9 Land use, agriculture, and forestry

What is covered in this chapter?

Agriculture and forestry together are responsible for about 30% of greenhouse gas emissions, partly from loss of carbon from soils and vegetation and partly from agricultural activities producing methane and nitrous oxides. Demand for food is the dominant driver of developments in agriculture and deforestation. Food security has always been high on the political agenda as is visible in the strong reactions to recent increases in food prices. There is a large potential to reduce emissions. Increasing carbon in agricultural soils, livestock manure management and conserving carbon in forests by reducing deforestation, planting new forests, and better forest management can halve emissions by 2030 at reasonable costs. Policy actions to realize this potential can best be focused on reforming the many existing policies and create financial incentives for farmers and forest owners to change their practices. International climate policy instruments created by the Kyoto Protocol can contribute.

Land use trends

About one-third of global land is used for agriculture. Two-thirds of that land is grassland, one-third cropland. Forests cover about 25%. The rest (about 40%) is desert, tundra, ice, wetland, or other natural area, except for a small amount covered by urban areas (less than 0.5%). Over time shifts have occurred from forested land to agricultural land (cropland and grassland), consistent with the increase in the world population and the need for food. Over the last 40 years agricultural land has increased by about 500 Million hectare (Mha) or 10%. About half of this increase came from deforested land. Due to erosion, salt accumulation (often due to bad irrigation practices), and other processes about 20% of cropland and 10% of grassland is degraded[1]. For global land use for agriculture and forestry over the last four decades see Table 9.1.

Growing populations and improving incomes will increase demand for food. Increasing meat consumption[2] will further increase land requirements, because land use for a meat diet is much larger than that for a vegetarian diet. For 1 kg of meat 2–7 kg of grain is needed (7 for beef, 3.5 for pork, 2 for poultry, and about 1.2 for fish)[3]. It is

Table 9.1. Global land use for agriculture and forestry over the last four decades

Land use	Area 2001–2002 (Mha)	Area 1961–1970 (Mha)	Change (%)	Current rate of change (Mha/year)
Cropland (incl. permanent crops)	1535	1379	+9	
Grassland	3488	3182	+10	
Forest	3952	4126	−5	−7.3 (12.9 loss; 5.6 increase)
Desert, tundra, ice, wetlands	5850			

Source: IPCC Fourth Assessment Report, Working Group III, chapter 8 and 9; FAO Global Forest Resources Assessment 2005.

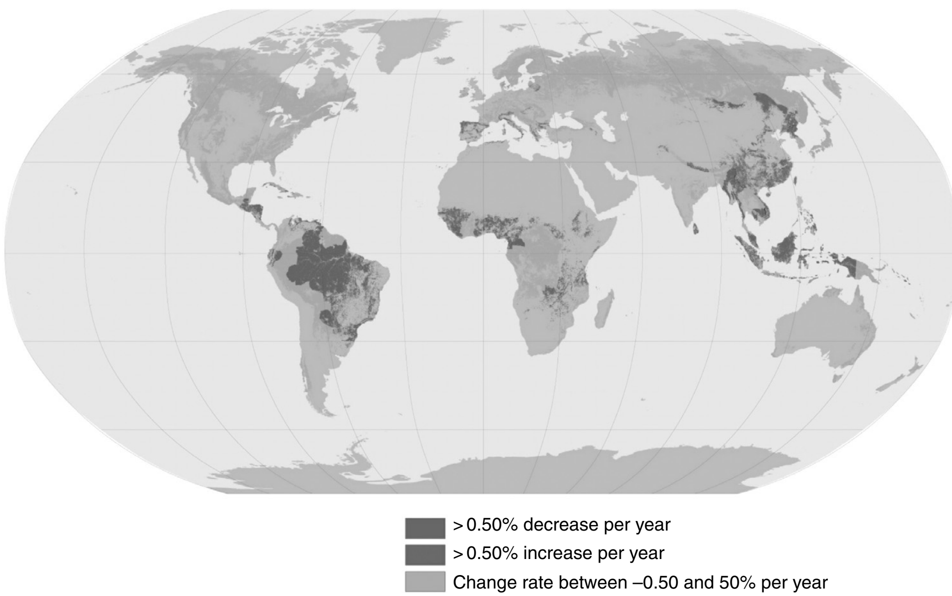


Figure 9.1 **Net change in forest area between 2000 and 2005.**
Source: FAO, Global Forest Resource Assessment 2005. See Plate 14 for colour version.

expected that another 400–500 Mha additional agricultural land will be needed between 2002 and 2020, even if crop productivity were to improve further[4].

Net loss of forest area (7.3 Mha/year) is the result of the difference between deforestation (on average about 12.9 Mha/year between 2000 and 2005) and the increase in newly forested areas (about 5.7 Mha/year)[5]. The largest losses are found in South America, Africa, and South-East Asia (see Figure 9.1). Most of the increase in forestation is in Europe and East Asia. Only part of the forests in the world is managed. Although in Europe 90% is managed, in developing countries more than 90% is unmanaged. Forest plantations only cover about 3% of the total forested area, but are growing by almost 3 Mha/year (more than half of the total forest area increase). About 30% of all forest land is degraded.

Land use and greenhouse gas emissions

Agriculture and forestry are very different from other economic sectors when it comes to greenhouse gas emissions. The reason is that agricultural soils and crops and forest represent enormous reservoirs of CO_2, in the form of organic matter and wood[6]. The amount of carbon stored in forest biomass and soils is larger than what is contained in the atmosphere. And much of that carbon is underground (see Figure 9.2). So emissions are not only determined by activities that generate emissions, but also by the loss or gain in these carbon reservoirs (absorbing CO_2 in vegetation and soils is called 'sequestration'). It is important to consider agriculture and forestry together, because of the interactions (more demand for food drives deforestation) and the coverage of lands that can be grouped under agriculture or under forestry (agro forestry and peat lands).

Figure 9.3 shows the man-made carbon fluxes together with the emissions of CH_4 and N_2O from agricultural practices and the amounts of carbon stored in reservoirs. The respective contributions are discussed below.

Agriculture

Emissions from agriculture consist predominantly of methane (CH_4) from animals, manure and rice production, and of nitrous oxide (N_2O) from nitrogen fertilizer application (see Figure 9.4). N_2O emissions from fertilized soils is the largest source (38%), followed by

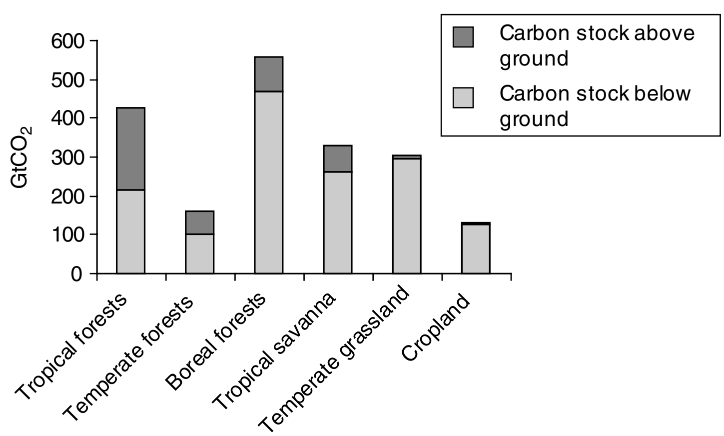


Figure 9.2 **Amount of carbon stored in agricultural and forest land.**
Source: IPCC Special Report on Land Use, Land Use Change and Forestry, 2000.

