forest questions related to livelihoods, governance, financing and cross-sectoral issues. Housed within the World Bank's Forests Team since 2002. PROFOR activities comprise analytical and knowledge generating work that support the strategy's objectives of enhancing forests' contribution to poverty reduction, sustainable development and the protection of environmental services.
Forest Investment Program (FIP)	Strategic Climate Fund (a multi-donor Trust Fund within the Climate Investment Funds)	Reduction of deforestation and forest degradation and promotion of sustainable forest management, leading to emission reductions and the protection of carbon terrestrial sinks.	Support developing countries' efforts to REDD and promote sustainable forest management by providing scaled-up financing to developing countries for readiness reforms and public and private investments, identified through national REDD readiness or equivalent strategies.
Forest Carbon Partnership (FCPF)	World Bank	Assistance to developing countries in their efforts to reduce emissions from deforestation and forest degradation and foster conservation, sustainable management of forests, and enhancement of forest carbon stocks--called REDD+--by providing value to standing forests.	Builds the capacity of developing countries in tropical and subtropical regions to reduce emissions from deforestation and forest degradation and to tap into any future system of positive incentives for REDD.

Amazon	Brazilian Development Bank (BNDES) (multi-donor, including governments and companies and will also receive donations from multilateral institutions, non-governmental organizations and individuals).	Support to reduce emission of greenhouse gases in coordination to activities for prevention, monitoring and combat against deforestation, as well as to those related to promoting the preservation and sustainable use of forests in the Amazon biome.	The main objective of the Amazon Fund is to provide support to projects to prevent, monitor and combat deforestation, as well as for the conservation and sustainable use of forests in the Amazon Biome.
Congo Basin Forest Fund (CBFF)	Governing council (provides strategic direction and oversight of the Fund)	Mobilization of resources to finance activities and projects aimed at promoting the equitable and sustainable use, conservation and management of the Congo Basin forests and ecosystems for poverty alleviation, sustainable social-economic development, re-gional cooperation and environmental conservation.	The areas of intervention for CBFF grant funding will mainly be those that slow the rate of deforestation, reduce poverty amongst forest dwellers, and contribute to a reduction in greenhouse gas emissions while maximizing the storage of carbon.

Considering an integrated approach for land-using sector policies, one central question is if intensification of agriculture reduces cultivated areas and results in land sparing by concentrating production on other lands. Land sparing would allow released lands to sequester carbon, provide other environmental services and protect biodiversity (Fischer et al., 2008). From 1970 to 2005 cultivated areas increased more slowly than world population between 1970 and 2005, but actual declines in cultivated area occurred infrequently at global, regional, and national scales (Rudel et al., 2009). The most common pattern involved simultaneous increases in agricultural yields and cultivated areas. With the exception of the early 1980s, demand for agricultural commodities during an area of globalizing markets remained sufficiently elastic to induce farmers, on net, to cultivate more land even as they produced more crops per hectare. Agricultural intensification was accompanied by decline or stasis in cropland area at a national scale during this time period, only in countries with grain imports and conservation set-aside programs.

The links between declines in cultivated areas, conservation policies, international trade, and agricultural intensification may have recently changed in one more important way as the prospect of payments for environmental services in the tropics has become a salient part of a proposed, worldwide climate stabilization policy. Both reducing emissions from deforestation and degradation and PES on abandoned agricultural lands only become politically more acceptable policy options when crop yields rise on the remaining lands and commodity price increases. The importance of coupling agricultural intensification with land sparing should grow and make the understanding the agricultural intensification-land-sparing relationship and alternatives as wildlife friendly farming (Fischer et al., 2008) a priority for social and environmental sustainability.

Less than 30% of the total biophysical potential for agricultural GHG mitigation might be achieved by 2030, due to price- and non-price-related barriers to implementation (P. Smith, Martino, Cai, Gwary, H Janzen, et al., 2007). Climate and non-climate policy in different regions of the world has affected agricultural GHG emissions in the recent past and may affect emissions and mitigation implementation in the future. Global sharing of innovative technologies for efficient use of land resources and agricultural chemicals, to eliminate poverty and malnutrition, will significantly mitigate GHG emissions from agriculture (P. Smith, Martino, Cai, Gwary, H Janzen, et al., 2007).

