Climate Strategies

CARBON SINKS AND BIOMASS ENERGY PRODUCTION:

A study of linkages, options and implications

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Special note

This report was drafted prior to the resumed session of COP6 in Bonn in July 2001 and so does not take account of the political agreement. It may nevertheless be relevant to assessing activities which have both a biomass energy and a sinks aspect

CARBON SINKS AND BIOMASS ENERGY PRODUCTION:

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Introduction and overview: Carbon sink debates and bioenergy contributions

Introduction

Whether, and if so how, to allow emissions to be offset against absorption by carbon sinks has remained one of the more enduring points of dispute in the Kyoto Protocol negotiations – both before and after the Protocol was agreed. The Protocol confirmed that certain categories of sink would be accepted but debate has continued in relation to scientific uncertainties and disagreements about the value, monitorability, reliability, durability and acceptability of carbon sinks in relation to emission reductions. The rules for accounting of afforestation, reforestation and deforestation under the Protocol's Article 3.3 have in principle been agreed. At the Hague conference however, disagreement about whether and how to account for other categories of sinks under the 'catch all' Article 3.4, and the possible inclusion of sinks as eligible in the Clean Development Mechanism, were amongst the causes of collapse. At the same time, some carbon sinks play a largely unremarked role in global energy trends. Biomass energy – from plants, chiefly (but not exclusively) forests – is by far the largest category of renewable energy use, particularly in developing countries, with both traditional (fuelwood) and modern (e.g., ethanol and cogeneration) uses. Moreover new technologies can greatly increase the efficiency of such biomass utilisation, and many scenarios of globally sustainable energy developments portray a huge growth in the use of biomass energy, to contributions on the order of 100 (+/- 40) EJ/yr – about a quarter of current global energy supply - by 2025, with continuing growth thereafter (to a range of 95 – 280 EJ/year by 2050; e.g. IEA, IIASA, IPCC, WEC, Shell, Greenpeace, UNDP as reviewed by Hall and Scrase, 1998[5])

Yet, what crop should this large quantity of biomass energy be derived from, if not from reforestation and revegetation which constitute carbon sinks? Could the rules governing carbon sinks encourage such developments, as a major route towards displacing fossil fuel use? And what might be the implications of biomass energy growth for the development of carbon sinks?

Carbon sinks and biomass energy: linkages and concerns

Biomass energy is often assumed to be a carbon neutral source, with all the carbon absorbed during growth being emitted in combustion. In fact this is rarely precisely true. Biomass energy projects that extract carbon from existing forests tend to somewhat reduce the carbon stocks and can therefore, temporarily, constitute a net source. Conversely, projects that involve establishing new crops on previously unforested lands will generally involve carbon accumulation for some period – in the case of wood-based crops, several years – before combustion; and the equilibrium level of above-ground carbon stock may be substantially different from that without such activity. In addition, several forms of biomass energy may result in changes in soil carbon (both positive or negative) potentially over long periods.

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[5] Obviously this would involve large land areas. Significant amounts of land could be available for afforestation/reforestation or energy plantations. Estimates for land availability are in the range 250-950 Mha (assuming an average yield of 15dry tones/ha/yr and a 18 GJ/dry tonne calorific value leads to an energy potential between 68 and 256 EJ).

Proponents of sinks have argued that they offer a low-cost way of meeting emission commitments under the Kyoto Protocol, and that it would be foolish to exclude such low-cost options; some countries have made it clear that their ratification depends upon some degree of sink crediting. Critics contend that carbon sinks are a distraction from the core business of limiting greenhouse gas emissions from energy systems (note: not deforestation), and raise a wide range of concerns, with elements of both pragmatism and principle.

One general objection is that crediting for sinks undermines the effective strength of emission commitments under the Kyoto Protocol. We do not attempt an economic analysis of this larger question; though we note that, obviously, if the Protocol proceeds without the US initially, overall demand in the Kyoto system will be much lower, and the inclusion of lax rules on sinks could further undermine emission credit prices to levels that would preclude significant additional investments emissions reductions and energy sector investments. [6]

Climate change specialists point to the difficulty of monitoring the real additional carbon benefits and related problems of leakage arising from activity displacement (issues which may also arise in certain energy projects). In addition, particularly concerning sinks in the Clean Development Mechanism, development specialists question the compatibility of some kinds of carbon sink projects with local sustainability needs, due to potential land use conflicts, and fear the consequences if powerful western companies have a vested interest in setting aside land for carbon absorption rather than local production. Environmental objections also include fears about the biodiversity and related implications of monocultures and activities aimed purely at carbon absorption.

Beyond these specific objections, there are deeper concerns about the relationship between carbon sinks and the long-term objective of atmospheric stabilisation. At the project level, carbon sinks could be reversed, for example in the event of forest fire or

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[6] The IPCC Special Report on LULUCF suggests that with continuation of conversion rates in the 80s and 90s the annual carbon uptake in developing countries in the first commitment period, resulting from afforestation and reforestation since 1990, would be between 190 and 538 MtC/yr (IPCC Special Report PROPER REF: Summary for Policymakers, Table 3); whilst the total across all ‘Article 3.4’ categories of improved land management could be around 700MtC. Taking account of real project constraints for additional projects under the CDM would make the potential *much* lower (notwithstanding the ability to accumulate credits for absorption from 2000) – the Quantifying Kyoto workshop, reported in *Climate Policy,* Issue 1, suggested a figure equivalent to c. 100MtC/yr whilst emphasising the uncertainties. This would still be comparable to the total demand for credits arising from the EU and Japan – probably on the order of around 50 MtC/yr each. Even if the real potential for LULUCF projects were still lower, such projects (some of which have been assessed at costs of just a few $/tC (Kremen et al., 2000)) could still deter significant action on emissions and energy sector investments; financing most such projects would require confidence in prices of several tens of $/tC.

due to a future land-use change – the problem of “non-permanence”, i.e. the release back to the atmosphere of carbon that has already been “credited” to offset some emissions from fossil fuels.[7] In the context of Kyoto, a solution to this has been advanced in the Colombian proposal for temporary credits, issued on a rental basis and withdrawn after a pre-defined timeframe. .[8] Whilst this could do much to address the shorter-term objections about project-level permanence, critics maintain a more fundamental case that carbon sinks in themselves are simply a distraction from the core need for action on CO2 emissions. [9] From this perspective, carbon sinks should be judged predominantly according to whether they could aid the ultimate transition away from fossil fuels – not defer it.

Following this reasoning, Peter Read has argued that at least for the potentially large volumes of sinks projects in the CDM, sink projects should carry a concomitant biofuel obligation.[10] Sinks, he argues, should be regarded primarily as building up a stock of renewable fuels. Only if carbon sinks are ultimately to be utilised to provide energy that displaces fossil fuels can they really make a large contribution towards solving the climate-change problem. Similar considerations, in principle could be relevant to sinks in industrialised countries.

In this project, after outlining these issues in more depth, we explore the possible links between carbon sink crediting and biomass energy; and in particular, whether crediting the carbon sinks accumulation that is associated with the use of biomass energy – *associated sink crediting* - could help to offer scientifically robust and credible approaches both to carbon sinks and the promotion of biomass energy. What might be the implications of biomass energy developments for the volume of carbon sink crediting? And what might be the implications of different sink crediting rules

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[7] For further detail on “permanence” see Schlamadinger and Marland, 2000.

[8] The Colombian proposal can be found at http://www.unfccc.int/resource/docs/2000/sbsta/misc08.pdf, pages 23-26. It is aimed at addressing the “permanence” issue, i.e., the question of who assumes responsibility for carbon stored in sinks projects but released later (see also Marland, Schlamadinger and Feldman, 1998). The idea is that investors rent carbon credits for the duration of the sinks project rather than purchasing them. During the project the risk of any carbon release back to the atmosphere is with the project host. After the project there are two basic options: either a prolongation of the project is negotiated (in which case the investor country would get to keep the credits for another period of time), or the investor country has to replace the “expired” credits with credits from another project.

[9] The scientific basis for this view has been summarised by Bolin (2001), who emphaises that the core need in moving towards atmospheric stabilisation is to reduce the overall injection of CO2 into the combined short-term reservoirs of atmosphere, terrestial ecosystems and surface oceans. He estimates the amount of carbon that could realistically be added sustainably to above ground ecosystems to be on the order of a tenth of the projected ‘business-as-usual’ fossil fuel emissions over this coming century.

[10] The option of linking sinks and bioenergy has first been proposed by P. Read in (Ecologic 2000) as follows: “COP6 should require that each 100 tonnes of carbon credit from sink-enhancing plantation projects shall be linked to a proportionate biofuel using project. This “biofuels obligation” may be a few tonnes initially, but should increase as costs come down with experience”. Ecologic’s proposal assumes the scale of sinks to be determined by tight definition of Sec 3.3 plus a quantum of Section 3.4 activities determined by negotiation (e.g. by ‘discounting’) and its purpose is to provide strong incentives for projects that use biomass produced in sinks as biofuel, which is a technology that is perceived to be lagging behind other renewable energy technologies. Ecologic also propose that the undiscounted residual from Section 3.4 projects be banked until 2012. Our proposal here reverses the sequence by proposing that CDM bioenergy projects could expand their system boundary to include a land-use component if certain criteria are met.

for the development of biomass energy? Could linking carbon sink crediting in some circumstances explicitly to biomass energy developments offer a constructive option in the Kyoto negotiations? These are some of the core questions that we explore in this study.

Biomass energy and sustainability

Biomass can contribute to achieving CO_2 reductions through fossil fuel substitution and the storage of C in organic matter. The question remains whether it can do so in a way that is economically, environmentally and socially sustainable. The answer is likely to be yes, if suitable management practices are observed.

Biomass is a promising contributor to the economic, environmental and social dimensions of sustainable development, in particular in terms of sustainable energy supply. It is a widespread resource that, if exploited with technically and economically viable technologies, can play an important role in economic development. It is a source of renewable energy which can contribute significantly to the rational use of natural resources, provided sustainable biomass resources are used. Furthermore, a proper exploitation of biomass energy can help preserve the environment, for example, through reduced emissions of atmospheric pollutants compared to conventional power sources. Also, biomass energy can enhance societal well-being through rural development and a more equitable distribution of resources.

Biomass can provide energy at a low social cost, a fundamental aspect of sustainable energy supply and a key requirement for economic development. Furthermore, biomass energy can result in significant economic benefits in terms of reduced expenditure associated with energy imports and enhanced energy security, in particular for developing countries.

Biomass can also provide an energy source compatible with environmentally sustainable development. The benefits of biomass fuel cycles in terms of atmospheric emissions can be considerable compared to fossil fuel cycles. The sustainability of biomass production, however, requires careful consideration. The renewable nature of the biomass resource needs to be ensured, and any negative impacts which could result from its procurement need to be avoided or minimised.

Biomass energy could bring about significant social benefits in terms of job creation, capacity building, poverty alleviation and rural development in general. The social sphere is a fundamental component of sustainable development, and biomass energy systems are likely to present social benefits compared to conventional power supply. Benefits arise mainly from the reliance on local resources and the contribution to rural development.

Greatest concern is often expressed with regard to the sustainability of energy plantations and its compatibility with sustainable agriculture, especially in relation to the application of inorganic fertilisers, herbicides and pesticides, and the effects of extensive monocultures. The main consequences could be on soil quality, water quality and use, biodiversity and human health. However, good practice in the development of energy plantations is likely to minimise adverse environmental impacts. Competition of energy plantations with other land uses is an issue which requires closer consideration, as discussed in section 1.

Structure of the study

Part 1 develops the core scientific information regarding the relationship between biomass energy and carbon sinks at the project level, in terms of the carbon profile of various forms biomass energy crops classified into four main categories as illustrated in Table 1:

	Previous forested land	Previous unforested land
Forest energy crops	Managed forest extraction: **(a) additional extraction** **(b) greater use of existing forest industry by-products**	**Short Rotation Coppice or forestry for energy**
Herbaceous energy crops	This option is not recommended because it would probably lead to a decrease in carbon stocks on the land.	**Energy grasses (e.g., Switchgrass) for power or liquid fuels**

This part also considers the wider environmental implications of biomass production for energy and discusses some possible economic implications of associated carbon sink crediting.

Part 2 examines the relationship between carbon sinks and biomass energy in the context of the Kyoto Protocol. It explores three main areas:
- relationship of activities that would fall under Article 3.3 (afforestation and reforestation) with bioenergy;
- issues regarding the treatment of biomass energy activities that would fall under other land categories under Article 3.4, including extraction of biomass energy from managed forests that forms the bulk of current biomass energy use in industrialised countries;
- options for linking sinks crediting to the use of biomass energy in the CDM.

Generally, part 2 highlights the trade-offs and synergies that can be expected between carbon sinks and bioenergy under the various Articles of the Kyoto Protocol.

Part 3 offers quantitative analysis of the implications of different biomass energy production routes for the substitution of fossil carbon and the volume of sink crediting in different countries in relation to Kyoto targets. It explores different biomass energy scenarios in Annex 1 and non-Annex 1 countries.

Overview of Conclusions

Part 1: Carbon stocks and flows associated with biomass energy use

- Different biomass energy pathways may differ greatly in the timing and nature of their carbon flows: they are not necessarily carbon neutral
- Consequently, associated carbon sink crediting will have differential implications for different kinds of biomass energy.
- There are some grounds for believing that associated sink crediting could favour more environmentally sound and sustainable forms of biomass energy production
- For short rotation forests, the carbon stock increase would be the most significant (if the forest is established on previously unforested lands). For instance, with a yield of 15 ton DM/yr and a rotation period of 6 years, the average carbon stock is roughly 22 ton C/ha.
- The economic incentives from associated sink crediting, at credit prices ranging from $10/tC to $100/tC, could offer an important boost to the development of new biomass energy,corresponding roughly 200-1000 USD/ha. (see text for details). Sink crediting will thus enhance the economics of longer rotation periods over shorter rotation periods and annually harvested crops.

Part 2: Concerning the rules governing the Kyoto Protocol:

- **Article 3.3: reforestation, afforestation, deforestation.** This article already implies associated sink crediting for new forestry-based biomass energy developments in industrialised countries.
- **Article 3.4:**
  - *Non-forest activities.* A net-net approach for agricultural activities would also imply associated sink crediting for new non-forest biomass energy activities established on former grazing, farm or other non-forest land.
  - *Managed forests.* Extraction of biomass could reduce carbon stocks although this might well be compensated under a capped system by accumulation elsewhere in the forest.
- **Article 12, Clean Development Mechanism.** Linkage to biomass energy could help address concerns of leakage, permanence and scale.
- **Article 6, Joint Implementation.** The rules governing JI must be consistent with the sink definition rules governing Art 3.3 and 3.4 activities.

Part 3. Projections of biomass energy developments in the EU and the US suggest that official biomass energy-related developments, eligible under Articles 3.3 and 3.4 (third tier) could reduce C emissions between 7 and 19-% and 1 and 12% of total 1990 emissions for the EU and US, respectively. These values account for above biomass C stocks possibly eligible for crediting in the period 2008-2012. Biomass C stocks could contribute significantly to the C emission reductions, as they could represent between 6 and 24% of C credits in the case of the scenarios investigated for the EU and US. The biomass potential in developing countries is large and the CDM mechanism could stimulate its use. Accounting for C credits in above ground biomass stocks associated with bioenergy plantations could provide an incentive for biomass energy schemes. While incentive associated with the crediting C stocks will be greater for plantations with longer rotations, and should clearly improve their economic viability, it should not be taken as a foregone conclusion that longer rotations will be preferred, economically, to shorter ones.

PART 1: Carbon stocks and flows associated with biomass energy use

Biospheric carbon stocks have received increasing attention since the signing of the UN Framework Convention on Climate Change (UNFCCC, 1992). Management of these stocks involve (i) reducing or halting deforestation, (ii) increasing the carbon content within existing forests, (iii) afforestation or enhancing reforestation, (iv) increasing the content of carbon in long-lived woody products, and (v) using wood as a substitute for fossil fuels.