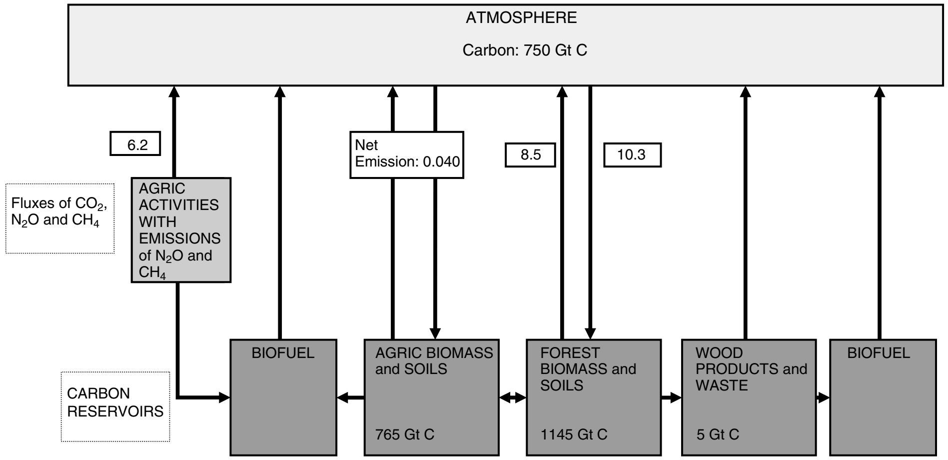


Figure 9.3 Schematic diagram of carbon reservoirs and emissions of greenhouse gases in agriculture and forestry. Reservoirs are expressed in Gt C. Fluxes are expressed in Gt CO_2-eq/year.

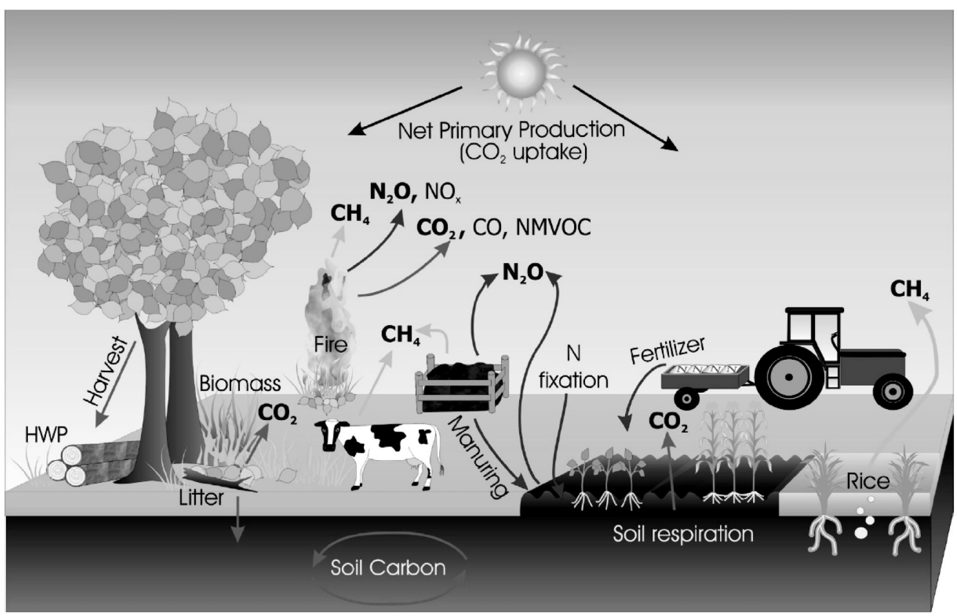


Figure 9.4 **Emissions from agriculture.**

Source: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4, Agriculture, Forestry and Other Land Use, chapter 1.

methane production in animals (32%), burning of crop residues (12%), rice fields (11%), and manure (7%). Although there are large amounts (fluxes) of CO_2 going into agricultural crops and soils, there are equally large fluxes going out (digestion and decomposition of agricultural crops and crop residues). The net flux is therefore small. Total CH_4 and N_2O emissions are about 6.2 GtCO_2-eq per year. Net CO_2 emissions due to the slowly decreasing carbon content of agricultural soils are less than 1% of that amount[7].

Regional differences in the magnitude and relative importance of CH_4 and N_2O emissions are large. Because of the importance of agriculture in developing countries and the large population, these countries are responsible for about 75% of all emissions. For rice production and crop residue burning the share is close to 100%. Emissions from manure are biggest in developed countries. Large livestock populations in Latin America, Eastern Europe, and Australia and New Zealand make this the dominant source in those regions.

Forestry

Emissions from the forestry sector are predominantly caused by loss from the large carbon reservoirs through deforestation and forest degradation (loss of trees due to selective logging or other disturbance), decomposition of wood residues, and some emissions of CH_4 from burning and N_2O from fertilized managed forests or forest plantations (about 5.8 $GtCO_2$/year), and dewatering and oxidation or burning of (deforested) peat lands (about 2.7 $GtCO_2$/year; see Box 9.1).

Wood products

Wood products are a temporary storage of carbon. Wooden houses, other structures and furniture, but also books, form a carbon reservoir of the order of 5 GtC. This is a very small amount compared to what is stored in vegetation and soils. Since wood products, including paper, have an average lifetime of about 30 years, the accumulation of carbon in wood products is limited. Wood products therefore have a very small contribution to emissions.

Biofuel

Biofuel or bioenergy is obtained from crop residues, crops, wood, or wood waste. If harvesting is done sustainably, biofuel does not contribute to emissions, since CO_2 is taken up again in the vegetation. In reality this sustainability assumption is not met, because of disturbance or fossil fuel use for harvesting and processing. Biofuel use therefore contributes to emissions. The amount depends on the specific situation.

Box 9.1 Peat lands

Peat lands are water logged, high organic soils produced by accumulation of rotting vegetation. In many countries a significant part of peatlands has been dewatered and is used for agriculture (see table below) or forest plantations. Together, agriculture and forestry are responsible for 80% of peat land loss; peat harvesting as fuel or soil supplement, urbanization and infrastructure, and flooding are responsible for the rest. Dewatered peat land produces CO_2 emissions through oxidation of organic material and through fires that keep burning underground (see picture) The biggest losses are now happening in Indonesia and Malaysia. Fires are responsible for about 2 Gt CO_2/year.

Peatland used for agriculture in selected countries

	Peatland used for agriculture (km^2)	% of total peatland
Europe	124490	14
Russia	70400	12
Germany	12000	85
Poland	7620	70
Belarus	9631	40
Hungary	975	98
Netherlands	2000	85
USA	21000	10
Indonesia	60000	25
Malaysia	11000	45

Source: Wetlands International et al. Assessment on Peatlands, Biodiversity and Climate Change, ch 3.

Peat fires.

Source: Wetlands International et al. Global Assessment on Peatlands, Biodiversity and Climate Change, 2007 and ScienceDaily.com, credit: Kim Worm Sorensen.

(Source: Wetlands International et al. Global Assessment on Peat lands, Biodiversity and Climate Change, 2007)

The total greenhouse gas emissions from agriculture and forestry are about 14.7 $GtCO_2$-eq/year, approximately 30% of the global total. The uncertainty of these numbers is high. Many of the emissions are not easily measured, such as N_2O from grasslands, CH_4 from rice production or savannah burning, and CO_2 from peat land and forest degradation. The real number could easily be several Gtonnes higher or lower.

Estimating future emissions is difficult. Agricultural emissions are going to increase, because of increasing food demand. Global grain demand is projected to increase by 75% between 2000 and 2050 and global meat demand is expected to double. More than three-quarters of growth in demand in both grains and meat is projected to be in developing countries[8]. The estimate is that emissions will go up from 6.2 to 8.3 $GtCO_2$-eq/year by 2030. How deforestation is going to develop is much more difficult to estimate. The best guess is that it will remain roughly at current levels until 2030 under a 'no climate policy' situation[9].