Acceptability by the farmers and practicability of the measures need to be considered because the efficiency of a policy is determined by the cost of achieving a given goal. Therefore costs related to education and implementation of policies should be taken into account (Jakobsson et al., 2002). In order to ensure effective GHG mitigation options, it is essential to identify policies that provide benefits for climate, as well as for aspects of economic, social and environmental sustainability. Improved nutrient management and nutrient use efficiency have a significant and cost-effective role to play in mitigating GHG emissions from agriculture. Nitrogen oxide (N_2O) emissions from soils are responsible for about 3 % GHG emissions and contribute approximately 1/3 of non-CO_2 agricultural GHG emissions. Emissions are often directly related to nutrients added to the soil in the form of mineral fertilizers and animal manure (see section 11.3). Nitrogen losses could occur via leaching, volatilization, and emissions to the atmosphere. Nutrient management can also help reduce methane (CH_4) emissions from rice and increase carbon sequestration in agricultural soils.

In many developed countries, environmental concerns since the mid 1990's led to an intensification of nutrient management research. As a consequence, many countries, or individual states, have adopted laws and regulations that now mandate improved agricultural nutrient management planning (Jakobsson et al., 2002). Although some of the soil-management strategies available may have positive effects, others may have negative social, economic, and environmental effects. The policies for energy, water, and food sectors are usually formulated by distinct groups of stakeholders with little interaction or understanding between them (Hussey and Schram, 2011). An assessment of the European Union relevant policy frameworks to assess potential synergies from various soil-management strategies, indicated that the encouragement of soil-management strategies would result in mitigation of GHG emissions but these synergies are currently not fully exploited at the EU policy level and options for better policy integration were identified (Henriksen et al., 2011). In terms of the effectiveness of environmental policies and agriculture, there was considerable progress controlling point pollution, but that the efforts to control non-point pollution of nutrients have been less successful.

Financial regulations are another approach to nutrient control. A range of instruments can be used: pollution charges; taxes on emission; taxes on inputs and subsidies (modified after Russel and Powel (1999) in (Russell, 2001). The complexity of the N cycle does not allow any measurement of the emission in a simple, inexpensive way but it is possible to consider a tax on the inputs to the nutrient cycle (N fertilizers). Subsidies are the financial instruments that are most commonly used to address nutrient pollution. Different types of subsidies can be distinguished: 1) lump sum payments for capital costs such as improvement of storage facilities or animal houses, 2) marginal subsidies for obtaining the desired results and 3) subsidies for achieving the required outcome. The lump sum payments are clearly most used in the nutrient management legislation.

In response to many different policy objectives, including climate change mitigation, energy security, and rural development, more than 50 countries worldwide have put in place targets and/or mandates for bioenergy (Petersen, 2008). The rapid increase of biofuels production worldwide has only been possible because of subsidies, excise exemptions, and other incentives from public authorities. In order to minimize possible negative impacts (deforestation for feedstock production, degradation of soil and air quality, increased water consumption, possible loss of biodiversity, possible competition with food production, and other potential social imbalances [AUTHORS: Reference will be added] coherent biofuel policies need to be promoted. Land use planning and governance is central to the implementation of sustainable biofuels (Tilman et al., 2009) as policy and legislation in related sectors, such as agriculture, forestry, environment and trade can have a profound effect on the development of effective bioenergy programs (Jull et al., 2007). Besides the relationships between bioenergy and sustainable development are complex, and depend on several factors, including the energy crop, method of cultivation, conversion technology and the conditions and alternatives in the specific country. Legislation that is vague could allow significant portions of the biofuels industry to develop along counterproductive pathways.

Box 11.1 Examples of new national plans for mitigation in the agriculture sector

Brazil - By the end of 2010, Brazil, the second largest food exporter, launched the national program Low Carbon Agriculture (LCA). Agriculture is the second largest source of greenhouse gas emissions in Brazil. In ten years, the program envisages a reduction of 104 Mt CO2 equivalent, from the actions taken in the sector alone. Besides recovering pastureland, the LCA program encourages the no-tillage system of farming and integrated systems (crops, livestock and forestry) among other activities. To put the plan into practice, about US$ 1 billion has been set aside by the Brazilian government for the first period of the program. The funds will be increased as demand by farmers grows.