We focus on the link between biospheric stocks of carbon and biomass as a source of energy that can substitute fossil fuels. Bioenergy is often considered CO_2 neutral, but the use of biospheric carbon stocks for the purpose of biomass energy could have positive, negative or neutral impacts on the stock of biospheric carbon.

In this paper, we will look at the impact of different sources of biomass energy on the biospheric carbon stock. Of course, there are other important aspects related to biomass energy but they are not dealt with in this report. Detailed discussions of biomass energy can be found in other reports and books, e.g., Johansson et al (1993), Larson & Kartha (2000) etc.

Biomass supply options

Bioenergy supplies can be divided into three broad categories:

* Residues (in the agricultural and forestry sector), by-flows (in industries) and organic municipal waste;

* Agroforestry;

* Dedicated energy crops plantations.

The first category includes wood from forest felling and thinning, sawmill and papermill residues, animal dung, and harvest residues from food and fibre crops production. It represents a large potential source of bioenergy. The energy value of residues generated world-wide in agriculture and the forest-products industry amounts to more than one third of the total commercial primary energy use at present (Hall et al. 1993, p. 607). For instance, bagasse (a residue from sugar cane processing) could be used to generate substantial amounts of electricity (some 4 EJ_e/yr by the year 2025 according to Larson & Kartha (2000)).

Agroforestry is a broad concept encompassing trees and crops cultivated jointly, where the trees might be harvested for energy purposes. These systems have the potential to improve overall yield and are therefore seen as a promising option, and in many cases alternative to monoculture plantations.

Dedicated plantations include sugar crops (sugarcane, sugar beet, sweet sorghus), starch crops (corn, wheat, barley), oil crops (rapeseed, soybean, sunflower, oilpalm), perennial herbaceous crops (switchgrass, reed canary grass, miscanthus), and short rotation woody crops (salix, poplar, eucalyptus).

Woody and herbaceous biomass used for heat, process heat and co-generation has substantially better net energy yields than traditional row crops used for production of liquid fuels since biomass yields are generally higher, the energy input in cultivation is lower and the conversion to heat is more efficient than the conversion into liquid fuels (Berndes *et al* 2001).

At present, bioenergy supplies are dominated by traditional sources. Roughly some 30-50 EJ/year are supplied in the form of firewood, dung and other agricultural residues. However, once carbon abatement policies are adopted, new markets for bioenergy are created. For instance, following the adoption of a carbon tax in Sweden in 1990, the annual use of forest residues in district heating began to rise rapidly (see Kåberger 1997).[11] Thus, bioenergy can be expected to play a more important role in the future if carbon abatement policies are adopted.

There are several estimates of the global supply potential for bioenergy. For instance, Hall *et al* (1993) estimate the potential supplies from residues at 77 EJ and the potential supply from dedicated energy plantations at 128 EJ by the year 2050. The plantations would require 429 Mha of land. This implies an average yield of 300 GJ/ha/year. In the LESS scenarios presented in IPCC (1996), total bioenergy supply is even higher (329 EJ/yr by the end of this century), claiming 572 ha of land. Leemans et al (1996) using the IMAGE model claim that the land use requirement for the LESS scenario is as high as 800 ha. In a study by IIASA/WEC the supply reaches 300 EJ/year, and land demand (in the most extreme scenario) above 1300 Mha. A more detailed assessment of global biomass supply potentials is given in Berndes, Hoogvijk and van den Broek (2001).

In short, residues are plentiful, but if we are to obtain very large amounts of biomass, plantations are required. Here energy crops (short rotation coppice and herbaceous crops) rather than traditional agricultural crops (such as corn or wheat) may be the most promising options. One important exemption is sugar cane in tropical countries.

Biomass supplies — impact on biospheric carbon stocks

Bioenergy is generally considered a CO_2 neutral source of energy. But as stated earlier, establishment of plantations to produce biomass, may lead to changes in the stock of biomass. In other cases, there may be time lags between the release and the reabsorption. This is the case when forestry residues, twigs and branches, are burnt. If the twigs and branches are left in the forest area, they will take decades before they have fully decayed and all the organic carbon is released into the atmosphere, but if they are burnt in a boiler, the emissions are immediate.

Table 1.1 summarises the impact of bioenergy on biospheric carbon stocks from six different classes of bioenergy.

Table 1.1 Impact on biospheric carbon stock

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[11] The carbon tax in Sweden is now about 200 USD/ton C.

Biomass source	**From non-forest lands**	**From forest lands**	**Comments**
Increased extraction from managed forests	Not applicable	Possibly negative, a new equilibrium will be established with a lower carbon content*	* If the rotation period is halved, then the time average carbon stock is also approximately halved and some 50 ton C/ha would be lost. (within wide margins)
Greater use of existing forest industry by-products	Not applicable	Does not have an impact on forest carbon stocks	
Short rotation forests	Positive impact if established on previously non-forested land. Typically adds some 20 ton C/ha to land.	If a natural forest is replaced, as much as 200 ton C/ha could be released to the atmosphere.	
Greater use of existing agricultural residues	Potentially a slightly negative impact on soil carbon*	Not applicable	* Assuming that the alternative would have been to leave the residues in the field
Perennial non-woody crops (e.g. energy grasses)	Potentially positive impact on above* and below ground** carbon	Strongly negative	* If the yield is larger than what was previously harvested ** If established on previously cultivated arable lands
Traditional row crops harvested annually	Negligible*	Strongly negative	* Since the same crop is used for energy rather than food.

** Managed forests*

Additional extraction of biomass from forests can be done through thinning and through an increased rate of extraction of residues. In these cases, a reduction of the biospheric carbon stock will occur. Thus, the increased use of biomass will initially be associated with some biospheric carbon releases but eventually the biospheric carbon stock will be in steady state (at a lower level than what would have been the case in the absence of the increased extraction rate).

In Annex-1 forests, which are typically gaining carbon at the moment, an increased extraction rate for biomass would reduce the rate of carbon accumulation (but this rate could still remain positive given reasonable extraction rates). At present, it seems unlikely that forest logs will be used for energy purposes. Removals through thinnings and logging residues are the more likely options.

** Short rotation forests*
The impact of short rotation forests on the biospheric carbon stock depends on what was previously cultivated, the yield and the rotation length. If the plantation replaces a natural forest, there will be a significant loss of carbon (as much as 100-200 ton C/ha), but if the plantation replaces cultivated lands or pastures/savannahs, there will be a build-up of carbon (by some 20 ton C/ha). See below (section 1.3) for more details.

** Herbaceous grasses*
The impact on biospheric carbon stocks depends again on what was cultivated previously. If forests are replaced, there will be a significant loss (as stated above), if agricultural land is used, there might be some build up above ground (if the average yield is higher, but that is likely to be rather small, in the order of a few tons of C/ha). A positive impact on soil carbon is expected, but quantification is difficult.

** Traditional row crops*
Traditional row crops as a source of bioenergy will not change the carbon stock on land since no change in the stock of crop takes place.

** Agricultural harvest residues*
Increased use of harvest residues from the agricultural sector is likely to reduce carbon stocks on land, but only by minor amounts compared to the carbon benefit that is obtained by using the residues to replace fossil fuels.

In summary, short rotation forestry is the source of biomass that is likely to gain most from a system where carbon credits are also given to changes in biospheric carbon stocks associated with the production of the biomass. However, these will need to be considered in conjunction with credits obtained from using the biomass produced as a source of energy. We will look into the issue of short rotation forests and biospheric carbon stocks in some more detail in later sections.

A more detailed look at biomass from short rotation plantations

Bioenergy plantations affect carbon stocks on land in three different ways: most obviously above ground carbon and soil carbon may change as a consequence of the establishment of a plantation, but it may also lead to changes in land use beyond the area where the plantation was established.

Changes in the stock of carbon above ground

Changes in the stock of carbon above ground can be estimated with reasonable accuracy, at least if the previous land cover is well known. The establishment of biomass plantations (woody crops) will generally lead to increases in the stock of carbon if it is established on crop lands in idle, crop lands used for traditional annual row crops or on pastures

The carbon content above ground on lands used for annual row crops can be estimated as follows: A good harvest is typically 5 ton DM grain/year/ha which is equivalent to 10 ton DM biomass/ha/yr. If the growing season is six months, this corresponds to 2.5 ton DM/ha on average, which is roughly equivalent to 1 ton carbon/ha on average over the full year. The above ground carbon content on pastures is typically less than this value.

The above ground carbon content in forests can be 50-200 ton C/ha depending on the type of forest. If a plantation is established on areas that were previously forested, then there will be a major reduction in the stock of carbon on that land.

The carbon content in a plantation depends on two factors: (i) the rotation period and (ii) the yield. Let us assume that the yield is y_c (ton C/ha/yr; assuming a conversion rate of DM to C of 1/2) and that the rotation period is T_p, then the average standing stock of carbon C_s is roughly equal to

$$C_s = y_s \cdot T_p/2. \qquad (1)$$

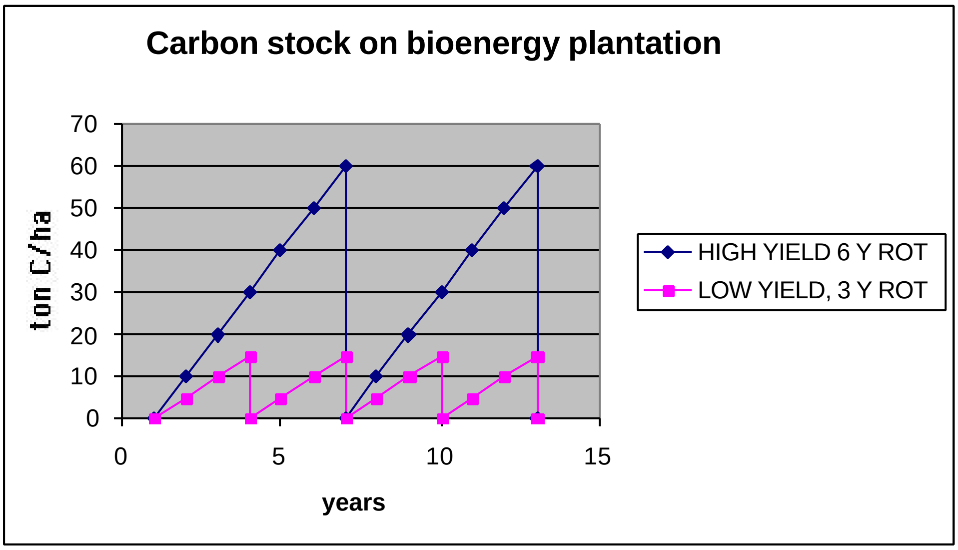


Figure 1.1 The carbon stock on one hectare of land under two different cases, “one high yield, medium long rotation period”, and one "low yield, short rotation period". The average carbon stock is three times higher for the first case.

In the high yield case, we have assumed a yield of 15 ton DM/ha/yr, and a rotation period of six years. Typical yield levels on well managed plantations in Brazil are 10-20 ton DM/ha/yr (see Azar & Larson 2000). Assuming an average value for the yield, we get a standing stock of carbon of 22.5 ton C/ha on average.

The low yield case has a yield of 10 ton DM/ha/yr which is equivalent to 5 ton C/ha/yr; this is typical for non-tropical countries (see Berndes et al 2001). We have chosen a rotation period of three years so as to more clearly demonstrate the impact of a shorter rotation period. Salix is typically harvested every three years in Sweden. From equation 1, we get that the average carbon stock would be 7.5 ton C/ha.

Changes in the stock of carbon below ground

The establishment of a plantation on agricultural lands typically has a positive impact on below ground carbon. Carbon is expected to increase since soils are covered year around, tillage is carried out much less frequently in a perennial energy plantation than in traditional agriculture and finally root systems are larger for trees.

In a recent review of soil sustainability in biomass plantations, Mann & Tolberg (2000) states that "conversion of agricultural lands to biomass crops has potentially beneficial effects on soil carbon dynamics, but these effects are less documented".

Impacts beyond the planted area

The establishment of plantations may cause changes in land use/land cover beyond the planted area. If degraded lands are targeted with plantations, then the rural poor who dwelled on the areas now planted may opt to cut down near by forest in order to get land for themselves. This critique has been raised by NGOs in developing countries, e.g., world Rainforest Movement based in Uruguay, when arguing against the establishment of eucalyptus plantations pulpwood (Carrere and Lohmann 1996).

Conversion routes

Biomass can be converted into essentially any energy carrier, solid fuel, heat, process heat, electricity, gaseous fuels (hydrogen, biogas, DME) or liquid hydrocarbons (methanol, ethanol, FT fuels). It is beyond the scope of this paper to discuss the optimal use of biomass, and thus we will only look at the production process. However, since there are significant energy losses associated with condensing power plants and liquid and gaseous fuels production, it is more energy efficient to convert biomass into heat (or co-generation of heat and electricity or fuels). An overview of the conversion routes are given in figure 1.

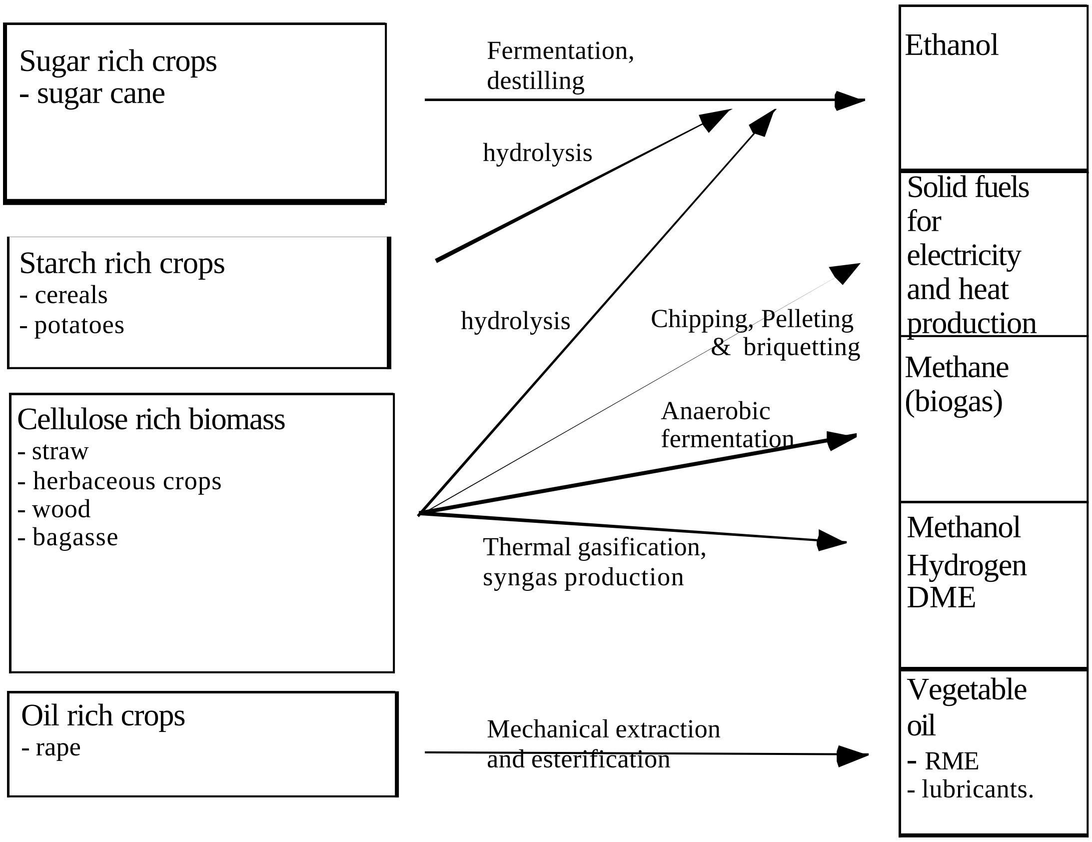


Figure 1.2 Major conversion pathways for bioenergy.

Carbon flows over time

In this section, we will offer some illustration of the carbon flows associated with three different biomass energy systems.