How can emissions be reduced and carbon reservoirs increased?

There are three broad categories of action that can be taken:

- Reducing emissions of CO_2, CH_4, and N_2O
- Increasing carbon reservoirs by increasing carbon in agricultural soils, agroforestry, and new and existing forests
- Using crops, crop residues, animal waste, wood cuttings, and wood waste as biofuel, replacing fossil fuel

In agriculture there are many specific actions that can deliver emission reductions. In many cases however there are complex relations between emissions of CO_2 and N_2O. In some circumstances emissions of N_2O could increase when CO_2 emissions are decreased, making the net effect uncertain.

The most important reduction measures are summarized in Table 9.2.

In addition to all the technical reduction options there is an important lifestyle option: change to a vegetarian diet. Vegetarian food requires less grains, land, and energy (for growing, transport, processing) than meat (see above). So changing to a vegetarian diet can avoid N_2O emissions from grasslands, CH_4 emissions from livestock and manure, CO_2 emissions from fossil fuel use, and free land for other purposes (forest, bioenergy crops).

In the forestry sector the most important actions that can be taken are summarized in Table 9.3.

Many of these actions take time to deliver results, since forest growth is slow. A disadvantage is that costs often have to be made up front and benefits come much later.

Table 9.2. Measures to reduce greenhouse gas emissions from agriculture

Category	Measure	CO_2	CH_4	N_2O	Net effect
Cropland management	Reducing ploughing, minimizing soil carbon loss	+		+/−	**
	Practices that increase returning crop residues to the soil, by leaving residues on the land and avoiding burning	+		+/−	**
	Keeping soils covered between crops and using legume crops to enhance nitrogen content of soils	+			***
	Better nutrient management, minimizing N_2O emissions	+		+	***
	Reducing CH_4 emissions from wetland rice cultivation by draining water from the field intermittently and addition of fertilizer in the dry phase	+/−	+	+/−	**
	Growing trees on farmland, in combination with livestock or food crops (agroforestry)	+		+/−	**
	Increasing the water table in drained cropland to reduce the conversion of organic soil matter into CO_2	+/−		+	*
	Set aside of part of the land for nature protection or environmental purposes, allowing increase of soil carbon	+	+	+	***
Grazing land management	Reducing fires	+	+	+/−	*
	Different grass varieties with deeper roots adding to soil carbon	+		+/−	*
	Reducing fertilizer use			+/−	*
	Increasing productivity by better water and nutrient application	+		+/−	**
Organic and peaty soils containing high carbon concentrations	Avoid draining these soils or re-establishing a high water table	+	−	+/−	**
	Minimizing ploughing of drained soils	+		+/−	**
	Keeping soils covered and avoiding tuber crops	+		+/−	*
Restoration of degraded land	Re-vegetation of eroded land	+		+/−	***

Table 9.2. (*cont.*)

Category	Measure	CO_2	CH_4	N_2O	Net effect
	Nutrient and organic matter application	+		+/−	**
Livestock management	Changing feed composition (more concentrated feed, less forage and feed supplements, such as certain oils); this reduces CH_4 emissions. Research is being done on other feed supplements		+	+	***
	Covering manure storage or composting solid manure (only for intensively managed livestock farming where herds are kept in a feedlot at least part of the time)		+	+/−	***
	(Longer-term) selective breeding of low CH_4 animals		+	+	**
Lifestyle options	Change to a vegetarian diet	+		+	***

+ indicates reduction of emissions; – indicates increase of emissions.
Net effect: more asterisks indicate higher net mitigation effect.
Source: IPCC Fourth Assessment Report, Working group III, table 8.3.

Table 9.3. Measures to reduce greenhouse gas emissions from forestry

Type	Measure	CO_2	CH_4	N_2O	Net effect
Maintain forest area	Reducing deforestation. This is by far the biggest contribution, given the big emissions from deforestation. Per hectare of forest maintained, 350–900 tonne of CO_2 emission is avoided	+	+		***
Increase forest area	The annual accumulation of carbon varies greatly between locations, tree species, and stage of the forest: it ranges from 1 to 35tCO_2 per hectare. Initially, when soils are disturbed prior to planting trees, soil carbon can be lost	+/−			***
Maintain forest density	Avoid forest degradation (preventing fires, managed	+			***

Table 9.3. (*cont.*)

Type	Measure	CO_2	CH_4	N_2O	Net effect
	logging, avoiding or reducing drainage of plantation soils)				
Increase forest density	Intensive management and nutrient application	+		–	**
	Increase the rotation period of forests	+			*
Wood products	Increase stocks of wood products and substitution of energy intensive materials by wood. This is a temporary gain in carbon reservoirs, because wood products eventually end up as waste. Some wood products however have a long life time (e.g. wooden houses, furniture) that does help to delay emissions	+			*

+ indicates reduction of emissions; – indicates increase of emissions.
Net effect: more asterisks indicate higher net mitigation effect.
Source: IPCC Fourth Assessment Report, Working group III, chapter 9.

How much can agriculture and forestry contribute to controlling climate change?

Agriculture

The (net) reduction of greenhouse gas emissions from agricultural options (see list in Table 9.2) depends on a lot of variables: climatic zone, existing practices, type of action, costs, time, etc. This means that effectiveness of mitigation strategies have to be determined locally. What works well in one place may not be effective elsewhere. In addition, information about reduction potential is limited for some regions and practices.

The relative contribution of measures till 2030 at the global level is shown in Figure 9.5. The economic potential is given[10] at three different cost levels (20, 50, and 100US$/t$CO_2$-eq avoided). In total this means that by 2030 about 4.3GtCO_2-eq/year can be reduced at costs up to US$100/t$CO_2$-eq. The figures are about 1.6 and 2.7 for costs up to US$20/t$CO_2$-eq and US$50/tCO_2-eq, respectively. The regional contributions to this global total vary. The relative contribution is shown in Figure 9.6. Most of the potential can be found in developing countries (about 70%).

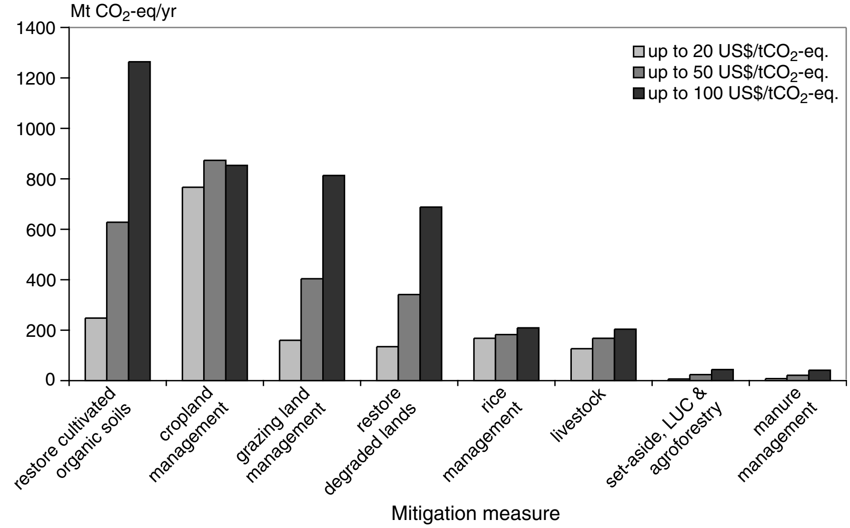


Figure 9.5 **Economic potential for greenhouse gas mitigation in agriculture at a range of carbon prices; based on SRES B2 sceanario.**
Source: IPCC Fourth Assessment Report, Working group III, figure 8.9.