Australia - In 2011, Australia's parliament endorsed the world's first national scheme that regulates the creation and trade of carbon credits from farming and forestry. The Carbon Farming Initiative (CFI) allows farmers and investors to generate tradable carbon offsets from farmland and forestry projects. Land use including agriculture accounts for 23% of Australian emissions. Projects can include tree plantations, cutting methane emissions from livestock, reducing fertilizer use and better fire management of northern grasslands. The Australian government estimated that the Carbon Farming Initiative would help cut Australia's carbon emissions by 460 million tonnes by 2050.

Several certification initiatives exist in agriculture (e.g. Sustainable Agriculture Network and Forest Stewardship) but the specificity of biofuels is due to its hybrid nature. Biofuels' pathways include several successive segments over the fuels' life cycle: (1) feedstock production, (2) conversion of the feedstock to biofuels, (3) wholesale trade, (4) retail, and (5) use of biofuels in engines. The multiple actors involved include the feedstock suppliers, biofuels producers, biofuels consumers who may partly buy biofuels produced abroad, and public authorities who regulate the sector and design and implement policy instruments for promoting sustainable biofuels. The length and complexity of the biofuel supply chains make the sustainability issue very challenging.

As biofuel targets often cannot be met nationally, global trade in biofuels, which is to some extent already taking place, might have a major impact on other commodity markets like vegetable oils or animal fodder, global land use change and environmental impacts (Zah and Ruddy, 2009). The international trade brought imports of biofuels–whether as feedstocks or liquids–into competition with domestic products. For instance, in Europe subsidies were paid on soybeans (later a feedstock for biodiesel) and sugar (later a feedstock for bioethanol) causing long trade disputes.

11.11 Gaps in knowledge and data

Data and knowledge gaps include:

- A global data base of the area of land use change and further fate of affected ecosystems
- A global, high resolution data base of typical land management practices
- A better characterization of global grazing areas, in terms of their quality, the intensity of use, management, including the GHG effects of changes in management
- Better data on agricultural management practices employed globally including crop rotations, variety selection, fertilization practices (amount, type and timing) and tillage practices
- More accurate data on C stocks in biomass for grasslands, croplands and wetlands, and C stocks in pools of dead organic matter and soils for different types of ecosystems around the world, including forests
- A global data base of fires, including forest fires (in particular large-scale and open forest fires), peatfires, fires on the grasslands and croplands with data on the amount of biomass burned
- Better data on GHG fluxes from managed and native wetlands and its mitigation potential
- Better data on and understanding of subsistence agriculture, in particular (but not only) for livestock rearing (herders) as well as shifting cultivation (large amounts of biomass burned in human-induced fires)
- Globally standardized and homogenized data on soil degradation and a better understanding of the effects of soil degradation on the productivity of vegetation
- Better data on forest degradation, in particular selective logging, collection of fuelwood and non-timber forest products and production of charcoal, grazing, sub-canopy fires, and shifting cultivation
- A better understanding of climate-change feedbacks on agricultural yields under real-world conditions, i.e. under nutrient limitation etc. At present, DGVMs provide limited understanding of feedbacks such as CO_2 fertilization and plant growth on croplands under different assumptions on fertilizer application
- A better understanding of the effect of current changes in climate parameters and rising CO_2 concentrations on productivity of different types of ecosystems around the world
- A better understanding of the role of mangrove forests in mitigation of climate change
- A global data set on the use of bioenergy and better understanding of its mitigation potential

- Potential changes of C stocks in different types of ecosystems around the world under various scenarios of climate change
- A better understanding of effects of different mitigation options on social and economic conditions of poor people, in particular on those living largely in subsistence conditions
- Prognosis of future global food security under various scenarios of climate change.

[AUTHORS: To be further developed for the SOD]

11.12 Frequently Asked Questions

[TSU: FAQ will be presented in boxes throughout the text in subsequent draft]

FAQ 11.1 How much does AFOLU contribute to GHG emissions and how is this changing?

Agriculture and land use change, mainly deforestation of tropical forests, contribute greatly to anthropogenic greenhouse gas emissions and are expected to remain important during the 21st century. At present, cumulative GHG emissions (mainly CH_4 and N_2O) from agricultural production comprise about 12% of global anthropogenic emissions. Annual C flux from land use and land use change activities accounted for approximately 12 - 20% of total anthropogenic greenhouse gas emissions with mean values of about 1.1± 0.9 Gt C / yr in the 1990s. The total contribution of the AFOLU sector to anthrpogenic emissions is therefore 24-34% of the global total.