- woody biomass from short rotation plantation replacing coal for heat (both used with an efficiency of 90%) (figure 1.3a-b)
- woody biomass replacing natural gas for electricity (biomass used with 35% efficiency and gas with 50%) (figure 1.4a-b)

The graphs were produced using GORCAM (for a description of the model see Schlamadinger et al, 1999). Two different graphs are generated for each case, the first representing the carbon stocks at the stand level (per hectare), the second at the landscape level (per 100 hectares). If we consider a single stand, the carbon content in trees essentially drops to zero at each harvest occasion, but since different plots are harvested at different points in time, the carbon stock in trees in the landscape reaches an equilibrium with a positive carbon stock (roughly given by equation 1).

The graphs clearly show that a positive carbon impact is obtained through fossil fuels displacement and through an increased stock of biospheric carbon. A general feature of the graphs is that the most carbon abatement is obtained through fossil fuels displacement.

In the graphs, we have assumed that the previous carbon stock on the land where the plantation was established was zero, which overestimates the impact the plantation has on biospheric carbon stocks, especially if a natural forest was replaced which could contain as much as 200 ton C/ha above ground.

The carbon benefit of liquid fuel from biomass for transport is generally of less interest based on current technology. For example, a corn-ethanol system displacing gasoline has a substantially lower, and in some cases even a negative, net carbon impact. However, ethanol production from sugarcane in Brazil presents greater energy and carbon benefits and, with the development of new technologies, may improve the prospects for liquid fuels production from biomass.

The biomass production system illustrated in Figure 1.3a-b is characterized by a linear growth rate of 15 ton DM/ha/yr, the rotation period is 6 years. Further, we have assumed that there is an increase in dead wood and litter by 10 ton C/ha per 12 years and in soil carbon by 10 ton C/30 years.

Figure 1.3a-b. Biomass replacing coal in heating systems

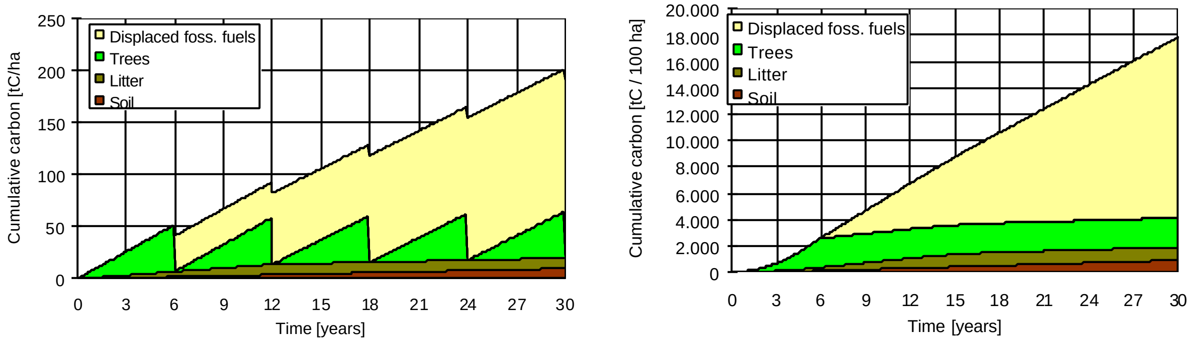
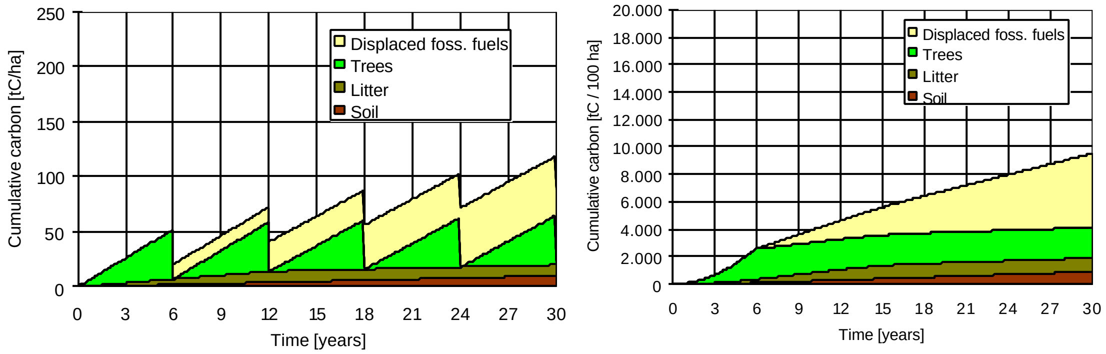


Figure 1.4a-b. Biomass replacing natural gas in electricity generation



Economic framework for calculating the levelised cost of biomass when the changes in carbon is credited

In this project, we suggest that carbon stock changes associated with certified biomass energy plantation projects (under CDM) should be credited. In this section, we would like to offer some insights into the economics of such crediting and to what extent it might have an impact on the overall analysis of plantations.

This is done by calculating the value of carbon crediting per hectare, and by comparing that value with the cost of establishing the plantation. An alternative approach would be to calculate the impact on the levelized cost of biomass energy production, but this is done elsewhere (Amatayakul & Azar 2001). The carbon credit is given by

$$\mathrm{C_c} = ?C \cdot P, \tag{2}$$

where Cc is the carbon credit, $?C$ is the change in carbon stock (ton C/ha) and P is the permit price (USD/ton C). Using equation 1, we can rewrite this into

$$C_c = P \cdot (y_c \cdot T_p/2 - I_c). \tag{3}$$

where the first term in the bracket is the new average standing stock of biospheric carbon above ground and I_c is the initial carbon stock that was replaced. Here we will assume that annual row crops are replaced and that would mean that I_c is roughly equal to 1 ton C/ha.

Thus, for "High yield 6 years" case (a plantation with 22.5 ton C/ha on average) typical of subtropical climates, and a carbon price of 10-100 USD/ton C which has been suggested necessary to reach the Kyoto agreement, we get a carbon crediting in the range 220-2150 USD/ha.

For the "Low yield 3 years" case (a plantation with 6.8 ton C/ha on average) typical of temperate climates, the benefit is not as large since we have assumed a shorter rotation period and a lower yield. In that case we get a carbon credit value equal to 65 -650 USD/ha.

Thus, the longer the rotation period, the more carbon one would have on land. This would favour longer rotation periods and strengthen the competitiveness of short rotation forests over annually harvested crops such as traditional row crops and/or grasses. However, this does not necessarily mean that longer rotations will be chosen, or that short rotation forests will be chosen over annually harvested grasses. The overall profitability of different biomass crops will be site specific and depend on more factors than mere considerations of carbon stock crediting. The point however is that carbon stock crediting will have a greater impact on the economic viability of longer rotations over shorter rotations or annually harvested crops.

It is interesting to compare the potential carbon credits estimated above with the cost of establishing plantations. In the tropics the establishment cost is generally in the range 200-1200 USD/ha, land costs not included (Carpentieri *et al*, 1993; Azar & Larson 2000, Amatayakul & Azar 2001).

However, in many cases, the establishment of the plantation is not the dominant cost component. It might therefore also be of interest to analyse how much carbon crediting might affect the cost of producing biomass energy. In figure 1.5, we show the cost of eucalyptus from plantations in Thailand, including the contribution from carbon crediting. Here, we have assumed that the carbon credit is spread over the full life time of the plantation (assumed to be 15 years), and that the carbon credit is 15 USD/ton C. For more information see Amatayakul & Azar (2001).

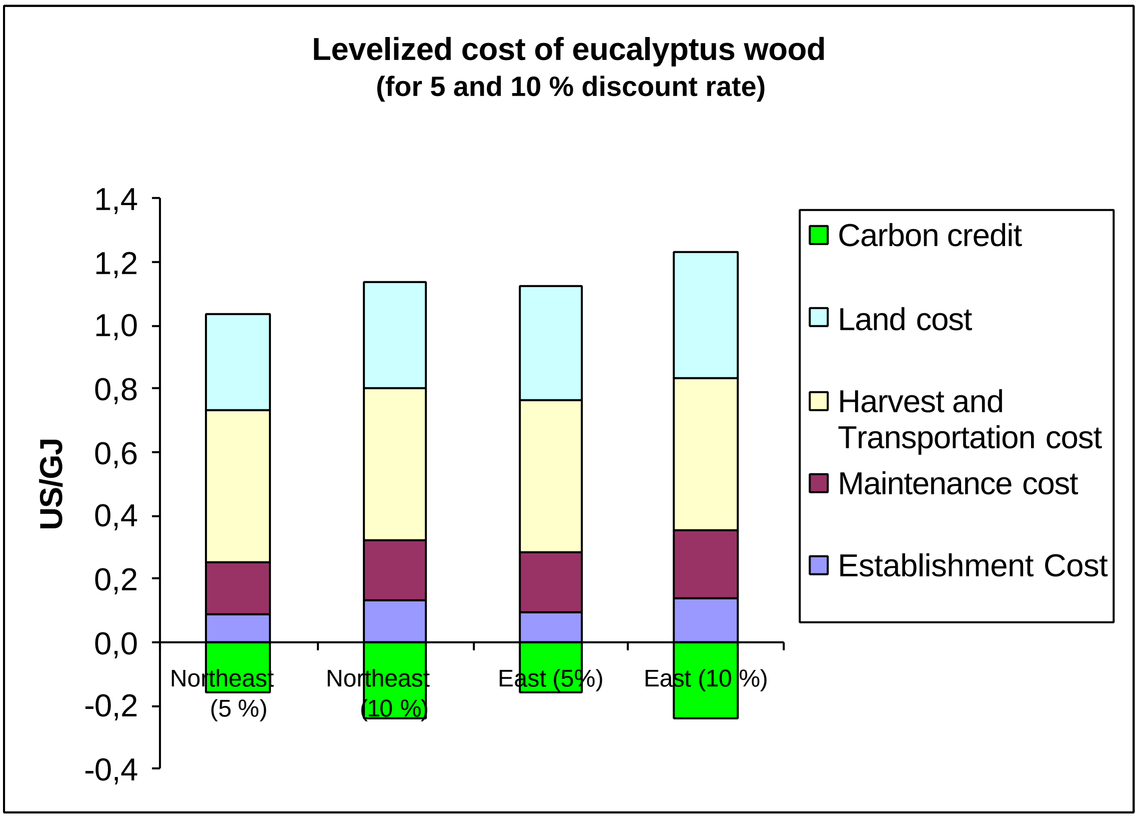


Figure 1.5. ***Levelized cost of eucalyptus wood in Thailand with carbon crediting of the change in carbon stock assuming that the plantation is established on previously agricultural lands. A plantation only captures carbon while there is net growth so the carbon credit generates early revenues and these are assumed to be spread over the entire lifetime of the plantation which is 15 years. A 25 USD/ton C value is applied and it reduces the cost of biomass by roughly 10-20%. With a 100 USD/ton C value, as some believe is to be required in order to meet the Kyoto protocol targets, a the carbon credit would correspond to the entire production costs.***

Source: Amatayakul & Azar (2001).

Thus, the crediting of the carbon stock increase could provide a very strong incentive for biomass energy plantations. Although this is positive, we should also be careful and make sure that land use conflicts are not intensified through these activities.

For instance, there is a risk that multinational companies or the local elite will buy land cheaply or expropriate lands that poor farmers in various parts of the South use today. Also, it should be kept in mind that plantations are much less labour intensive than normal agricultural activities, and an expansion of plantations on lands previously used for agricultural would mean an increased risk of rural unemployment or an increased rate of migration to urban areas (see Carrere and Lohmann 1996, for a critique of short rotation plantations in the South). But the establishment of plantations will also provide opportunities for medium and large land-owners. Work opportunities will also be created if the plantations are established on pastures. Thus the provisions concerning sustainable development and CDM in the Kyoto protocol needs be given proper attention.

Positively, for rural communities without access to grid-connected power, and where crop residues or animal wastes are readily available, as well as plantation outputs, establishing a bioenergy project can protect existing employment levels and result in new employment opportunities for the local population thereby reducing the continuing trend towards urban drift. New skills are developed as a result of related training and education programmes. Local health can be improved, particularly where cooking is previously carried out indoors, over open fires. The community can become self-sufficient and a sustainable energy system be developed (Read, Sims and Adam, 2001).

Nevertheless, large scale monocultural plantations of exotic fast growing species have a bad reputation that casts a shadow over the notion of plantations generally, despite modern plantation practice that gainsays the bad examples (Tiffen and Mortimore, 1990). The case of eucalyptus plantations in Ethiopia has recently been reviewed in relation to environmental impacts (Jagger and Pender, 2000) and found on a variety of counts to yield mixed results depending on the quality of project design. What emerges from this study is the need to adapt to local circumstances and avoid very large monocultural developments.

If the potential of biofuel for generating synergies between carbon management and sustainable development is to be realized, each project needs to be tailored to the ecological and socio-economic circumstances of its location. This means that biofuel projects need to emerge from the sustainable development objectives of host countries and meet the specific needs and aspirations of the communities settled on the land where community scaled biofuel plantations are located. The prospect of 100,000 projects averaging 5000 hectares presents an obstacle to prospective investors that can only be overcome by training host country people to develop their own projects in negotiation with the communities affected (Haque et al, 1999). This barrier to entry for biofuel technologies, along with the lead times involved in providing time to grow, means that the land use changes implicit in the role of biofuel in most low emissions scenarios are already falling behind (Ecologic, 2000).

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PART 2: BIOENERGY AND THE KYOTO PROTOCOL PROVISIONS ON SINKS: TRADE-OFFS, SYNERGIES AND OPTIONS

Introduction

Biomass can play a dual role in greenhouse-gas mitigation related to the objectives of the UNFCCC, i.e. as an energy source to substitute for fossil fuels and as a carbon store. Modern bioenergy systems offer significant opportunities towards reducing greenhouse-gas emissions while providing additional benefits. Moreover, via the sustainable use of the accumulated carbon, bioenergy has the potential of resolving some of the critical issues surrounding long-term maintenance of biotic carbon stocks (IEA Bioenergy, 1998). This paper discusses the impacts of various sinks-crediting provisions under the Kyoto Protocol on biomass energy, including possible trade-offs and synergies.

The matrix (Table 1) shows different bioenergy options, depending on a) whether biomass fuels are derived form forest or non-forest systems, and b) whether these options are implemented on former forest or non-forest lands. The matrix also shows which Articles of the Kyoto Protocol could apply.

Table 1: Overview of different biomass energy categories, and their relationship to the land-use related Articles of the Kyoto Protocol

	Previous forested land	**Previous unforested land**
Woody biomass	Managed forest extraction: (a) additional extraction (b) greater use of existing forest industry by-products • *Article 3.4 (forest management) for (a)* • *(b) does not directly impact forest C stocks.* • *CDM (forest protection)*	Coppice or Short Rotation for energy • *Article 3.3 (afforestation, reforestation), provided that these crop are "forests"* • *CDM (afforestation and reforestation)*
Non-woody biomass	This option is not recommended from a carbon balance perspective because there is likely to be a decrease in carbon stocks on the land (deforestation). There may be some exceptions like agroforestry systems.	E.g. switchgrass for power / liquid fuels • *Article 3.4 (either cropland/ rangeland management, or revegetation)* • *CDM (activities other than afforestation and reforestation)*

Article 3.3 and the use of new forests and their residues for energy

Stock changes in the 2008-2012 commitment period, resulting from afforestation / reforestation / deforestation activities since 1990, are accounted under Article 3.3. Following discussion on the definitions of terms like "forest" and "reforestation", and with information from the IPCC Special Report on land use, land-use change and forestry (LULUCF) (IPCC, 2000) and recent technical papers (UNFCCC, 2001) it is likely that afforestation and reforestation will be defined as conversion of non-forest to forest, and deforestation as conversion of forest to non-forest; the term "forest" (refer to actual definition in Bonn agreement? will be defined as land that has a crown cover above an agreed threshold (e.g. 10-30%) or that will reach such a status with continuation of ongoing management (i.e., bare land after clear cut, but planned for regeneration, is also considered forest). With these definitions the regeneration of forests after clear-cut harvest does not qualify as reforestation because it is part of an ongoing forest management regime.