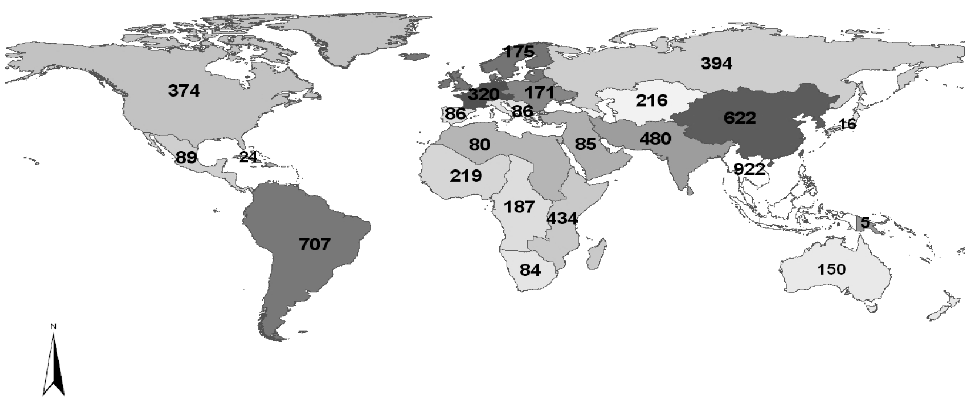


Figure 9.6 **Spread of mitigation potential for greenhouse gas mitigation in agriculture over different regions (numbers indicate relative importance of potential in regions); based on SRES B2 scenario.**
Source: IPCC Fourth Assessment Report, Working group III, figure 8.5.

About 90% of the total potential comes from increasing soil carbon reservoirs. This is completely the opposite picture to that for emissions, where CO_2 does not play a big role.

The potential of changing to a vegetarian diet is not included in these numbers. Data for the average per person emissions due to food consumption show a significant decrease of 1–2 tonnes of CO_2-eq per year when shifting towards a vegetarian or vegan diet (see Table 9.4). Numbers will differ from country to country, depending on food consumption patterns and the amount of energy used in the system.

Table 9.4. **US data on emissions from food consumption**

Type of diet	Annual emission per person from food consumption (tCO_2-eq/year)
Omnivorous diet	3.8
Mostly vegetarian diet	3.0
Vegetarian diet	2.7
Vegan diet	2.0

Source: http://www.conservation.org/act/live_green/carboncalc/pages/methodology.aspx

Forestry measures

Estimating the mitigation potential of forestry measures is difficult. One particular problem is that there is no scientific consensus on developments in the forest sector in the absence of climate policies. In particular future rates of deforestation are very hard to predict. So we do not have a very good idea of what difference specific measures will make.

The other big problem is that there are different methods to estimate a global mitigation potential for forestry: (1) from global forest sector models; and (2) from adding up regional bottom-up assessments. Global models assume population growth, income growth, changes in food consumption, and agricultural productivity increase, leading to a certain need for agricultural land. Then they calculate how much carbon release can be avoided compared to an assumed baseline by using land that is not needed for food production for forests, assuming a certain cost of forest management, afforestation, and avoiding deforestation for different regions. Regional bottom-up studies however start with existing forested areas and estimate what would happen to those areas with changing demand for food and with incentives for forest conservation in the form of carbon prices[11].

For the year 2030 global forest models calculate a 3 to 10 times higher reduction potential than bottom-up regional studies: 13.7 $GtCO_2$-eq/year (top-down) versus 1.3–4.2 $GtCO_2$-eq/year (bottom-up) for carbon prices of up to US$100/$tCO_2$-eq. These are large numbers when compared to the baseline estimate of 8.5 $GtCO_2$-eq/year by 2030. If the higher top-down numbers were correct this could lead to ‘negative emissions’ from the forest sector. Figure 9.7 shows the differences per region. Tropical countries represent about 65% of the total potential.

Among forestry experts there is widespread scepticism about the global forest sector model calculations. Assumptions are seen as too optimistic and specific regional circumstances are not adequately covered in those models. They generally have more trust in bottom-up methods. It is likely however that the bottom-up estimates incorporate barriers to realizing certain measures. Only a small percentage of what would be technically feasible is then incorporated in the estimate. In other words they probably are not giving pure economic potential estimates, but something that may be closer to a market potential (see Box 6.6). Another factor explaining the difference is that bottom-up studies are not covering all options in all regions. The true magnitude of the forestry

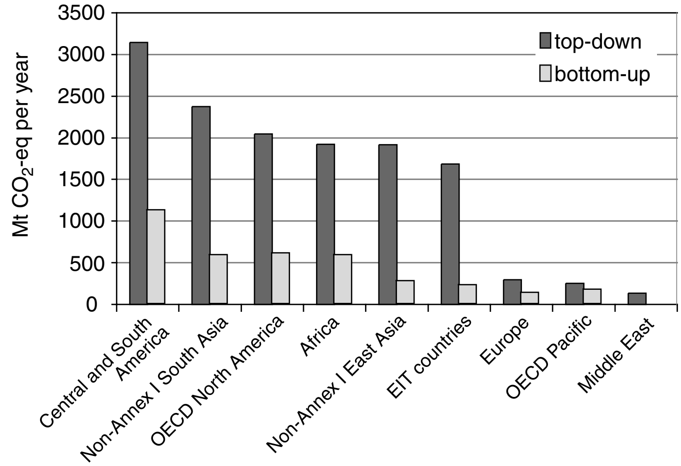


Figure 9.7 **Comparison of estimates for the 2030 economic potential of forest mitigation measures; 'top-down' estimates are from global forest models; 'bottom-up' estimates are from regional assessments.**
Source: IPCC Fourth Assessment Report, Working group III, figure 9.13.

sector mitigation potential is thus probably somewhere in the middle between the bottom-up and the top-down numbers.

Avoiding deforestation

Avoidance of deforestation represents a large share of the total mitigation potential. In South America and Africa it is by far the most important measure. Depending on the specific study, the cost level considered, and the timeframe, the contribution of reduced deforestation ranges from 30% to more than 50%. Studies for the Amazon region show that in the period up to 2050 about 40% of the Amazon forest would be lost without action and that this could be halved by an active forest protection programme, supported by financial incentives. This would avoid 60 $GtCO_2$ (i.e. more than 1 Gt per year on average)[12]. Costs are estimated to be relatively low compared to mitigation in other sectors: according to some global modelling studies for a carbon price of about US$30/$tCO_2$-eq almost 300 $GtCO_2$ could be avoided in the period till 2050 (i.e. more than 5 Gt per year on average).

New forests

The biggest potential for planting of new forests can be found in East Asia, the former Soviet republics, Central and South America, and Africa, with North America and Europe also providing substantial potential. It is a matter of availability of land and competition with the economic value of other land use (as affected for instance by agricultural subsidies), as well as land ownership and legal conditions. Estimates for the share of afforestation in the forest sector mitigation potential vary considerably,