FAQ 11.2 What are the main mitigation options in AFOLU and what is the potential for reducing GHG emissions?

In general, available top-down estimates of costs and potentials suggest that AFOLU mitigation will be an important part of a global cost-effective abatement strategy. However, potentials and costs of these mitigation options differ greatly by activity, regions, system boundaries and the time horizon. Especially, forestry mitigation options - including reduced deforestation, forest management, afforestation, and agro-forestry - are estimated to contribute between 1.27 and 4.23 Gt CO_2 / yr of economically viable abatement in 2030 at carbon prices up to 100 US$ / t CO_2-eq. About 50% of the mean estimates are projected to occur at a costs under 20 US$ / t CO_2-eq. (= 1.55 Gt CO_2 / yr). Global economic mitigation potentials in agriculture at 2030 are estimated to be up to 4.30 Gt CO_2-eq / yr at carbon prices of up to 100 US$/ t CO_2-eq, with a large proportion of the estimated economic potentials expected to arise from soil carbon sequestration.

FAQ 11.3 What are the barriers to reducing emissions in AFOLU and how can these be overcome?

The barriers to emission reduction are many fold. Firstly, mitigation practices may not be implemented for economic reasons (e.g. market failures, need for capital investment to realise recurrent savings), or a range of non-economic reasons including risk-related, political/bureaucratic, logistical and educational/societal barriers. Technological barriers can be overcome by research and development, logistical and political / bureaucratic barriers can be oivercome by better governance and institutions, education barriers can be overcome through better education and extension work networks and risk-related barriers can be overcome, for example, through clarification of land tenure uncertainties.

FAQ 11.4 How will decisions in AFOLU affect GHG emissions over different timescales?

There are many mitigation options in the AFOLU sector which are already being implemented, for example afforestation, avoided deforestation, cropland and grazing land management and improved livestock breeds and diets. These can be implemented now. Others (such as some forms of biotechnology and livestock dietary additives) are still in development and may not be applicable for a number of years. In terms of the mode of action of the measures, in common with other sectors, non-CO_2 greenhouse gas emission reduction is immediate and permanent. However, a large portion of the mitigation potential in the AFOLU sector is carbon sequestration in soils and vegetation. This mitigation potential differs, in that the measures are time-limited (the potential saturates), and the enhanced carbon stocks created are reversible and non-permanent. There is, therefore, a significant time component in the realisation and the duration of much of the mitigation potential available in the AFOLU sector.

FAQ 11.5 How will AFOLU be affected by climate change feedbacks?

The thawing permafrost and the resulting microbial decomposition of previously frozen organic carbon can be seen as one of the most significant potential feedbacks from terrestrial ecosystems to the atmosphere in a changing climate. Generally, climate change interactions with GHG emissions and mitigation options from AFOLU differ greatly by regions and time horizon. For example, CO_2 fertilization might increase terrestrial C uptake by global ecosystems, but as a result of increased fire events and climate-induced feedbacks the mitigation benefits from deforestation reduction or afforestation could be reversed. In addition, increased warming, changes in precipitation patterns, extreme events and CO_2 fertilization will affect agricultural yields (including bioenergy crops) in both directions – affecting land expansion rates on the cost of deforestation and associated emissions. Carbon sequestered in soils and vegetation, could be released under future climate, though the impact of climate change on future carbon stocks is uncertain.

FAQ 11.6 Are there any co-benefits associated with mitigation actions in AFOLU?

A: In several cases the implementation of AFOLU mitigation measures may result in an improvement in land management and therefore have socio-economic, health and environmental benefits: For example, reducing deforestation, reforestation and afforestation can improve local climatic conditions, water quality, biodiversity conservation and help to restore degraded or abandoned land. Minimum tillage for soil carbon sequestration may also reduce the amount of wind and water erosion due to an increase in surface cover. Further considerations on economic co-benefits are related to the access to carbon payments either within or outside the UNFCCC agreements and new income opportunities especially in developing countries (especially for labor intensive mitigation options such as afforestation).

FAQ 11.7 What are the top-down and bottom up models, and how can deviating results be explained/integrated?

[AUTHORS: To be completed when Ch6 results are available for SOD]

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