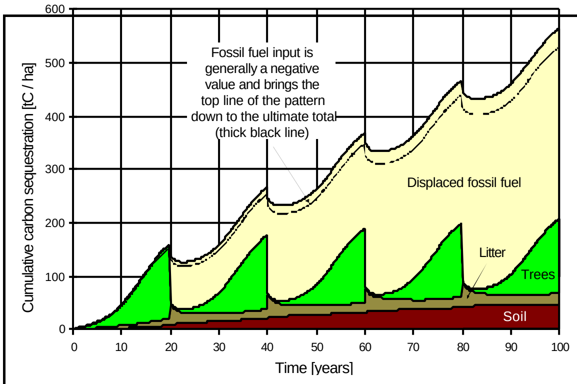
How might Article 3.3 affect bioenergy?

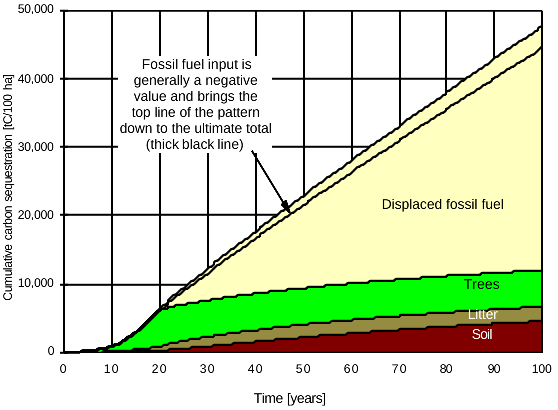
Article 3.3 provides an additional incentive to establish new biomass plantations if they fulfill the definition of a “forest” and are created since 1990 on former cropland, pasture land, or other non-forest land. Carbon credits (in addition to credits for any emissions reduction due to biomass fuels displacing fossil fuel) would be equal to carbon stock increases on such lands between 2008 and 2012. If the plantation is in equilibrium by the year 2008, i.e., harvest equals regrowth, there would be no LULUCF credits and thus no additional incentive. A net increase of carbon in the plantation would occur if a) it is not yet harvested but still growing during the commitment period, b) the rate of harvest is lower than the rate of growth, or c) if the harvest equals regrowth but there is a net increase in soil carbon. Obviously any increase in the level of harvesting for biofuels or other forest products will be at the expense of LULUCF credits that can be earned for afforestation or reforestation in the first commitment period and in practice owners of plantations would be free to balance carbon stock increases and bioenergy sales to maximise returns. There would of course be a general increase in time average carbon stocks from the plantations, limited by the equilibrium state underlying the concept of the normal forest (box 1) and because of this Article 3.3 is generally favorable for biomass energy - in the long term the incentives for afforestation and reforestation will create a new source for bioenergy and timber.

BOX 1: THE CONCEPT OF A “NORMAL FOREST”

Energy (and other) plantations will usually not consist of one single stand that is harvested every n years, but of an ensemble of n stands, n equaling the rotation length in years. This allows one stand to be harvested each year, while n-1 stands are regrowing. Such a system is often referred to as “normal forest”. If, for example, each stand is growing from zero tC carbon to 50 t carbon per ha, then the average carbon per hectare in the normal forest is 25 tC/ha. This is the time-average, as well the spatial average, of carbon stocks per hectare. Therefore, if carbon accounting is done for the full normal forest, there will be no debit as would be the case for an individual stand. Carbon credits in the first commitment period would accrue to the extent that the carbon stock in the forest is still increasing during the commitment period. Figure 1 shows the carbon stored in trees (in green) for a stand (left) and a normal forest (right) managed with 20-year rotation length.

Figure 1: Reforestation with subsequent use of harvested biomass for energy on the stand level (left) and landscape level – that is a plantation system producing a constant stream of biomass (right).





The carbon stock in standing trees reaches equilibrium after 20 years. Credits for C sequestration in trees will occur if the equilibrium state is reached after the beginning of the first commitment period. In general, any new "since 1990" plantations that have not yet reached their equilibrium state by 2008 are eligible for carbon credits. The equilibrium level of carbon stocks is the greater, the longer the rotation length of the forest. Therefore, there may be an incentive, from a carbon-credit perspective, to delay harvesting, because harvest is associated with the opportunity cost of not being able to claim further carbon sequestration. However, new plantations that are encouraged by carbon deliberations will in any event provide an additional timber and possibly biofuel resource that would not have been available otherwise.

The trade-off between maximizing on-site carbon stocks and maximizing output will depend on the relative prices of biofuels/timber vs. the price of CO_2 credits, but also on the amount of carbon in fossil fuels that can be displaced with one ton of carbon harvested for bioenergy. The more carbon can be displaced that way, the more likely harvesting for biofuels will be favoured. For further details on the trade-offs between on-site sequestration and fossil-fuel substitution see Marland and Schlamadinger (1997).

Article 3.4 analysis in relation to biomass energy production

Two broad groups of options have been proposed for LULUCF activities in Article 3.4: narrowly defined activities (such as improved forest thinning, longer rotation periods etc.) and broadly defined activities (forest management, cropland management, grazing land management) (IPCC, 2000). Recent negotiations have focussed mainly on the latter. The current negotiating text (UNFCCC, 2001) proposes to include forest management, discounted by 85%, up to a cap for each Party which would also limit agricultural activities (cropland and grazing land management and revegetation[12]), afforestation and reforestion sinks in the CDM[13], and "Joint Implementation" sinks.

How does Article 3.4 crediting affect bioenergy?

For the sake of this discussion we distinguish between bioenergy uses that increase carbon stocks in forest management / cropland management / grazing land management, and those that decrease stocks.

A) Biomass energy increases carbon stocks

An example is cultivation of herbaceous energy crops on former cropland, such as miscanthus or switchgrass. This activity is likely to increase soil carbon stocks and/or carbon in vegetation. Adequate consideration of such bioenergy projects in terms of their sinks component seems to be ensured with (draft decisions as proposed in (UNFCCC 2001)ref?). These draft decisions propose a net-net accounting approach for cropland and grazing land management ("net-net" means that the sink strength in the first commitment period is compared with that in 1990, and any increase of sink being credited and any decrease debited). Such an incentive through Article 3.4 crediting would be in addition to the reduction in carbon emissions from substituting fossil fuels with biofuels.

Biomass energy production leading to greater carbon stocks may also occur within the narrowly defined activity "revegetation", which has also been proposed as a separate activity under Article 3.4.

B) Biomass energy decreases carbon stocks

Carbon credits for sequestration in existing forests ("second Tier" in proposal for Article 3.4, UNFCCC 2001) may create disincentives for biomass harvest that decreases equilibrium carbon stocks. Examples are the increased removal of logging residues, enhanced thinning, or a shortened rotation length possibly combined with a change in tree species, for increased output of timber and biomass fuels. However, the disincentive will be small if only a small fraction of carbon uptake is credited using broadly-defined activities (such as in the 15% discount proposed for existing forests, UNFCCC, 2001). Moreover, so long as the discounted uptake (plus third Tier in Art 3.4, and relevant JI and CDM credits) exceeds the cap, any reduction in biomass because of energy uses would be compensated by crediting of uptake elsewhere in the forest and there would be no disincentive.

Due to the perceived disincentive some wood-based industries are concerned about carbon crediting under Article 3.4. They see a competitive use of forests emerging that may move the equilibrium towards less harvesting and that could increase wood prices. The same concerns apply to the bioenergy objectives in the EC White paper on Renewable Energy. Bioenergy, pulpwood and carbon credits are often competing for the same lands and for the same biomass. However the commercial value of the timber harvest is likely to be greater than its carbon value under Article 3.4 and so the effect may not be so significant in practice.

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[12] Under the political agreement reached at the resumed session of COP6, these agricultural activities are included on a net-net basis uncapped.

[13] Under the political agreement reached at the resumed session of COP6, the afforestation and reforestation sink projects are included in the CDM under a separate cap.

Furthermore, associated sink crediting in the first commitment period may allow to increase the resource for future bioenergy uses, and may therefore prove beneficial for bioenergy in the long term. The overall conclusion is again that the Art 3.4 proposals in the Consolidated Negotiating text (UNFCCC, 2001) are reasonably favourable to the development of forestry options which would increase the use of biomass fuels in the longer term, but that the short-term trade-offs should be kept in mind when selecting rules for national implementation of Article 3.4.

2.3.2 Additional observations on forest management in Article 3.4

The following discussion focuses on biomass fuels derived from the land-use category "forest management" (Second Tier in proposal for Article 3.4, UNFCCC 2001). If at some future stage parties wanted to address the trade-off between bioenergy (and other industrial wood uses) and sinks enhancement in the first commitment period, and to provide better incentives for truly additional forest management projects for carbon sequestration, then some options would be:

1) allowing very limited credit (e.g., 10 or 15%) for existing sinks in managed forests. This is low enough not to compromise enhanced removals for bioenergy, low enough to minimize windfall credits, but still high enough to provide (politically important) carbon credits to some countries. In addition, one could allow an increase in the discount factor to the degree that the use of bioenergy (possibly excluding residues from various wood-based industries, because they are not directly derived from the land) is increased since 1990 on the national level. This could be done with a simple conversion factor that relates the increase in the amount of bioenergy (or the increase in total harvest share that is used for bioenergy) with the additional carbon credits for sinks in Article 3.4 (Second Tier, "forest management").

This option could offset a disincentive for bioenergy that results form Article 3.4 crediting. However, an impediment may be the poor data availability on bioenergy use in many countries. And this option would not create a full incentive for new, and truly additional, carbon mitigation projects in managed forests.

Formula as a start for discussion:
Discount factor = 10% + Constant x [$B_{2010} – B_{1990}$] */ LULUCF sink in managed forests in 1990*

B_{2010}: Bioenergy use in 2010 (PJ)
B_{1990}: Bioenergy use in 1990 (PJ)

If bioenergy is measured in the form of end-use energy such as electricity, heat or liquid biofuels, then there would also be an incentive for improving the efficiency of biomass conversion, besides that for using more biomass. The constant in the above formula could be chosen such that an increase in the share of bioenergy by 1 PJ could yield an increase in the discount factor by 1 (5, 10, 15 ...) %. However, this would mean that a large, forest-rich country could get more credits for each PJ of increase in biomass use than a small country. Therefore, one could introduce the additional part *in Italics,* thereby ensuring that the bioenergy increase is considered in relative terms to the sink strength.

2) using narrowly defined activities, i.e. to allow full crediting for new land management projects which are truly "additional". Such projects would have to

address concerns of leakage, and thereby address the negative effects for wood industries and bioenergy explained earlier. A LULUCF project would have to show that it can provide the same, or a greater amount, of goods and services (such as timber and biofuels) than the reference land use, before stock changes on the land can be credited. For lands not undergoing a "project" there is no disincentive for biomass energy because no carbon crediting occurs on such lands.

Very importantly, option 2 would provide a 100% incentive for Article 6 (Joint Implementation) sinks projects that are not afforestation or reforestation projects - whereas option 1 would not.

3) discounted crediting for activities between 1990 and 2000 combined with a full project-based crediting for new LULUCF activities since 2000 or a subsequent date, provided that these activities meet an additionality test and similar criteria as in the CDM. This would imply limited credit (e.g., 10 or 15%) for existing sinks in forests, which could be seen as a proxy for sink activities initiated between 1990 and 2000. In addition, any new sinks projects since 2000 would be credited according to option 2 (narrowly defined activities). In terms of calculation procedure, the (10 or 15%) credit for forest management would apply to (national balance minus credits for new projects since 2000).

Option 3 would create a full, undiscounted, incentive for new projects (including LULUCF projects under Article 6 Joint Implementation) while not compromising the bioenergy use on other lands.

4) individual countries could refrain from implementing Article 3.4 in the first commitment period, thereby removing any adverse impacts on forest industries and bioenergy.

5) individual countries could claim credits for Article 3.4 activities internationally, but refrain from national implementation, thus giving no price signals that would discourage forest management for timber and biofuels.

Article 6 and potential treatment of sinks and biomass energy under Joint Implementation

Projects under Article 6 ("Joint Implementation") could encompass activities covered by Articles 3.3, 3.4, or covered by neither of these two articles.

(1) Afforestation and reforestation projects
Such projects would be credited to the country where they occur, with credits being transferred to the investor country thus resulting in a neutral result for the host country.

(2) Projects under Article 3.4 that are subject to discounting.
The viability as joint implementation projects depends on the discount rate applied in national crediting.

In the Article 3.4 category "forest management" the carbon accumulation due to a project would be credited to the host country with a discount of about 85%. However, the transfer of credits to the investor country according to Articles 3.10 and 3.11 would likely encompass the entire amount of carbon accumulated. Thus the host country is likely to incur a deficit of carbon credits. In order to overcome this, the host country could use the pool of the 15% credits from national forest management accounting, and transfer part of these credits to the investor countries. But nevertheless, any new JI project will decrease the amount of emission credits that is available to the host country, and will take it further away from compliance.

(3) Projects under Article 3.4 that are not subject to discounting

In the categories “cropland and grazing land management”, if a net-net approach is used, there does not seem to be a problem as in category (2) because genuinely new projects would fully enter the equation under Article 3.4.

(4) Projects that fall neither under Article 3.3 nor under Article 3.4

If a project is covered by neither of Articles 3.3 and 3.4, or if the project falls under Article 3.4 but the host country decides not to report Article 3.4 activites in the first commitment period, then the project will not create carbon credits to the host country, and therefore a transfer of credits to an investor country will create a negative outcome – in terms of compliance –to the host country.

Article 12 and options for linking sinks crediting with biomass energy projects in the CDM

The consolidated negotiating text (UNFCCC, 2001) introduced in June proposes to include afforestation and reforestation as eligible for project crediting under the CDM. The effect of afforestation and reforestation on incentives for bioenergy would be similar in the CDM as it is under Article 3.3. In the CDM the incentive to establish biofuels plantations would be somewhat greater due to the banking of carbon credits starting in 2000.

An alternative option for the CDM could be to allow associated sink crediting of mainstream bioenergy projects only. For example: project activities under the CDM that use new biomass-derived fuels to displace the use of fossil fuel could include in the project boundary the stock change between 2000 and 2012 resultant from associated LULUCF activities (afforestation, reforestation, and revegetation) that produce the biomass fuels. To avoid tokenism it might be necessary to specify that the proportion of carbon credits from LULUCF may not exceed the fossil fuel carbon displaced by the biomass energy project by more than a factor of between, say, 1 to 4.[14] The expansion of the project boundary to include a LULUCF component must be

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[14] The “factor” [1, 2, 4] is put forward based on numerical simulations (see Appendix). For plantation establishment, there are two independent variables to be considered in the modeling: 1) start date of plantation establishment, and 2) harvest-cycle length. For any combination of these two, it is possible to calculate the carbon accumulated on the site, and the amount of carbon in biofuels produced, between 2000 and 2012. A third consideration is whether all harvested wood is used for biofuels or whether other co-products (e.g., pulpwood or timber) are produced from the plantation. The ratio of (carbon accumulated / carbon in biofuels produced) will be at high levels if a) harvesting starts very late (e.g. in 2010) and b) if a considerable fraction goes to uses other than biofuels. The numerical simulations have shown that in order to credit stock changes associated with most dedicated biofuels plantations that are operational before or in the first commitment period, the “factor” would have to be greater than 2 or even better greater than 4. On the other hand, in order to limit credits from most

within the same country. Biofuel use in other countries could be considered based on future SBSTA methodological work, including decisions on accounting for harvested wood products.

This proposal might help address concerns of:

Market leakage. This is minimized through use of a significant part of harvested biomass in new local markets. Local bioenergy uses may also enhance the acceptance of the project by the local population. Leakage due to displacement of food and feed production may remain a concern, but that is also true for unrestricted afforestation and reforestation.

Permanence. LULUCF activities that are part of bioenergy projects may well produce more permanent emission credits than stand-alone LULUCF activities, because the usefulness of the product should help guarantee continuation. Remaining concerns about the permanence of the "land-use carbon" could still be addressed through an equivalent to the Colombian proposal. Also, a possible loss of C stocks in the land-use part of the project would reduce the opportunity for continued generation of emission credits from the bioenergy produced, so that there is an additional incentive to maintain these carbon stocks.

Technology transfer. Implicit in the bioenergy linkage is the need for conversion technology associated with the bioenergy component; given this, there is an intrinsic incentive for the investor to use efficient and reliable equipment to ensure continuing production of energy and CERs.