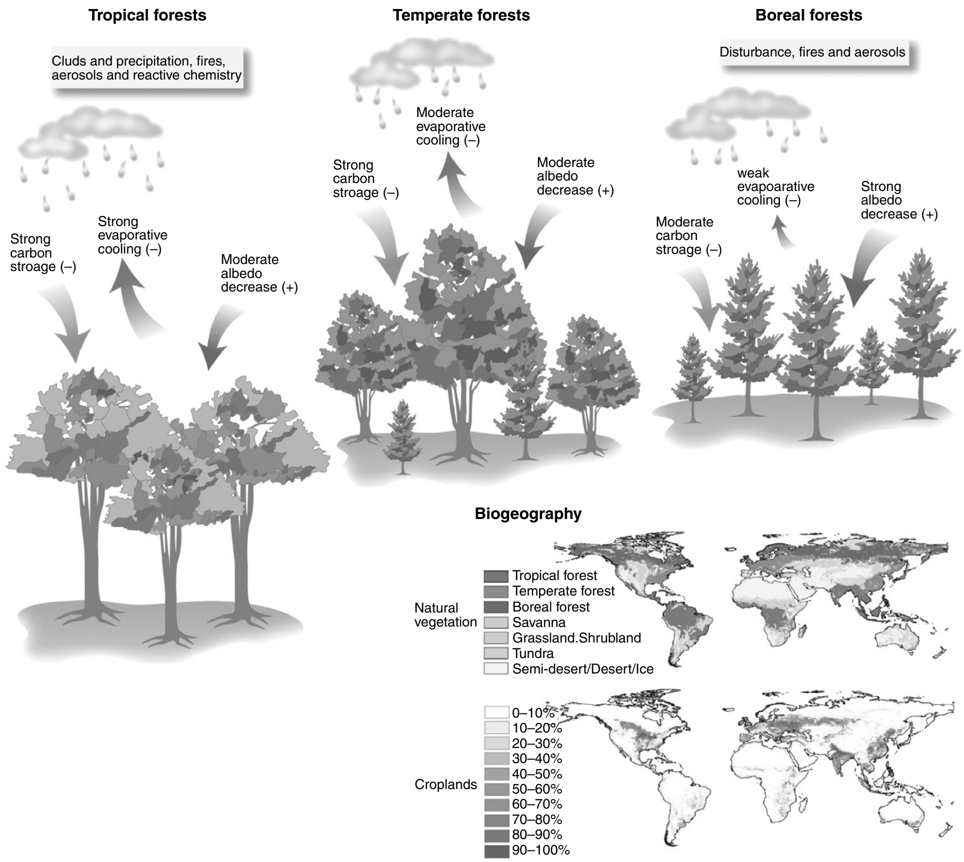


Figure 9.8 **The role of evaporation and reflectivity (albedo) in forests at different locations.**
Source: Bonan,et al. Forests and climate change: Forcings, feedbacks and the climate benefits of forests, Science, vol. 320, June 2008, p.1444. See Plate 15 for colour version.

because studies often combine the potential of new forest with that of better forest management. Russian forests are good for an economic potential in 2030 of about 0.2–0.5 $GtCO_2$/year at costs of up to US\$100/tCO_2 sequestered. In the USA 0.4–0.5 $GtCO_2$/year can be economically sequestered through new forests at costs of up to US\$100/tCO_2.

There are additional effects of planting new forests that can strengthen or weaken the effect of CO_2 sequestration: (1) evaporation of water that cools the air and forms clouds above a forest; and (2) change in reflectivity (albedo) of the land. In tropical forests evaporation is strong and clouds are formed (this is why large tropical forests generate their own rain). This has a cooling effect. In boreal forests the evaporation effect is small. A forest is darker so there is a reduced reflectivity of the land, leading to some additional warming in tropical and temperate climates. In northern areas however this decrease in albedo is much bigger, because trees do not have snow cover in winter, while grasslands do. The net effect of boreal forest planting is therefore much lower than would be expected based only on the carbon fixed (see Figure 9.8).

Forest management

Forest management consists of a range of measures, such as avoiding forest degradation by preventing and controlling fires, pest control, managed logging, avoiding or reducing drainage of plantation soils, thinning to enhance growth rates, nutrient application (partly offset by N_2O emissions), and increased rotation periods of forests. Effectiveness of measures is fully determined by local circumstances. Estimates of the total mitigation potential are therefore aggregates with a limited accuracy. In general the highest potential exists in North America, East Asia, and Russia, where management capacity exists and forest management is still underdeveloped. Global top-down models estimate forest management to be the biggest contributor to the mitigation potential in 2030, followed by afforestation and avoided deforestation.

Wood products

Substitution of steel or concrete by wood in construction can save up to 0.5 tonne of CO_2 per square meter of building floor space over the lifetime of the building. Wooden furniture and houses can keep carbon out of the atmosphere for periods of up to a century or more. Using the wood waste to generate energy does add to the mitigation effect. Every cubic metre of wood stored in the form of wood products keeps about 0.9 tonnes of CO_2 out of the atmosphere. But that is only temporary. When that wood is used in the waste stage to replace fossil fuel it can save 1.1 tonne CO_2 per tonne of wood used. Compared to the huge potential of forest conservation and forest expansion, the mitigation potential of these wood product measures is relatively small.

Overall potential

The overall mitigation potential is summarized in Table 9.5. There is a large uncertainty in the forestry mitigation potentials. Taking the lowest numbers however we can say that

Table 9.5. Total economic mitigation potential for land use and forestry

Contribution	Economic mitigation potential in 2030 ($GtCO_2$-eq/year)			Projected baseline emissions 2030 ($GtCO_2$-eq/year)
	At cost US$20/t	At cost US$50/t	At cost US$100/t	
Agriculture	1.6	2.7	2.3–6.4	8.3
Forestry	1.1–5.7	1.9–9.5	2.7–13.7	8.5
Wood products	Very small	Very small	Very small	
Total	2.7–7.3	4.6–12.2	5.0–20.1	16.8

Source: IPCC Fourth Assessment Report, Working Group III, chapters 8 and 9.

in agriculture and forestry about 30% of the projected emissions by 2030 can be reduced at costs lower than US$100/t$CO_2$-eq.

What can bioenergy contribute?

The mitigation effect of modern bioenergy[13] is realized mainly in the energy supply and transport sector. That is where the replacement of fossil fuel emissions happens. Chapters 5 and 6 discuss this in detail. The supply of biomass however comes mostly from the agriculture and forestry sector, except for some waste from households and industrial processes. The big question therefore is how much biomass can be supplied in a sustainable manner, so that food security, biodiversity protection, and water supply are not threatened. The other main question is what is the net carbon gain after subtracting the energy and emissions created by planting, managing, harvesting, transporting, and processing the biomass? The supply issue will be discussed here, but the energy balance question is discussed in Chapters 5 and 6.

As Figure 5.16 shows, the main sources of biomass are crop residues, energy crops, animal waste, and wood processing and paper making waste. Data for the biomass energy that can be produced are scarce. Indicative data are available only for 2050. Table 9.6 shows a total of 125–760 EJ/year (same order of magnitude as the total global energy use in the year 2005) and gives indicative numbers for the various sources. Since agriculture can respond quickly, these supply rates could in principle also be delivered in 2030. Crop productivity increases (of the energy crops and of the food crops that determine the availability of surplus land) would however be lower, so that the total sustainable supply for 2030 is somewhat lower than for 2050.

Comparing these supply data with demand estimates for 2030, in Chapters 5 and 6 it was concluded that biomass supply is not the limiting factor for the use of bioenergy. Demand for bioenergy is the limiting factor, caused by the relatively high cost of bioenergy compared to other alternatives.

Some doubts have been raised recently about the validity of this conclusion as food prices have increased sharply (see Figure 9.9). Are bioenergy crops causing these food price increases? Let's have a closer look.About one-third of the US maize production and more than half of the EU rapeseed production is now being converted to biofuels[14]. This suggests a considerable influence on food commodity prices. However, worldwide only 5% of oilseeds and 4.5% of cereals are used for biofuel production. Estimates of the contribution of biofuels to food price increases vary enormously. A contribution from biofuels to recent grain price increases of 30% is seen by most analyses as the maximum on average, with maize contributing much more than wheat[15]. This does not mean however that there is a structural scarcity of land for food production. There is general consensus that poor harvests, export bans, and neglected agriculture in many countries contributed strongly to the recent price increases. The productivity especially can be influenced by agricultural policy. There does not seem to be good reason to doubt the potential for bioenergy supply in the future as discussed above.