Scale. The problem of excessive potential scale of LULUCF activities leading to a price collapse is limited because, within all afforestation and reforestation projects, only those that are associated with new uses of biomass for energy would be eligible.

Of course a plantation system, once subject to harvesting, does not generate any further increases in C stocks, with the possible exception of soil carbon, and the crediting regime would need to ensure that carbon credits were only issued for real increases in the time-average carbon stocks.

Finally, the question arises how to handle cases where biofuels are a co-product with other outputs (such as pulpwood)? In such a case only the bioenergy fraction of the harvested wood enters the calculations. If the bioenergy component is very small, then the "factor" should limit crediting of LULUCF (see Footnote 1 and Appendix for a detailed discussion).

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plantations where biofuels are a minor by-product, the "factor" would have to be less than 1. Whatever value is finally chosen, there will always be some errors on both sides. One option would be to select the "factor" at a higher level (about 4) for dedicated biofuels plantations, and at lower levels (1 or below) for plantations not mainly established for biofuels production. The use of a formula for deriving the threshold factor is recommended, such as:

Threshold factor = 4 x (share of biomass fuels produced, relative to total biomass harvested).
With this the factor will usually be between 0.5 and 4. In cases where biomass for energy is produced along with other products like timber or pulpwood, only a portion of associated stock changes - corresponding to the share of bioenergy relative to total use of wood - is credited.

A connection between carbon sinks crediting and bioenergy, as proposed here, may be easier to implement in the CDM than in Article 3.3 because the CDM requires, on the international level, the existence of legally defined projects with an agreed duration and scope. Therefore the future use of biomass for energy could be fixed in such a contractual agreement.

Some implications for the economics of biomass energy

The change in carbon stock due to afforestation and reforestation projects is roughly equal to the average carbon stock in the newly established tree crop. For a typical project in a developing country, this may be around 20 tones C/ha/yr, averaged over entire plantations.[15]. It should also be noted that forests established on previously cultivated lands are likely to enhance soil carbon stocks (the exact magnitude is more uncertain; including soil carbon could thus increase crediting but would be more costly to verify at given confidence levels).

Carbon credit prices in the range 10 – 100 $/tC would then imply that accumulated revenues from carbon credits of roughly 200-2000 USD/ha could be generated for the type of plantation discussed above. This can be compared to the costs of plantation establishment, which typically range between 200 and 900 USD/ha (Amatayakul and Azar, 2001,for Thailand; and Azar and Larson, 2000, for Brazil). Thus, crediting the carbon sinks component of plantations could potentially provide a significant push for biomass energy. It would also favor longer rotation periods and some types of crops over others, with annually harvested crops such as corn, sugar cane or grasses having less incentive than short rotation forests.

On the other hand the additional incentive for plantation establishment may increase concerns about intensified land-use conflicts in many developing countries (see e.g., Carrere & Lohman 1996). Thus, it remains important that adequate attention is paid to sustainable development criteria in the CDM when designing carbon abatement projects, including socio-economic and biodiversity criteria. These issues would apply with at least equal force to any LULUCF crediting. Creating a linkage to productive use of accumulated carbon, namely generation of energy to displace fossil fuels, would enhance the wider sustainable attributes in respect of both local employment and contribution to wider national goals of sustainable development – as well as addressing a number of other concerns surrounding the more general crediting of sinks in the CDM.

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[15] The carbon content in a plantation depends on the rotation period (Trot) and the yield (tons C/ha/yr) and is roughly equal to yield*Trot / 2. Typical yield levels on well managed plantations in Brazil, for example, are 10-20 tons dry matter/ha/yr, half of which is carbon, and the rotation period (for pulpwood or charcoal) is typically around six years (Azar & Larson 2001). Assuming the central value for the yield, we get a carbon stock of 22.5 tons C/ha.

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APPENDIX. Potential Carbon crediting under CDM for different biomass energy cycles

Example 1:

Reforestation of a "normal forest system" with annual growth rate of 7 tC/ha/yr, initiated in 2002 (1 parcel planted in 2002, 1 parcel in 2003, 1 parcel in 2004 etc.). Harvest cycle length 8 years. 70% of harvestable material is assumed to be used as biofuels. Each parcel is assumed to comprise 12.5 ha, so that the totals system size is 8 x 12.5 = 100 ha. Such a plantation system would produ ce 12.5 x 39.2 tC/ha harvested = 490 tC to biofuels in each year 2010, 2011 etc.

Figure 2 shows the C budget at the stand level (1 ha), Figure 3 at the landscape level (assumed size 100 ha). Further analyses below focus on the landscape level. Several examples are used to demonstrate how the ratio of carbon sequestered, and biomass harvested, can differ. Finally these results are discussed with relation to possible limits of carbon credits for afforestation and reforestation.

Figure 2: Stand level carbon balance of reforestation for biofuels: maximum C per ha is 56 tC, trot = 8 years. Initial stand establishment in 2002.

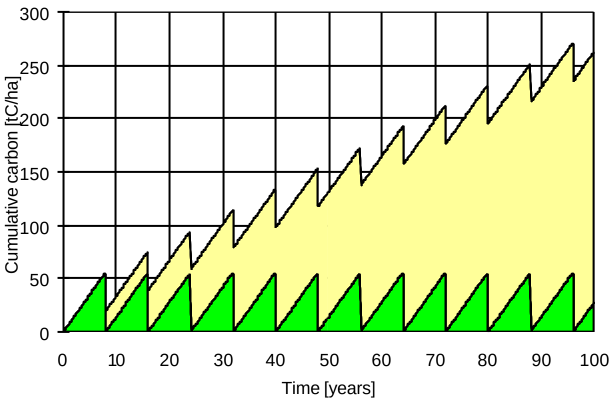
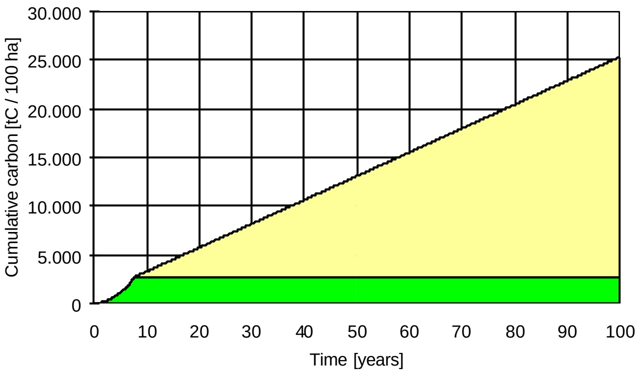


Figure 3: 100 ha of "normal forest" (8 stands comprising 12.5 ha each). The average C stock of the plantation is 56/2 tC/ha x 100 ha = 2800 tC. This is approached between 1 Jan 2002 and 1 Jan 2010. Due to "banking" in the CDM the full amount may be eligible for credits.



<u>LULUCF stock change: 2800 tC</u> (see caption of Figure 2). Biofuel produced by 2012 from this system: 3 years in which harvest occurs (2010, 2011, 2012) on 12.5 ha each. <u>Biofuels produced</u>: 0.7 x 56 x 12.5 x 3 = <u>1470 tC</u>

The ratio of stock change on the land, and biofuels produced (2800 / 1470 in this example) is independent of growth rate. The example excludes changes in soil carbon. If soil carbon were to increase due to the project, then the potential LULUCF credits would also increase.

Example 2:
Same plantation system, but established in 2004, and for the first time harvested in 2012:
LULUCF stock change: 2800 tC
Biofuels produced: 0.7 x 56 x 12.5 = 490 tC

Example 3: (extreme case):
Harvest cycle length is 12 years, plantation initiated in 2000, first harvested in 2012. Growth rate 7 tC/ha/yr, LULUCF stock change: stock accumulated on 100 ha: 7 x 12 = 84 / 2 = 42 x 100 = 4200 tC
Biofuel produced: 84 x 0.7 x 8.333 ha per stand = 490 tC

The difference to the previous example is that now the total accumulated stock is greater (whereas the amount of biofuels produced is the same as in example 2). This is an extreme case because the growth phase of the plantation covers the full time period for which credits are possible (13 years, 2000 – 2012).

Example 4:
As example 1, but stand establishment in 2000 (instead of 2002), and first harvest in 2008 (instead of 2010). This is a pulpwood plantation with only 20% of the harvestable biomass used for energy.
LULUCF stock change: 2800 tC
Biofuels produced: 0.2 x 56 x 12.5 x 5 = 700 tC

Example 5:
Plantation established in 2004, harvesting starts in 2008.
LULUCF stock change: 1400 tC
Biofuels produced: 0.7 x 28 x 25 x 5 = 2450 tC

Table 2: summary of the five examples which have been chosen to include some extreme cases. A more thorough analysis of all possible cases can be found in the Figure 4.

All carbon numbers in this table are for the period 2000 - 2012	**LULUCF stock change (tC)**	**Biofuel Produced (tC)**	**Ratio (LULUCF stock change / biofuels produced)**
Example 1: Bioenergy starts in 2010 (t_rot = 8)	2 800	1 470	1.9
Example 2 Bioenergy starts in 2012 (t_rot = 8)	2 800	490	5.7
Example 3: Bioenergy starts in 2012 (t_rot = 12)	4 200	490	8.6
Example 4:	2 800	700	4.0

Bioenergy starts in 2008 (t_rot = 8)			
Example 5: Bioenergy starts in 2008 (t_rot = 4)	1400	2450	0.6

The ratio (LULUCF stock change / biofuels produced) is between 0.6 and 8.6 in the five examples. If one were to fully credit the stock changes in all five cases, then the threshold "factor" would need to be 8.6 or greater. On the other hand, if one were to begin limiting LULUCF credits from the pulpwood plantation (with biomass for energy as a by-product) in example 4, then the threshold "factor" would need to be below 4.

In more general terms, the "factor" needs to be large enough to allow credit for all projects that have a reasonable biofuels component. The main point of using the factor is to prevent projects that have a biofuels component just for the sake of qualifying afforestation/reforestation for crediting. I.e., the biofuels component should be significant in itself. On the other hand, the factor should be low enough to exclude projects where biofuels only constitute an insignificant project output.

It becomes clear that single cases are not sufficient to systematically analyze this problem. The two parameters that have been modified in the above examples are:

- The year in which plantation establishment begins, and
- The harvest-cycle length.

These two parameters have been modified simultaneously and all possible combinations have been calculated. The output can be shown in three-dimensional diagrams in Figure 4. The top diagram shows the carbon sequestered in an LULUCF project as a function of the two parameters. The two diagrams in the center show the amount of biofuels produced as a function of the same parameters (the left diagram is for a biomass plantation with 70% of the harvested material used for fuel, whereas the right one is for a pulpwood plantation with only 15% of the harvested material used for fuel). The two diagrams at the bottom are a combination of the top and middle diagrams and represent the ratio of (LULUCF carbon stock change between 2000 and 2012 / carbon in biofuels produced between 2000 and 2012). These diagrams provide a comprehensive overview of all possible cases that could occur in the proposed linking of carbon sinks and bioenergy.

In deriving recommendations about the threshold factors, the bottom diagrams will be most important. Taking the example of dedicated biomass plantations (bottom left), it can be seen that the uniformly shaded area in the lower part of the diagram corresponds to those cases where the ratio of (LULUCF stock change / carbon in biofuels produced) is below 2. I.e., if the threshold factor were chosen to be 2, then all these projects would be fully credited. If the factor were chosen to be 4, then also the projects in the dark purple area of the 3-dimensional surface would be fully credited. It appers that a threshold factor of 4 is sufficient to fully credit all projects (except those where the combination of plantation establishment year and harvest-cycle length results in an initial harvest only very late in the first commitment period, so that these projects would not likely be bioenergy projects in the first commitment period. These are the combinations shown on the left of the digram.

The bottom right diagram shows the same situation, but for a plulpwood plantation where only 15% of the harvested biomass is used for energy, 55% is used for pulpwood, and 30% remains on the site. For pulpwood plantations the are of the three-dimensional surface that is below “4” (two different shadings in the lower part of the diagram) is smaller. This means that not as many plantation cases would be fully credited at a threshold factor of 4. However, crediting does not appear sufficiently restricted. For example, a pulpwood plantation established in 2000 and first harvested in 2008 would still fully qualify. It seems more appropriate, in cases where bioenergy is a by-product, to award credit for only a portion of the carbon stock changes on the land. If one quarter of usable biomass is used for energy, and three quarters are used for pulpwood, then a quarter of the LULUCF stock changes could be allocated to the bioenergy project and thus credited – This would suggest an adjustment of the threshold factor depending on the relative share of bioenergy:

Threshold factor = 4 x (share of biomass fuels produced, relative to total biomass harvested).

Part 3:
Potential C crediting of bioenergy options associated with fossil C substitution and C stock change over Kyoto commitment periods

In this section, we give quantitative estimates of the potential contribution of biomass energy to meeting the national emissions commitments in Annex 1 countries and the potential contribution of biomass to carbon emissions mitigation in developing, based on the linking of carbon sink crediting to biomass energy discussed in previous sections. The bioenergy potential depends on supply side factors such as forest wood availbility, land availability for plantations and achievable average yield levels on such plantations. But also demand side factors— including energy technologies, infrastructure, policies and the image of biofuels— come into play[16]. The focus here will be on the supply side. However, we include quantitative estimates based on official national and regional goals for the future bioenergy supply. Both supply and demand side considerations are then implicitly considered, to the extent that such goals reflect a well-informed understanding of both the supply and demand side constraints.

As described in section 1, the net GHG emissions reduction from biofuel use varies substantially among the bioenergy options available (feedstock source, biofuel choice, and fossil fuel substitution pattern). Furthermore, as pointed out in section 2, there might be tradeoffs between maximizing GHG emissions reductions and maximizing eligble emission-reduction credits under the Kyoto Protocol. Any increase in the level of harvesting for biofuels during the First Commitment Period 2008-2012 (CP1) will be at the expense of LULUCF credits that can be earned for afforestation or reforestation in the same period. The trade-off between maximizing on-site carbon stocks and maximizing biomass product output will depend on the relative prices of biofuels/timber vs. the price of CO2 credits, but also on the amount of carbon in fossil fuels that can be displaced with one ton of carbon harvested for bioenergy.

The aim here is to indicate potential C crediting of bioenergy options associated with fossil C substitution and C stock change over the Kyoto first commitment period. Main focus is on activities in Annex 1 countries. First, we present illustrative estimates of potential C credits based on the goal for bioenergy supply in the European Union White Paper on Renewable Energy [2] and the Clinton Executive Order of increasing biobased products and bioenergy use 3 times by 2010 [3, 4]. Then, we provide indicative data on potential C credits from energy crops production, and utilization of forest wood and agricultural residues for energy in Annex 1 countries. Finally, we indicate the potential for achieving emissions reductions outside Annex 1 countries via the inclusion of bioenergy-associated C crediting in the CDM.

The analysis in this section adopts a narrow focus in order to concentrate on the link between C sink credits and bioenergy. There are other, equally or perhaps more important social and environmental aspects related to bioenergy. They have only been

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[16] See e.g., [1] that assessed achievable emission reductions from increased fuelwood use in five selected European countries.

considered in very general terms in relation to biomass energy in developing countries.

The contribution of bioenergy-producing LULUCF activities to national emissions commitments in EU and the United States

Bioenergy has a key role in several national and regional strategies for increased use of renewable energy sources. Below, we will use goals for the bioenergy supply in 2010 in the European Union and the United States as bases for estimates of the contribution of bioenergy-producing LULUCF activities to national emissions commitments.

The estimates (summarized in Tables 5 and 7) should be regarded as *illustrative* of the contribution to emissions commitments, and of the relative importance of the induced C stock change compared to the fossil fuel substitution. As noted in earlier sections, a variation of parameters such as plantation initiation and harvest cycle length influences the amount of eligble emission reduction credits under the first commitment period. Also, the amount of fossil C that is substituted depends on how much of the harvestable biomass[17] that is used as biofuel, and on the net carbon benefits from substituting fossil fuels with biofuels (displacement value). The displacement value varies considerably between different biofuel production pathways.

The European Union

The European Commission 1997 White Paper on renewable energy [2] sets an overall EU target of doubling the contribution of renewables by 2010 (from 5.4 percent 1995 to 11.5 percent of total energy use) with some 85 percent of the renewables being bioenergy.

The biomass supply for energy suggested by the EU is given in table 1. Biogas comes from livestock production, agro-industrial effluents, sewage treatment and landfills. Feedstock for liquid biofuels is not clearly specified in the White Paper. Both short rotation lignocellulosic crops (SRLC) and crops such as sugar beet, rapeseed and wheat could be used as feedstocks. Solid fuels are derived from wood, agricultural residues, and SRLC.

Table 1. EU White Paper goal for bioenergy supply in 2010 (Final energy, Mtoe/yr, PJ/yr in parenthesis).

	Solid	Liquid	Gas
Biogas			15 (641)
Residues	30 (1281)		
Energy crops	27 (1153)	18 (769)	
Total	**57 (2434)**	**18 (769)**	**15 (641)**

Estimates of the potential biomass supply for energy from non-plantation sources in EU are given in Table 2. The estimated potential of wood residues in the forest sector

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[17] Harvestable biomass is here defined as the aboveground biomass in plantations subject to harvest.

can be considered conservative[18], given that commercial forest can offer a range of wood fuel components, e.g. residues, small dimension stemwood and poor quality final crops. Agricultural residues are restricted to straw (part of other agricultural residues —mainly dung— is assumed to be used in the production of biogas). The estimated straw production is based on [6]. Other estimates suggest that more straw (2700-2800 PJ [7, 8]) is produced. Thus, the straw availability for energy assumed for the scenario constructions below may be supplied using a lower fraction than indicated.

When comparing Table 1 and Table 2, note that the numbers in Table 1 refer to final energy[19] while the numbers in Table 2 refer to the energy content of the biomass feedstock (primary energy). For example, given a conversion efficiency of 50 percent in wood-based ethanol production, 2 PJ biomass (primary energy) is converted to 1 PJ ethanol (final energy).

Table 2. Supply of roundwood, industrial wood residues / waste wood, and straw in the EU (PJ/yr). Based on [5]

	Stem wood	forest residues / wood waste	Straw
Forest sector demand	2161[a]		
Supply	2579[b]		1836
Potential supply for bioenergy	418[c]	342[d]	

[a] ETTS V base-low forecast of total demand for stem wood as raw material for forest industries [9]

[b] The supply is set equal to net annual increment

[c] The potential supply of wood for energy is equal to the Roundwood supply – forest sector demand

[d] Wood residues not used in the forest industry

Below, we construct two scenarios for the biomass supply to meet the White Paper goal for biomass in 2010 (see Table 3). In both scenarios, residues from the forest sector and from agriculture are used for the supply of solid fuels. In scenario 1, SRLC provide the balance of feedstock for solid fuels production and also provide the feedstock for liquid fuels production. In scenario 2, SRLC provide the balance of feedstock only for solid fuels production since liquid fuels are produced based on oil, starch and sugar crops. We assume that solid biofuels are produced from biomass at 100 percent efficiency, and that liquid biofuels are produced from biomass at 50 percent efficiency[20] (see e.g., [10-12]).

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[18] Based on [5]. No residues from logging operations are assumed to be recoverable due to the risk that removal of branches and tree tops will affect site productivity in a negative way and hence be in conflict with sustainable forest management. 20 percent of industrial wood residues, and non-recycled waste wood corresponding to 35 percent of total domestic annual consumption of solid wood products, is assumed to be available for energy purposes. Wastepaper recovery rates rise to a technical maximum of 60 percent. No wastepaper is available for energy since non-recycled wastepaper is assumed to be either unrecoverable (e.g., toilet paper) or stored for a long time (e.g., books).

[19] The energy content of the gas, liquid, and solid fuels that is either used for electricity generation, or used directly for the supply of energy services such as heat and mechanical work.

[20] We only consider the conversion of biomass into fuel. Energy inputs in the harvest, transport and processing of biomass into fuels are not considered here.

Table 3. Scenario assumptions for the biomass supply in the European Union in 2010.

	Scenario 1	Scenario 2
Feedstock for liquid biofuel production	lignocellulosic feedstocks	oil, starch, and sugar crops
Availability of non-used forest stem wood for energy	No	Yes
Availability of forest residues/wood waste for energy	Yes	Yes
Availability of agricultural residues for energy	50% of straw	50% of straw

The biomass supplies from residues and SRLC in the two scenarios are given in Table 4. Around 2460 PJ and 735 PJ of biomass are supplied from SRLC in Scenario 1 and Scenario 2, respectively. Note that in Scenario 1, cogeneration of electricity in liquid biofuel production is credited as an extra supply of solid agricultural residues. The two scenarios represent two quite different situations, where Scenario 1 corresponds to a high penetration of SRLC and Scenario 2 corresponds to a low penetration of SRLC due to the use of (i) traditional annual food crops for liquid biofuel production and (ii) additional forest wood from existing managed forests for solid fuel production.

Table 4. Biomass supply in 2010 from forest stemwood, residues and lignocellulosic crops in the two scenarios (PJ/yr, primary energy).

	Feedstock for solid fuels production		Feedstock for liquid fuels production		Total	
	Scenario 1	Scenario 2	Scenario 1	Scenario 2[b]	Scenario 1	Scenario 2
Forest stem wood	0	418	0	0	**0**	**418**
Forest residues / wood waste	342	342	0	0	**342**	**342**
Agricultural residues	1170[a]	939	0	0	**1170**	**939**
SRLC	922	735	1538	0	**2460**	**735**
Total	**2434**	**2434**	**1538**	0	**3972**	**2434**

[a] Cogeneration of electricity in liquid biofuel production is credited as an extra supply of solid agricultural residues. 1 GJ lignocellulosic feedstock yields 0.5 GJ liquid biofuel + electricity corresponding to 0.15 GJ of solid residues (see, e.g., [10, 11, 13]).

[b] Liquid fuels are produced based on oil, starch and sugar crops in Scenario 2

Below, we present estimates of the potential climate change mitigation and C crediting from fossil C substitution and C stock change over the Kyoto first commitment period, based on the biomass supply in the two scenarios. The biomass supply is assumed to be constant at the 2010 level up to year 2012.

For SRLC, it is assumed that the C stock change corresponds to the C assimilation in growing aboveground biomass stock change and does not consider emissions from fossil fuel inputs used in producing the biomass resource. A more careful approach would calculate the C stock change as the sum of (i) the net change in aboveground biomass stock (considering pre-plantation vegetation) and (ii) the change in soil C content induced by the establishment of SRLC production (considering pre-plantation land use history). Our simplifying approach can be considered relevant for the situation where primarily agricultural land and other land with sparse vegetation is used for SRLC production (see also Section 1.5).

We also make the simplifying assumption that the use of straw and forest residues in the two scenarios does not lead to any C stock change. The use of stem wood for energy is assumed to result in a C stock change equal to the carbon content of the harvested stems.

The C stock change associated with the utilization of agricultural residues (straw) for energy, depends on the present straw management and how this is influenced by the increased energetic use of straw. Presently, part of the straw is used for fodder, animal bedding and non-wood pulp production, and some is already used as a solid fuel. In the past, straw used to be burned in the field, but the introduction of regulations governing straw burning in 1983 have increased the incidence of straw incorporation. For example, in the UK, burning in the field of cereal residues decreased from 38 to 11 percent between 1983 and 1992 [14], and the rate of straw incorporation increased from 2 percent in 1983 to 18 percent in 1988. [15]. Based on data for the UK, Lee and Atkins [14] estimated that about 20 percent of generated straw and stover was burned in the field in Western Europe in the early 1990s.

Several of the present straw uses lead to C sequestration, at least temporary. If increased energetic use of straw results in decreased “sequestering” straw uses, the C stock change will be negative. However, if the “base-line” situation includes extensive straw burning without energy recovery, and the straw burned in the field instead is used for energy purposes, the C stock change can be expected to be negligible. Thus, the use of straw for energy will either lead to negative changes in C stock or negligible changes, depending on what is the “base-line” situation.

The use of forest residues for energy is restricted to non-recycled waste wood and projected volumes of industrial wood residues that are not used by the forest industry. The major alternative management options for this wood would be burning without energy recovery or landfilling. Wood sent to landfills decomposes relatively slowly and the energetic use of such wood flows would clearly lead to a C stock decrease. We have not assessed the wood flows to landfills in EU, but the landfill option can be expected to decrease in importance due to restricted landfill capacity and policies aiming at reducing the flow of burnable material to landfills.

The use of forest stem wood for energy will influence both the C assimilation and the amount of stored C in the forest. Stem wood harvest obviously leads to a C stock decrease if the wood would otherwise remain in the forest or be incorporated in long-lived wood products. However, forests are dynamic systems and changing forest conditions influences the structure of the C balance. Old stands that are harvested normally store a large amount of C, but the C assimilation capacity is low (or even negative). The new young stands that are established after the harvest obviously store less C, but have a higher C assimilation rate. When the cutting of stem wood is considerably lower than the growth in forests (which is the case for EU), the general trend is towards older forest stands with decreasing C assimilation rate. In such cases —over national/regional scales— increased cutting of stem wood will result in changes in the age structure towards younger forests in general, with lower average C stock per hectare but higher average C assimilation rate (under otherwise unchanged forest management practices).

The contributions from biomass supply for energy and C stock change over the Kyoto first commitment period, to the emissions commitments are given in Table 5. Since we have chosen to present the potential C crediting as the sum of C in biofuel and the induced C stock change, stem wood harvest for energy will result in zero C credit (C stock change + C in biofuel = 0). Consequently, the contribution from C stock change is consequently restricted to C assimilation in aboveground biomass associated with SRLC production.

It is assumed that SRLC plantations are established with the following characteristics[21]:

-annual growth rate of 7 tC/ha/yr,
-harvest cycle length of 8 years,
-establishment initiated in 2002,
-full plantation area established in 2010,
-constant establishment rate,
-70% of harvestable biomass is assumed to be used as biofuel.

This growth rate is consistent with a biomass yield of 4.9 tC/ha/yr, in line with present yield levels for Europe (see, e.g., [16-19]). The 8 year rotation has been as an average between longer rotations typical of for example eucalyptus, and shorter rotations typical of for example willow.

It is assumed that the energetic use of straw and forest residues is increasing from current levels at a constant rate from 2002 to 2010, so that the supply in Table 4 is met by 2010. For the sake of simplicity, we have assumed that the C and energy content of all biomass sources correspond to 40 GJ/Mg C.

The potential climate change mitigation and C crediting from fossil C substitution and C stock change over the Kyoto first commitment period, based on the biomass supply in the two scenarios, are presented in Table 5. The C in biofuel production in the year 2010 gives an indication of the fossil C that could be substituted and, hence, an indication of possible reductions in emissions. This value, however, is likely to be towards the higher end of the C reduction potential and a more thorough analysis would require consideration of fossil fuels substituted, energy inputs in biofuel vs fossil fuel production, and end-use efficiencies.

The estimates above indicate a potentially significant role for C stock changes associated with SRLC plantations in providing C credits during the first Kyoto Protocol commitment period. Considering that all SRLC production is assumed to have an eight-year rotation, the Table 5 data can be considered indicative of higher end levels regarding potential C credits from C stock changes associated with SRLC production. Annually harvested lignocellulosic crops such as miscanthus have been suggested as attractive candidates in middle and south Europe (see, e.g., [20-22]). Extensive use of annually harvested lignocellulosic crops would reduce the C credits from C stock changes associated with SRLC production substantially.

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[21] See also the C flow modelling in section 1, where similar growth rates but shorter harvest intervals (6 years) are used.

Nevertheless, it is evident that *the total of fossil C substitution and C stock change could contribute significantly to meeting GHG emissions reduction targets.*

One crucial issue is whether enough land could be made available for bioenergy plantations. The White Papers states that "...it is doubtful that more than a maximum of 10 Million hectares, i.e. 7.1% of the agricultural area, would be sustainable for biomass crop production" (pp38). Note that in *Scenario 2*, the production of liquid biofuels would require production of oil, starch and sugar crops on additional land. At an average gross liquid biofuel output of 50-100 GJ/ha/yr [11, 17, 23, 24], approximately 7-15 Mha would be required for the production of 769 PJ of liquid biofuels. Thus, based on the assumed biomass supply patterns and yield levels in SRLC production, both scenarios appear to reach higher end levels what regards land availability.

The issue of land availability for bioenergy plantations is further discussed in subsequent sections.

Table 5. Potential contribution of biofuel supply and C stock change to climate change mitigation and fulfillment of emissions commitments in the first Kyoto Protocol commitment period (EU commitments).

	Scenario 1	*Scenario 2*
Contribution from a CC mitigation perspective		
C in cum. biofuel production from residues up to 2012 (Mt)	227	192
C in cum. biofuel production from SRLC plantations up to 2012 (Mt)	185	55
C in aboveground SRLC plantation biomass in year 2012 (Mt)	351	105
Contribution from a 1st commitment period perspective		
C-stock change 2008-2012 (Mt)	121	36
C in biofuel production from SRLC plantations in year 2010[a] (Mt)	62	18
C in biofuel production from residues in year 2010[a] (Mt)	38	32
C in total biofuel prod. 2010 + C-stock change 2008-2012 compared to 1990 aggregate net emissions, excl. LULUCF (% of net em.)	19%	7%
Land requirement		
Area planted in 2010 (Mha)	12.6	3.8[b]

[a] Indicative of the contribution in the commitment period of 2008-2012

[b] This is only the land decicated to lignocellulosic crops production. Additional land will be required for the production of annual food crops (e.g., cereals, oil crops sugar crops) in order to provide feedstocks for liquid biofuel production.

The United States

The Clinton administration initiated in 1999 a multi-agency effort with the goal of tripling U.S. use of biobased products and bioenergy by 2010 [3, 4]. The quantified goal for the energy sector depends on whether it should apply to (i) the *primary supply* (i.e., tripling of biomass supply from about 3 to 9 EJ), or (ii) *energy output* so that efficiency improvements could facilitate a 3x increase at biomass inputs well below 9 EJ. Early interpretations suggested that the fulfillment of the goal required an increase from 3 EJ to 9 EJ in terms of total biomass used (see, e.g., [25]), while later interpretations suggest less ambitious levels for the biomass supply in 2010. An interagency strategic plan published in December 2000[22], stated the goal as: "...facilitate tripling the use of emerging biobased products and bioenergy and 30 percent use increase of mature lumber, pulp, and paper products by 2010".

Below, we construct two scenarios for the biomass supply in the United States in 2010, based on two different interpretations of the goal of tripling the use of biobased products and bioenergy by 2010. In *Scenario 1*, the early interpretation of the goal (i.e., a tripling of biomass supply to 9 EJ by 2010) is used as an *optimistic* case. In *Scenario 2*, the interagency strategic plan statement of the goal (i.e., a tripling of emerging bioenergy by 2010) is used as a *less optimistic* case[23].

The biomass supply in *Scenario 1* is based on a state level analysis of biomass feedstock availability in the United States in 1999 [27]. SRLC systems are represented by switchgrass, poplar, and willow in that analysis. These crops are presently not produced as dedicated energy sources[24], and the lack of large-scale commercial production, necessitates the use of research data and expert estimates to determine yields and management practices. The outcome of the analysis suggests that for a delivered price up to $55/dt[25], about 3.1 EJ of biomass from SRLC plantations could be produced at a profit at least as great as could be earned producing traditional crops on the same land. The SRLC supply is completely dominated by switchgrass, which is assessed as relatively the least expensive bioenergy crop to produce in the United States (see Figure 1).

However, the absolute supply of SRLC, as well as the relative importance of switchgrass vs. poplar and willow[26], depends on modelling assumptions about biomass prices and management practices. This is illustrated in Figure 1 where an alternative estimate of SRLC availability for a delivered price up to $42-45/dt is included[27] [28]. This estimate is based on SRLC management practices designed to

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[22] http://www.bioproducts-bioenergy.gov/publications.html.