Table 9.6. Biomass supply estimates for 2050

Sector	Source	Potential supply 2050 (EJ/year)[25]
Agriculture	Crop residues	15–70
	Dung	5–55
	Energy crops	20–400
	Energy crop degraded lands	60–150
Forestry	Forest residues	12–74
Waste management	Organic waste	13
Industry	Process residues	n/a
Total		125–760

Source: IPCC Fourth Assessment Report, Working Group III, table 11.2.

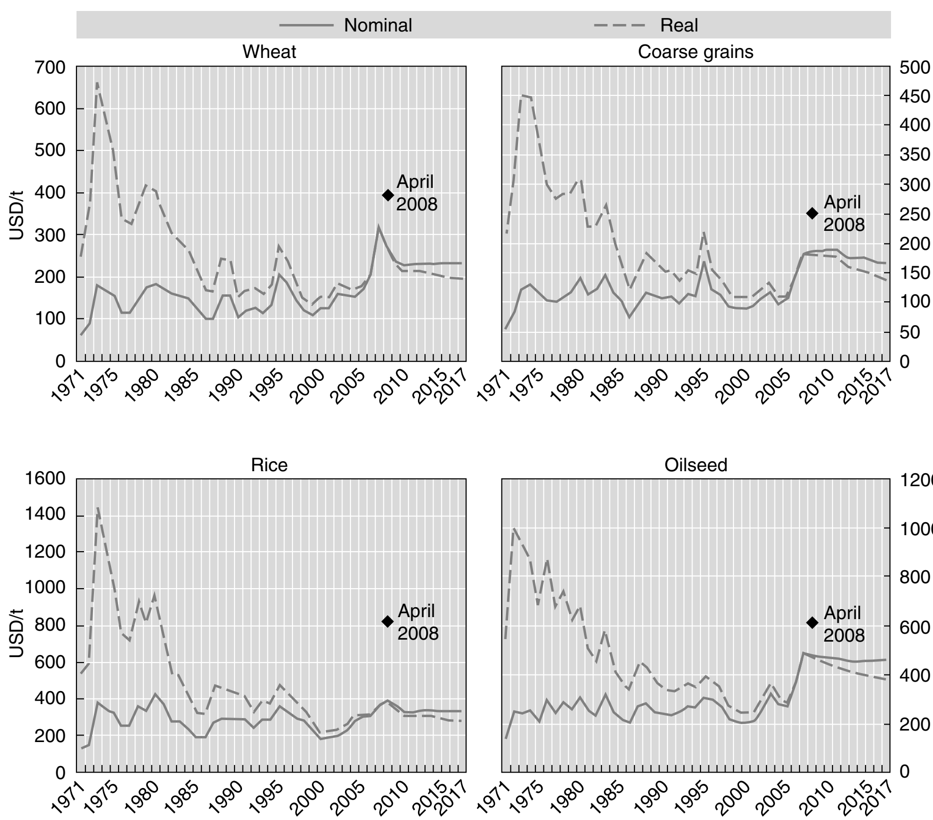


Figure 9.9 **Food prices 1971–2007, April 2008, and projection till 2017. Both the nominal as well as the real (= corrected for inflation) numbers are given.**
Source: OECD/FAO Agricultural Outlook, 2008–2017.

What policies are available?

Agriculture and forestry are heavily regulated: in agriculture, because food security (the guaranteed supply of adequate food) is generally seen as politically very important; and in forestry, because forests are a common good, often located on public land. This has led to a variety of regulations, price controls, subsidies, and other policy actions. This high policy density has important implications for ways of reducing greenhouse gas emissions from these sectors.

Agriculture

In agriculture, price signals are the primary factor that influences agricultural practices. And these price signals do not only come from the markets. In agriculture, subsidies play a dominant role: subsidies for production of crops or animal products, subsidies for export of agricultural products, subsidies for food processors to keep basic food affordable for poor people, and subsidies to 'set-aside' land for reasons of price control or erosion prevention (e.g. the Conservation Reserve Program (CRP) in the USA was introduced in 1985). There are non-price policies as well, such as quota systems (putting a maximum on production) and 'set-aside' rules, meaning requirements for farmers to leave a percentage of the land idle. Soil fertility policies are in place in some countries to combat and prevent soil erosion (such as China's Grain for Green programme, initiated in 1999 by the central government to address concerns about erosion, water retention, and flooding[16]), ecological policies to maintain or rebuild hedges and wooded strips or keep water tables high, and water quality policies that limit fertilizer application. Air quality policies have led to bans on burning of crop residues and grasslands in the EU and South Africa.

In addition, agriculture is very sensitive to macro-economic policy changes. When currencies were devaluated in South America in the 1970s and exports were promoted to restore trade balances, the result was a strong increase in large scale mechanized crop production and meat production. This contributed strongly to the massive deforestation. The economic restructuring of the countries of the former Soviet Union and Eastern Europe in the 1980s and 1990s led to drastic reductions in agricultural production. Oil import and employment considerations led Brazil to start its alcohol from sugar cane programmes in the 1970s[17]. Similar forces are at the origin of the current US ethanol from corn programmes (subsidy driven). Subsidy removal in agriculture in Australia and New Zealand in the 1980s[18] led to a substantial reduction in agricultural production.

Specific climate policies aiming at reduction of N_2O and CH_4 emissions are basically non-existent. And it would also be ineffective to add a set of new policies to the vast array of existing policies. By far the best approach is to change existing policies to create the right incentives to reduce greenhouse gas emissions, but with one exception: application of international Clean Development Mechanism policies that would generate funding for specific management changes leading to reduced emissions (see

Chapter 12). Use of domestic greenhouse gas emission trading programmes could also be considered[19].

What are the most promising policy changes in agriculture? Since most of the reduction potential in agriculture is in the form of soil carbon enhancement, we have to look for policies that can effectively promote that. Strong candidates are[20]:

- Banning burning of crop residues and grasslands as has already been implemented in China, South Africa, and the EU. They have benefits for air quality improvement. Since farmers do the burning in the belief that it releases nutrients more quickly, information programmes and other support may be needed to help farmers comply with such bans
- Set-aside policies as practised in the USA and EU: they have additional advantages for improving the ecological conditions in rural areas. With current high food prices there is a tendency however to abandon them (as the EU is currently considering[21])
- Soil fertility policies in the form of promoting reduced/zero tillage (practised in Brazil, Argentina, Uruguay, and Paraguay)
- Banning the dewatering of organic (peat) soils and restricting the use of such soils (no ploughing, no tuber crops)
- Subsidies for raising the water table in organic soils, to compensate for loss of productivity, as practised in parts of the Netherlands
- Mandatory land restoration of degraded lands, such as through China's Land Reclamation regulation of 1988
- Acquisition by State or private organizations of agricultural lands for nature conservation purposes and managing those lands as protected areas (as done in China and many other countries for wildlife or water quality management)
- Agricultural research and outreach to inform farmers about better farming practices

Promising policies to limit CH_4 and N_2O emissions include:

- Regulations on mandatory storage of manure (in feedlot operations) and subsidies for biogas installations (The Netherlands)
- Information programmes on vegetarian diets and alternatives for meat
- Subsidizing or regulating reduced fertilizer application in ecologically sensitive areas
- Air quality regulations controlling nitrogen oxides and ammonia from agriculture for reasons of air quality improvement (UN Convention on Long-Range Transport of Air Pollution)

Forestry

The role of price signals in forestry is even stronger than in agriculture. It is very profitable to convert forest into crop or grazing land, because the financial returns on the land can increase more than a hundred times when turning a forest into an oil palm plantation (see Figure 9.10). Implementation and enforcement of regulations on deforestation have been weak, in some countries because of corruption amongst officials. Controlling deforestation on private lands is difficult in many countries.