[23] Also this statement of the goal may be revised. A recent analysis of what could be accomplished came up with the conclusion that it would be impossible to obtain a tripling by 2010 (even of just the emerging bioenergy and bioproducts) although a lot could be done. A new time frame has not been clearly established yet, but if it is, it will be closer to 2015 or even 2020 to reach a tripling [26].

[24] About 80,000 hectares of poplar are being commercially produced as a fiber source, and some switchgrass is grown as a forage crop [28].

[25] $55 per dry tonne. [27] report the results in U.S. tons, where 1 ton = 0.9072 tonne. The price $50 per dry ton corresponds approximately to $55 per dry tonne (1 tonne = 1000 kg).

[26] Poplar and willow are grouped together under the acronym SRWC (short rotation woody crops) in Figure 1.

[27] Represented by "switchgrass(WMS)" and "SRWC(WMS)" in Figure 1. WMS is an acronym for wildlife management scenario. The WMS includes restrictions on fertilizer and chemical inputs, and also restricts switchgrass harvest on CRP areas to alternating halves of a field each year. The delivered

achieve high levels of wildlife diversity on Conservation Reserve Program (CRP) areas. In this case, 1.6 EJ could be available from SRLC plantations, with about 60 percent being switchgrass and 40 percent being poplar.

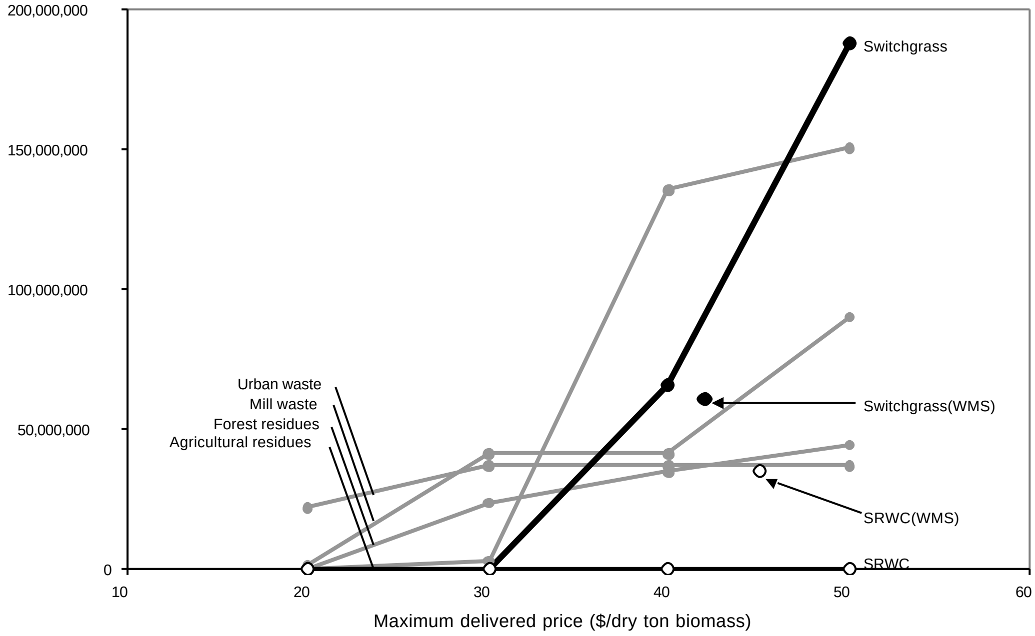

Figure 1. Estimated biomass feedstock availability in the United States in 1999 [27]. An alternative estimate of SRLC availability at the $50/dt level, based on management practices designed to achieve high levels of wildlife diversity on Conservation Reserve Program (CRP) areas [28], is also included (named Switchgrass (WMS) and SRWC (WMS)). SRWC = short rotation wood crops (salix and poplar), WMS = wildlife management scenario. The WMS includes restrictions on fertilizer and chemical inputs, and also restricts switchgrass harvest to alternating halves of a field each year. Agricultural residues are restricted to corn stover and wheat straw. Note that the prices and delivered quantities are given in U.S. tons (1 ton = 907.2 kg).

As was shown in section 1, the revenues from carbon sink credits could potentially provide a significant push for biomass energy —and especially for tree crops such as salix and poplar. Present understanding suggests that switchgrass is relatively more profitable than poplar and willow in the United States, but the difference is not very large[28]. The WMS case, included in Figure 1, is one example of how changing management practices may alter the relative profitability enough that significant areas of SRLC production shift from switchgrass production to poplar production. The linking of C sink crediting to bioenergy production will alter the relative profitability in the same direction. However, while the altered relative profitability of poplar/salix compared to switchgrass followed from a *reduced* relative profitability of switchgrass in the WMS case, the linking of C sink crediting to bioenergy production will lead to an altered relative profitability due to an *improved* relative profitability of SRLC

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price $42-45/dt is based on a farmgate price of $1.94/MBtu. Since the energy content of switchgrass, salix, and poplar differs slightly, the delivered $/dt price differs somewhat among the three crops. An average transportation cost of $8.8/dt is added in order to determine the delivered price.

[28] According to De La Torre Ugarte and co-authors [28], combinations of yields, production costs, and market prices that provide a 15-20% differential in net present value returns between poplar/salix and switchgrass would result in more areas being allocated to poplar and salix, over switchgrass.

plantations in general and of tree crop plantations in particular[29]. Thus, biomass supplies will tend to shift towards tree plantations at the expense of herbaceous crops and all forms of residues.

We make the assumption for *Scenario 1* that SRLC plantations provides 3500 PJ of biomass in 2010, and that 1000 PJ of this biomass comes from tree plantations. The remaining biomass supply is assumed to consist of 2500 PJ agricultural residues, 1000 PJ forest residues, 1500 PJ wood mill residues, and 500 PJ urban waste (see Table 6). In order to avoid double counting of biomass resources, we subtract the present energetic use of biomass in the estimate of the potential contribution of bioenergy to national emissions commitments[30]. The present energetic use of biomass in the United States is dominated by the use of wood in the forest industry and the residential sector. Since this biomass use (about 3 EJ) is roughly equal to the aggregated supply of forest residues, wood mill residues and urban waste in 2010, we simplify the calculations below by excluding these sources[31]. Thus, the total supply of new biomass for energy in *Scenario 1* is assumed to come from SRLC plantations and agricultural residues exclusively.

In *Scenario 2*, it is assumed that the goal of tripling bioenergy use by 2010 applies to emerging bioenergy only. Corn-based ethanol production is used as a basis for calculating the biomass supply corresponding to a tripling of emerging bioenergy. In 1994, around 1.4 billion gallons of ethanol were produced from corn in the United States. This corresponds to around 3 percent of biomass use for energy in 1994 [29]. Since corn-based ethanol constitutes such a small share of total bioenergy supply, even a tripling of its production represent a relatively small change in total bioenergy supply. However, the calculation of the contribution of bioenergy to national emissions commitments in *Scenario 2* is restricted to considering a tripling in ethanol production.

The 1994 level of corn-based ethanol production corresponds to around 110 PJ (21 MJ/liter, LHV basis) and, consequently, about 330 PJ of biofuels would have to be produced in 2010 in order to fulfill the goal of tripling the bioenergy use. Note that this goal is given on a *final energy* basis. The required biomass supply depends on the efficiency in converting biomass to final energy carriers. We assume that 130 PJ of corn-based ethanol is produced in 2010. The remaining 200 PJ of biofuels is produced from lignocelulosic feedstocks at a conversion efficiency of 50 percent. Thus, 400 PJ of biomass is required in order to fulfill the goal. This biomass is assumed to come

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[29] Given that cropland and other land with sparse vegetation is used, so that the C stock increases on land used for SRLC production.

[30] This means that we disregard from the possibilities of efficiency improvements in the present energetic use of biomass as an option for emission reductions.

[31] Forest residues includes logging residues and rough, rotten, and salvage dead wood. The relative importance of these sources is not reported in [27]. To the extent that this wood would otherwise be left in the forest, their use for energy purposes clearly leads to an accelerated C stock decrease. Around 45 percent of the wood mill residues are presently used as fuel in the United States. The rest is used for the production of pulp and composite wood products[31], and a variety of other uses such as bedding, mulch, and charcoal [27]. Obviously, since a substantial share of the wood mill residues are incorporated in products with potentially long lives, an increased use of wood mill residues for energy would lead to a C stock decrease. A proper consideration of C stock changes due to the energetic use of these sources would require a thorough assessment that goes beyond the scope of this report.

from SRLC plantations: 100 PJ from tree plantations and 300 PJ from switchgrass (see Table 6).

Corn-based ethanol production is not included in any of the two scenarios. Since corn is harvested annually, there are no prospects for any substantial aboveground C stock increases due to expanded corn production. In fact, the land-use change induced by an expansion of corn-based ethanol production is by some analysts suggested to lead to C emissions [30]. In addition, the net C benefit from using corn-based ethanol in the transportation sector is relatively small (see e.g., [24, 31]).

Table 6. Biomass supply in 2010 in the two scenarios

	Biomass supply in 2010 (PJ)	
	Scenario 1	**Scenario 2**
Switchgrass	2500	300
Tree plantations	1000	100
Sum SRLC	**3500**	**400**
Agricultural residues (mainly corn stover and wheat straw)	2500	
Forest residues (logging residues, and rough, rotten, and salvage dead wood)	1000	
Wood mill residues	1500	
Urban waste	500	
Sum biomass supply from sources other than SRLC	**5500**	**3000**
Present biomass supply for energy	3000	3000
Sum new biomass supply for energy[1]	**6000**	**400**

[1] The new biomass supply for energy is calculated as the difference between present biomass supply for energy and the total biomass supply in 2010. In *Scenario 1,* the new biomass supply comes from SRLC plantations and agricultural residues. In *Scenario 2,* the new biomass supply comes from SRLC plantations exclusively.

Below, we present the potential climate change mitigation and C crediting from fossil C substitution and C stock change over the Kyoto first commitment period, based on the biomass supply in the two scenarios. As for the EU case, the biomass supply is assumed to be constant at the 2010 level up to year 2012 and the C and energy content of all biomass sources are assumed to correspond to 40 GJ/Mg C.

The energetic use of agricultural residues —mainly corn stalks and wheat straw— is not assumed to lead to any C stock changes. This assumption will lead to a positive bias what regards the C stock (i.e., in reality the C stock can be expected to decrease). The assumption is probably more questionable for the United States than for the European Union, since conservation tillage[32] is more prevalent in United States than in Europe. It is assumed that the energetic use of agricultural residues (wheat straw and corn stover) increases at a constant rate from 2002 to 2010, so that the supply in Table 6 is met by 2010.

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[32] A conservation tillage system is defined as “any tillage and planting system that covers 30 percent or more of the soil surface with crop residue, after planting, to reduce erosion by water. Where soil erosion by wind is a primary concern, any system that maintains at least 1000 pounds per acre of flat, smal grain residue equivalent on the surface throughout the critical wind erosion period” [29]. 1000 pounds per acre is around 1120 kg per hectare.

Switchgrass production is not assumed to alter the aboveground C stock. Although the long-term C balance may be clearly positive if the switchgrass is planted on land used for annual food crops production, or other land with sparse vegetation. The area used for switchgrass production is assumed to increase at a constant rate from 2002 to 2010, so that the supply in Table 6 is met by 2010. Using the national average switchgrass yield from the modelling study that was used for the state level analysis of biomass feedstock availability in the United States in 1999 (about 180 GJ/ha/yr [28]), around 13.9 and 1.7 Mha of land will be required for the switchgrass production in 2010 in *Scenario 1* and *Scenario 2* respectively.

For the share of the SRLC plantation area that is dedicated to tree crops, the same parameters are used as in the illustrative calculations for the European Union:

-annual growth rate of 7 tC/ha/yr,
-harvest cycle length of 8 years,
-establishment initiated in 2002,
-full plantation area established in 2010,
-constant establishment rate,
-70% of harvestable biomass is assumed to be used as biofuel.

The resulting biofuel yield (4.9 tC/ha/yr) and the harvest cycle length can be compared with the poplar yield ranges used in the modeling employed to support the state level analysis of biomass feedstock availability in the United States in 1999, referred to above [27, 28]. The state-average yields range from approximately 4 to 6.5 tC/ha/yr[33] and the harvest intervals range from 6 to 10 years. The area dedicated to tree crops production by 2010 is 5.1 and 0.5 Mha in *Scenario 1* and *Scenario 2* respectively.

The potential climate change mitigation and C crediting from fossil C substitution and C stock change over the Kyoto first commitment period, based on the biomass supply in the two scenarios, are presented in Table 7. As for the EU case, the C in biofuel production in the year 2010 gives an indication of the higher end of the C reduction potential from fossil fuel substitution. As can be seen, the results for *Scenario 1* indicate that the fulfillment of the goal of tripling biomass *supply* for energy would potentially lead to a substantial reduction of aggregate net GHG emissions in the United States. The potential contribution to reaching the emissions commitments under the first Kyoto Protocol commitment period would also be substantial. On the other hand, the restriction of the 3x goal to apply to emerging bioenergy only (represented by *Scenario 2*), would lead to quite modest potential GHG emissions reductions and the fulfillment of the emissions commitments would mainly have to be based on other options.

From a climate change mitigation perspective, the potential contribution from switchgrass and residues up to the year 2012 is indicated as larger than the contribution from tree crops in Table 7. From a 1st commitment period perspective on the other hand, tree crops potentially become the major contributor. As emphasized earlier, the climate change mitigation efficiency —as well as the potential C credits during the first Kyoto Protocol commitment period— depends on the replacement

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[33] 3.56-5.73 dt/ac/yr [28]. The C content of 1 dt is assumed to be 0.9072 x 0,5 = 0.45 tonne.

value of biofuels. The replacement value of biofuels also determine the relative importance of C stock changes relative to biofuel production. If the replacement value is low, the relative importance of C stock changes become larger and tree plantations become more favourable. If the replacement value is high, annually harvested crops such as switchgrass may be preferable.

Table 7. Potential contribution of biofuel supply and C stock change to climate change mitigation and fulfillment of emissions commitments in the first Kyoto Protocol commitment period (US commitments).

	Scenario 1	*Scenario 2*
Contribution from a CC mitigation perspective		
C in aboveground plantation biomass in year 2012 (Mt)	143	14
C in cum. biofuel production from tree plantations up to 2012 (Mt)	75	8
C in cum. biofuel production from switchgrass up to 2012 (Mt)	375	45
C in cum. biofuel production from residues up to 2012 (Mt)	375	0
Contribution from a 1st commitment period perspective		
C-stock change 2008-2012 (Mt)	49	5
C in biofuel production from tree plantations in year 2010[a] (Mt)	25	2,5
C in biofuel production from switchgrass in year 2010[a] (Mt)	63	8
C in biofuel production from residues in year 2010[a] (Mt)	63	0
C in total biofuel prod. 2010 + C-stock change 2008-2012 compared to 1990 aggregate net emissions, excl. LULUCF (% of net em.)	12	0.9
Land requirement		
Area planted in 2010 (Mha)	19	2.2

[a] Indicative of the contribution in the commitment period of 2008-2012

The biomass supply from SRLC plantations and total amount of land used for SRLC production in *Scenario 1* (3500 PJ, 19 Mha) can be compared with the approximately 17 Mha that was dedicated to switchgrass production in order to supply the 3075 PJ of biomass that was estimated available for a delivered price up to \$55/dt (see Figure 1). According to [28] this amount of land could be dedicated to switchgrass production at a profit at least as great as could be earned producing traditional crops on the same land[34]. Thus, the land requirements seem not to rule out *Scenario 1*.

The plantation expansion rate may be more limiting than ultimate availability of land. The planting rate depends on both supply-side factors such as adoption rates among farmers, and demand-side factors including biomass energy technologies and infrastructure. We have not considered the planting rate as a constraint here. However, one way to explore the supply-side constraints on the possible expansion rate of SRLC plantations is to analyse the adoption rates of new crops among farmers. This approach was used by Walsh [32], who used the soybean experience as basis for projecting the potential production expansion rate for bioenergy crops. Soybean increased from almost zero in 1920 to around 6 Mha in USA in 1950. The soybean area in 1961 was 10,928 Mha and 23,626 Mha in 1992 (an expansion of 2.5% per year leading to 36% of total cereal area). Adoption rates were then 202000 ha/yr during 1920 to 1950, 410000 ha/yr during 1961-1992, and almost 330000 ha/yr over the whole 1920 to 1992 period. This can be compared to the expansion rate of RSLC plantations in *Scenario 1*, which is about 2.1 Mha/yr during the 2002-2010 period.