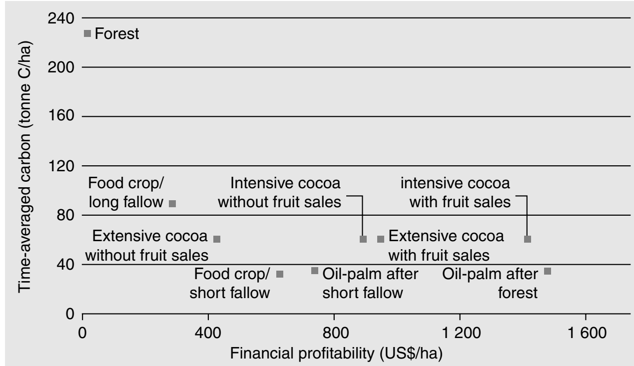


Figure 9.10 Profitability of changing forest into agricultural use and loss of carbon (tonne C/ha); case of Cameroon.

Source: FAO, The State of Food and Agriculture: paying farmers for environmental services, 2007.

International certification schemes for sustainably produced wood are still fragmented, strictly voluntary, and only affect a small percentage of the trade in wood. That is why most policies to reduce deforestation so far have been ineffective.

The general consensus is that stronger financial incentives than currently available will be able to reduce deforestation. The idea is that payment for maintaining a forest is justifiable because that forest provides environmental services in the form of acting as a carbon sink, keeping an amount of carbon out of the atmosphere, and preserving biological diversity as well as providing clean water. Costa Rica for instance introduced an environmental service payment system in 1997 (see Box 9.2). On the other hand moral objections are raised against these payments, because forest preservation is in the self interest of societies, given the important services they provide, and because forest preservation is often mandated by national and international law. The joint government–local community programmes for forest protection in India have been built around this principle (see Boxes 9.2 and 9.3).

Box 9.2 Forest protection in Costa Rica

Costa Rica is one of the few countries in Latin America to promote reforestation through incentives such as tax credits, direct payments, and subsidized loans that have benefited landowners, large and small. Among the important steps Costa Rica has taken are the following:

- The Natural Resources Administration has merged the administration of forest and protected area activities into one unified organization
- It has successfully developed a National System of Protected Areas that has a minimum of infrastructure and an institutional presence in each region of the country
- The National Forest Fund was established to handle financial issues for forests and natural resources

- Important legislation has been passed to protect the nation's forests, including the Environment Law, the Biodiversity Law, and the Forest Law
- The 'polluters pay' principle was introduced through the establishment of a tax on fossil fuels to pay for environmental services
- Many efforts have been made to protect biodiversity and generate income from it
- The Costa Rican Office of Joint Implementation was established to trade carbon emissions in the international market and Carbon Tradable Offset Certificates were developed that could serve as a model for trading other environmental services
- The government instituted a national system to certify good forest management practices
- Costa Rican forest owners have strong organizations that give them technical support for reforestation, forest management, and forest conservation. In recognition of this, Costa Rica has delegated much responsibility for forest management and conservation to private landowners

(Source: http://lnweb18.worldbank.org/oed/oeddoclib.nsf/DocUNIDViewForJavaSearch/A25EFCF3220878D585256970007AC9EE)

Box 9.3 **Forest protection in India**

Joint Forest Management (JFM) is now a principal forest management strategy in India. In June 1990 the government issued a resolution that made it possible for state forest departments to formally involve people in forest management through JFM1. In return for providing improved forest protection, communities receive better access to non-timber subsistence forest products and a share of net commercial timber revenues. The state retains most of the control and decision making over forest management, regulation, monitoring, timber harvesting, and forest product marketing. The government views JFM as a pivotal strategy for addressing the national policy goal of achieving 33% forest cover by 2012 (22% in 2005). The main focus of JFM in India is forest protection and conservation.

(Source: http://siteresources.worldbank.org/INDIAEXTN/Resources/Reports-Publications/366387–1143196617295/Chapter-1.pdf)

Increased forest planting (afforestation) has been reasonably successful in several regions, particularly in China, Korea, and parts of Europe. In total 5.6 Mha of forest were added worldwide per year in the period 2000–2005. Government policies have been the key factor. Successful policies often serve the purpose of combating erosion (e.g. the Chinese forest planting programme in desert prone areas), or producing wood for local communities (the Indian Joint Forest Management strategy). To overcome the barrier of high upfront investment in tree planting for private land owners, governments often use investment subsidies on planting or tax deductions on investments as the primary policy instrument. In areas where demand for food is high, such afforestation programmes can only work if agricultural productivity goes up. Appropriate agricultural policies therefore are a necessary condition for successful afforestation.

Forest management to increase carbon stocks is a complex issue, where policy approaches are generally very location specific. For public forest lands management is usually entrusted to a State agency and changing the management practices is then a matter of government instructions to such agencies. On private lands policy instruments have limited effect. Capacity building programmes to educate forest managers are often used in such circumstances. Some countries, such as Costa Rica, have had success with paying forest managers for improved (carbon) management (see Box 9.2). In general, better forest management has limited potential in industrialized countries, where forest management is already quite intensive. In developing countries the potential is much bigger, but there the capacity for better management is not available[22].

Kyoto Protocol policy instruments

The Kyoto Protocol contains several possibilities to create incentives for emission reductions in agriculture and forestry. The most important is the Clean Development Mechanism (CDM, see also Chapter 12). It allows countries with emission limits under the Protocol (the so-called Annex I industrialized countries) to invest in projects in developing countries that reduce emissions and contribute to sustainable development. The reductions realized can then be deducted from their own emissions. Under the current rules, projects on reducing methane from animal waste and afforestation and reforestation projects are eligible under the CDM. The effect is that there is a bonus of about US\$10/tCO_2-eq avoided for such reduction projects in developing countries, which makes some projects financially attractive. So far only limited use has been made of the CDM in the agriculture and forestry sector. The main reason is the complex procedures to get approval for CDM projects and the exclusion of many agriculture and forestry measures from the CDM. Agricultural soil carbon enhancement, the biggest mitigation option in agriculture, is for instance not accepted so far. Measurement problems for N_2O from fertilized soils make it very hard to include this type of mitigation measures in the CDM.

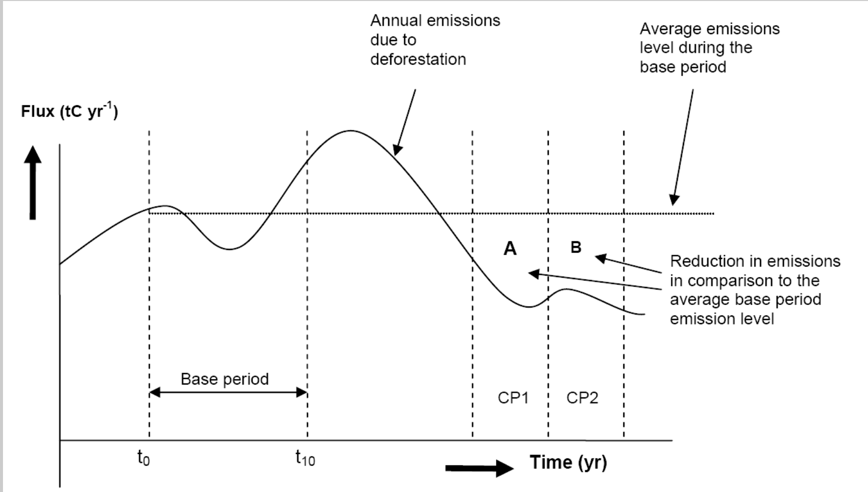
New international policy instruments

Intense discussions are being held on the possibilities to create a new instrument (usually called REDD = Reducing Emissions from Deforestation and Forest Degradation[23]) to stimulate forest conservation under the Kyoto Protocol or its successor agreement for the period after 2012. The main reason is that avoidance of deforestation has such a big potential to reduce CO_2 emissions. It requires overcoming a range of difficulties that have prevented the inclusion of avoided deforestation in the current Kyoto Protocol. The difficult questions are:

- *How to determine a baseline of deforestation in a country*? Is it reasonable to assume continuation of current deforestation rates and give countries credit for any slowdown of deforestation? Or are there good reasons to say that it is the responsibility of the country to reduce the deforestation rate or even to stop deforestation altogether? When applied to forest degradation, determining a baseline is even more complicated (see Box 9.4).
- *How to avoid leakage*? Leakage refers to the phenomenon that deforestation is reduced in a certain region of a country, while elsewhere in that same country deforestation increases. Even if deforestation is reduced overall in a country, then how can we avoid its increase in another country?
- *Will the forest remain in the future*? If credit is given for retaining the carbon stock in a forest, how can we guarantee that it is not disappearing in the future (with all of the carbon still ending up in the atmosphere)?
- *How to measure the carbon stocks maintained?* As discussed above, carbon stocks are to a large extent underground. In addition carbon stocks in forests vary considerably from place to place. And when we look at forest degradation, measuring carbon stocks is even more difficult.
- *How to monitor implementation?* In light of the risk of leakage do we need to accurately monitor forests country wide, or even in the whole world? Are the current forest monitoring systems, as used by the FAO for its regular forest assessments, adequate or are new and more precise methods needed?
- *How to create financial incentives?* There are in principle various ways to operationalize an REDD system. It could be coupled to the existing carbon market, i.e. credits from avoided deforestation or degradation could be sold internationally to countries or companies that are subject to emission limits and trading systems. This could be done on a project by project basis as in the CDM; it could even be integrated in the CDM. To reduce the risk of leakage it could also be done on a country wide basis.

Box 9.4 **Crediting for reduced deforestation**

In its simplest form a baseline is established of emissions due to deforestation in a base-period. Then any reduction over a certain commitment period compared to the baseline is credited to the country (see figure). More sophisticated approaches could take a declining baseline or an increasing domestic share of avoided deforestation.



Solid line indicates annual emission levels due to deforestation. The dotted horizontal line is the average emissions during the base period. Area A is the reduction in emissions during the first commitment period below the base period's emission level. Area B is the same but in the second commitment period, if there was to be one.

Source: Trines E et al. Integrating agriculture, forestry and other land use in future climate regimes: Methodological issues and policy options. Report 500102 002, Netherlands Environment Assessment Agency, October 2006.

Interaction with adaptation and sustainable development

Mitigation action in the agriculture and forestry sector can help reduce the vulnerability to climate change. Increasing soil carbon in agricultural soils will make them more drought resistant. The same applies to forest conservation. Large forest areas, especially in the tropics, create their own climate and rainfall through evaporation and cloud formation. Forest conservation and expansion also helps protect biodiversity, which will be under stress when the climate changes. Forest fires and insect plagues, which are likely to increase in a changing climate, can be countered with better forest management. Bioenergy crops can provide farmers with an additional source of income that can help them compensate reduced incomes from other crops when yields go down due to higher temperatures and more irregular rainfall.

It depends however on the way these mitigation actions are performed. Forest plantations that replace a primary forest always lead to loss of biodiversity[24]. More intensive management of forests will also harm biodiversity by disturbance and the effect of fertilizer. Bioenergy crops could harm biodiversity if grown on former grasslands or marginal unused lands.

So what does this mean for the role of agriculture and forestry?

A few key points stand out. First, in agriculture and forestry the stocks of carbon in soil and vegetation are more important than the emissions from activities. This plays a role in emissions caused by deforestation, but also in measures to absorb CO_2 from the atmosphere in soils and vegetation.

There is uncertainty about emissions from agriculture and forestry, particularly from the forest sector. You can find quite different numbers in various publications. The contribution by peatlands is not always included and is very uncertain. Agriculture emissions of CH_4 and N_2O are also much more uncertain than CO_2 emissions from energy use. Emissions from agriculture and forestry are large however.

The uncertainty of the economic mitigation potential is also large. Estimates for the forestry sector vary by almost a factor of 10. Again, they are very large, and if the optimistic estimates are correct, this could create large negative emissions in the forestry sector. For agriculture the biggest contribution comes from enhancing the soil carbon content.

In terms of policies needed to capture the mitigation potential, this sector is quite different from others. Given the presence of extensive existing regulations, it is more important to adjust existing (non-climate) regulations than to invent new (climate) policies. There is one important exception though: additional financial incentives in forestry can make a difference in terms of reducing deforestation, forest planting, and better forest management. And these financial incentives will have to come from new international climate change mechanisms. Actions to reduce emissions from agriculture and forestry go hand in hand with adapting to a changed climate.

Notes

1. FAO, http://www.fao.org/newsroom/en/news/2008/1000874/index.html.
2. In developed countries 56% of protein is obtained from animal products; in developing countries this is about 30%. With increasing incomes in developing countries it is expected they will move towards the dietary pattern of developed countries; see IPCC WG III, table 8.2.
3. See Brown LR. Outgrowing the Earth: The Food Security Challenge in an Age of Falling Water Tables and Rising Temperatures, W.W. Norton & Co., NY, 2005.
4. IPCC Fourth Assessment Report, Working Group III, ch 8.2.
5. IPCC Fourth Assessment Report, Working Group III, ch 9.2.1.
6. $1\,m^3$ of wood contains on average 0.92 tCO_2.
7. Emissions from farm machinery and trucking are covered under the transportation sector.
8. International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD), Global Summary for Decision Makers, 2007.
9. IPCC Fourth Assessment Report, Working Group III, ch 9.3.

10. See Box 6.6 for definition of economic potential.
11. If there is a carbon price as a result of policy to limit greenhouse gas emissions, forest sector managers have an incentive to manage their forests better, plant new forests, or to avoid deforestation. This works through a system of tradable emission permits. Industrial installations can then opt to buy permits from foresters that avoid emissions or fix CO_2 in trees, instead of taking their own measures (if forest measures are cheaper).
12. IPCC Fourth Assessment Report, Working Group III, box 9.1.
13. Traditional biomass is not considered to be a mitigation option, because it is often unsustainably harvested. Its use is declining as incomes of people in developing countries grow. Its use is still large however providing about 7.5% of total primary energy (see Chapter 5). Improving the efficiency of wood stoves however is a mitigation option discussed in Chapter 7 on the buildings sector.
14. See USDA Foreign Agricultural Service, EU-27 Oilseeds and Products, Annual Report 2008, http://www.ebb-eu.org/stats.php, and http://www.esru.strath.ac.uk/EandE/Web_sites/02–03/biofuels/quant_biodiesel.htm.
15. See Banse M, Nowicki P, van Meijl H. Why are current world food prices so high? LEI Wageningen UR, Report 2008–040, Wageningen 2008.
16. FAO, State of Food and Agriculture, 2007.
17. See Chapter 4, Box 4.2.
18. http://www.newfarm.org/features/0303/newzealand_subsidies.shtml.
19. New Zealand is planning to include agriculture in its emission trading system, see Kerr S, Ward M. ‘Emissions Trading in New Zealand: Introduction and Context, 2007, see http://www.ecoclimate.org.nz/ETS.htm.
20. IPCC Fourth Assessment Report, Working Group III, ch 8.6.
21. See http://ec.europa.eu/news/agriculture/080520_2_En.htm.
22. IPCC Fourth Assessment Report, Working Group III, ch 9.6.3.
23. http://unfccc.int/methods_science/redd/items/4531.php.
24. See Stokstad E. ScienceNews, Vol 320, 2008, pp 1436–1438.
25. 1 Exajoule (EJ) = 10^{12} Joule; see chapter 5, Box 5.1.