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[34] Traditional crop prices increased by 8 to 14 percent and net farm income increased by \$6 billion annually.

Based on this comparison, the SRLC planting rate in *Scenario 1* appear to represent a very ambitious target.

Potential C credits from SRLC production and use of forest wood and agricultural residues for energy in Annex 1 countries

In the subsequent sections, we provide indicative data on the C credits that could result from (i) production of SRLC biomass as dedicated energy sources, (ii) increased utilization of forest biomass for energy, and (iii) utilization of agricultural residues for energy. The data are given for Annex 1 countries. For the SRLC biomass option, the data are supplemented with estimates of the possible extent of SRLC plantations on country and regional level.

The analysis presented in this section constitutes the basis of a more detailed analysis of scenarios involving different biomass production pathways. A spreadsheet model has been developed that allows to perform the calculations for different biomass production routes based on assumptions about parameters such as yield and harvest cycle length.

SRLC plantations on agricultural land in Annex 1 countries

Figure 2 indicates the possible contribution of SRLC plantations to meeting the national emissions commitments in Annex 1 countries. The C in biofuel produced in 2010[35], and the aboveground plantation C stock change during the first commitment period, are given as percentages of aggregate net GHG emissions 1990, excluding LULUCF[36].

The SRLC plantation characteristics underlying the results in Figure 2 are as follows:

SRLC system 1 (identical to the one used in Section 3.1)

- -annual growth rate of 7 tC/ha/yr,
- -harvest cycle length of 8 years,
- -establishment initiated in 2002,
- -full plantation area established in 2010,
- -constant establishment rate,
- -70% of harvestable biomass is assumed to be used as biofuel.

SRLC system 2 (shorter harvest interval)

- -annual growth rate of 7 tC/ha/yr,
- -harvest cycle length of 3 years,
- -establishment initiated in 2001,
- -full plantation area established in 2010,
- -constant establishment rate,
- -70% of harvestable biomass is assumed to be used as biofuel.

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[35] Indicative of the contribution in the commitment period of 2008-2012

[36] Available at http://www.unfccc.de/

It is assumed that 1 percent of the agricultural area in a country/region is planted with energy crops by 2010. This allows to derive indicative estimates of C credits based on other assumptions about land availability for biomass plantations. For example, if plantations on 1 percent of agricultural land produces biomass and sinks crediting corresponding to 2 percent of aggregate net GHG emissions (as in the EU), then *ceteris paribus* biomass supply and sink crediting from plantations on 10 percent of agricultural land would correspond to 20 percent of aggregate net GHG emissions. The calculations presented in Figure 2 could be performed for a variety of other plantation characteristics, by varying parameters such as yields and rotation length.

As illustrated by the selection of examples in Appendix 1 to Section 2, a variation of parameters such as plantation initiation and harvest cycle length influences the amount of eligible emission reduction credits under the first commitment period. Thus, Figure 2 should be valued with the insights from that Appendix in mind. Note also that the amount of C in *biofuels* is presented in Figure 2. The amount of *fossil* C that is substituted depends on the replacement value of the specific biofuel route chosen[37].

Soil C changes are not considered here. The impact of land use change on soil C content depends on land use/land cover history, energy crop species, management practice and time period under consideration. The soil C changes are likely to be positive when annual crops are replaced with SRLC plantations that are subject to less intensive soil manipulation. However, the changes can under other circumstances be negative. For example, managed pastures have the potential to increase the carbon storage in surface soils, and the soil C content in pastures can be several times higher than in croplands [33]. If such pastures are converted to energy crops production, the initial soil C loss during land conversion may lead to soil C levels that are below the pasture level for many years, unless the soil C accumulation rates under SRLC production are significantly higher than for pasture management.

It is evident from Figure 2 that SRLC plantations could make a significant contribution to meeting national emissions commitments even if only a few percent of agricultural land could be used for such plantations[38]. Other studies support these findings, in particular with regard to the biomass potential for fossil C substitution. However, it is also clear from Figure 2 that the contribution from aboveground plantation C stock change during the first commitment period can be substantial. Thus, the linking of carbon sink crediting to biomass energy could significantly increase the attractiveness of using SRLC plantations for GHG emissions reduction in Annex 1 countries. From a comparison of the two different SRLC systems in Figure 1, it is evident that one effect of the proposed carbon sink crediting would be that short rotation forests that are grown for several years before harvest would be favourable over other crops such as corn, sugar cane, and herbaceous crops. The implication of this effect warrants further investigation.

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[37] See Section 1 and APPENDIX 1 for illustrating examples.

[38] Provided, of course, that the biomass is produced and used to substitute for fossil fuels in way that generates substantial reductions in net GHG emissions per hectare.

Tables 8-10 presents data complementary to Figure 2. In Table 8, the aboveground plantation C stock change during the first commitment period, and the amount of C in aboveground biomass in 2010, are presented in terms of Gg C in biomass, and also as percentages of aggregate net GHG emissions 1990, excluding LULUCF. Table 9 presents a comparison of the total plantation area and annual planting rate for the *1-percent* case presented in Figure 2, with present plantation area[39] and data on projected average annual area afforested 1990-2012 (as estimated in documents submitted by parties until 15 August 2000[40]). Unfortunately, no afforestation projections for countries with economies in transition were available.

Table 10 summarizes the findings from a selection of studies assessing the availability of land for bioenergy plantations in Europe and the United States. Assessments of the availability of land for bioenergy plantations in industrialized countries have focused on the possibilities to use agricultural land. Most assessments have been based on analyses of future supply and demand for agricultural products. Surplus agricultural production is seen as an indication of a future surplus of agricultural land that can be available for uses other than food production. Set aside schemes such as those under the Common Agricultural Policy (CAP) in the European Union, and the Conservation Reserve Program (CRP) in the United States, have also been used as bases for assessments of future availability of land for bioenergy plantations. More recently, agricultural sector models have been modified so as to include energy crops in order to analyze the impact of large-scale energy crop production on e.g., farm income and prices of traditional food crops. One indication from these studies is that, given a large enough demand, energy crops will not be restricted to surplus (idle or set-aside) land but also compete for cropland with traditional food and feed crops. In fact, conversion of cropland to energy crops production could take place before the surplus land area is fully utilized for bioenergy plantations.

As can be seen, the lands claimed for bioenergy plantations in the European Union and the United States in the *1-percent* case are below most estimates of land availability in Table 10. However, the possible plantation contribution to meeting emissions commitments under the first Kyoto Protocol commitment period, is more likely limited by the planting rate than by ultimate availability of land. The planting rate depends both on supply-side factors such as adoption rates among farmers, and demand-side factors, including biomass energy technologies and infrastructure. The data on projected average annual area afforested 1990-2012 in Table 9 provides a benchmark that can be used for evaluation of the annual planting rate for the *1-percent* case.

As can be seen, both Australia and Canada (both have high C credits in Figure 2) project much lower average annual afforestation rates than what is claimed in the *1-percent* case. Note also that only 10 percent of the projected afforestation 1990-2012 in France is induced by means of planting or artificial seeding. Thus, based on this benchmark, the SRLC planting in the *1-percent* case for France can be considered high despite the fact that the projected total afforestation rate is approximately twice as high.

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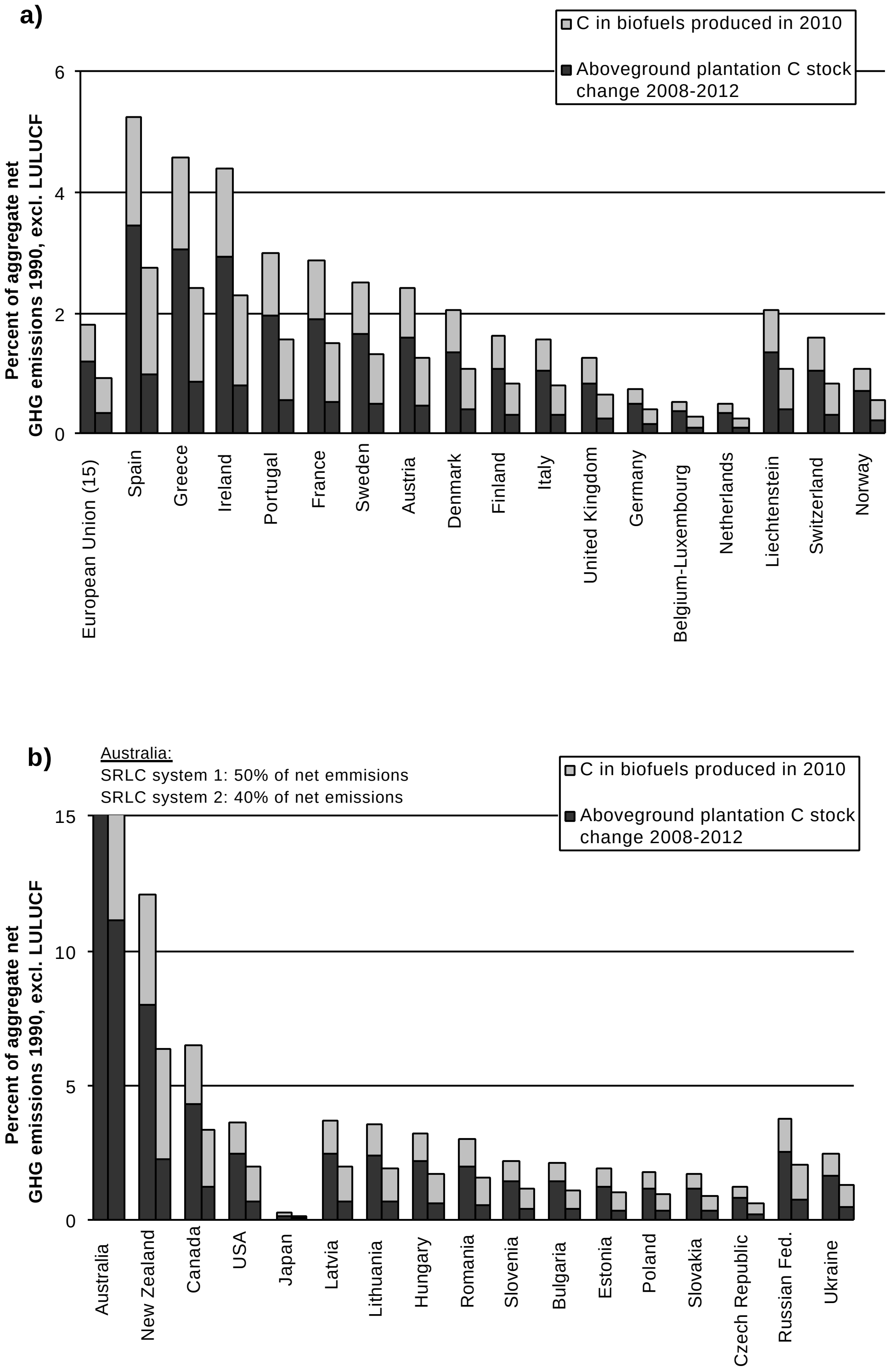
[39] Forest Resources Assessment 2000, http://www.fao.org/forestry/fo/fra/index.jsp

[40] FCCC/SBSTA/2000/9/Add.1

There are also countries that project higher afforestation rates. Portugal is one notable example, where the projected average annual afforestation rate 1990-2012 is almost 10 times the SRLC planting rate in the *1-percent* case. Assuming a SRLC planting rate similar to the projected average afforestation rate, the potential C credits (C stock increase 2008-2012 and C in biofuels produced in 2010) correspond to 16-30 percent of aggregate net GHG emissions in 1990 for SRLC system 1 and 2 respectively. Also New Zealand, which already in the *1-percent* case had a very favourable situation, projects higher average annual afforestation rates 1990-2012 (approximately 100%). The favourable situation for New Zealand in this regard has also been pointed out by others. For example, Ford-Robertson and co-authors [34] report that carbon uptake by afforestation of pastures in New Zealand since 1990, during the first commitment period, could be as high as 38 Mt C. This can be compared with the C stock change 2008-2012 associated with C assimilation in aboveground SRLC biomass of 0.5-1.6 Mt C for SRLC system 1 and 2 respectively (see Table 8).



Australia:
SRLC system 1: 50% of net emmisions
SRLC system 2: 40% of net emissions

Figure 2. The possible contribution of SRLC plantations to meeting the national emissions commitments in Annex 1 countries. The C in biofuel produced in 2010, and the aboveground plantation C stock change during the first commitment period, are given as percentages of aggregate net GHG emissions 1990, excluding LULUCF. It is assumed that an area corresponding to 1 percent of agricultural land is used for SRLC production. The two bars for each country refer to SRLC system 1 (left) and SRLC system 2 (right). See text for characterization of the two SRLC systems.

Table 8a. Contribution of SRLC plantations to meeting the national emissions commitments in Annex 1 countries. The data refer to the case where 1 percent of agricultural area is used for SRLC production (SRLC system 1) by 2010.

	Aboveground plantation C-stock change 2008-2012		C in biomass produced 2010	
	(Gg C)	(% of aggregate net emissions of all GHG 1990, excl LULUCF)	(Gg C)	(% of aggregate net emissions of all GHG 1990, excl LULUCF)
OECD countries				
European Union (15)	13,716	1.2	6,983	0.6
Austria	329	1.6	168	0.8
Belgium-Luxembourg	146	0.4	74	0.2
Denmark	257	1.4	131	0.7
Finland	220	1.1	112	0.5
France	2,882	1.9	1,467	1.0
Germany	1,672	0.5	851	0.3
Greece	875	3.0	445	1.5
Ireland	425	2.9	216	1.5
Italy	1,480	1.0	753	0.5
Netherlands	190	0.3	97	0.2
Portugal	344	2.0	175	1.0
Spain	2,895	3.5	1,474	1.8
Sweden	315	1.7	160	0.8
United Kingdom	1,685	0.8	858	0.4
Liechtenstein	1	1.4	0.5	0.7
Monaco	0	0.0	0	0.0
Switzerland	152	1.1	77	0.5
Norway	101	0.7	51	0.4
Iceland	219	31.2	112	15.9
United States of America	40,257	2.4	20,494	1.2
Canada	7,190	4.3	3,660	2.2
Japan	520	0.2	265	0.1
Australia	45,430	39.3	23,128	20.0
New Zealand	1,596	8.0	812	4.1
Countries with transition economies				
Bulgaria	597	1.4	304	0.7
Croatia	303		154	
Czech Republic	412	0.8	210	0.4
Estonia	138	1.2	70	0.6
Hungary	596	2.1	303	1.1
Latvia	239	2.5	122	1.3
Lithuania	336	2.4	171	1.2
Poland	1,775	1.2	904	0.6
Romania	1,419	2.0	723	1.0
Slovakia	235	1.1	120	0.6
Slovenia	75	1.4	38	0.7
Russian Federation	20,901	2.5	10,641	1.3
Ukraine	4,005	1.6	2,039	0.8

Table 8b. Contribution of SRLC plantations to meeting the national emissions commitments in Annex 1 countries. The data refer to the case where 1 percent of agricultural area is used for SRLC production (SRLC system 2) by 2010.

	Aboveground plantation C-stock change 2008-2012		C in biomass produced 2010	
	(Gg C)	(% of aggregate net emissions of all GHG 1990, excl LULUCF)	(Gg C)	(% of aggregate net emissions of all GHG 1990, excl LULUCF)
OECD countries				
European Union (15)	3,879	0.3	6,983	0.6
Austria	93	0.5	168	0.8
Belgium-Luxembourg	41	0.1	74	0.2
Denmark	73	0.4	131	0.7
Finland	62	0.3	112	0.5
France	815	0.5	1,467	1.0
Germany	473	0.1	851	0.3
Greece	247	0.9	445	1.5
Ireland	120	0.8	216	1.5
Italy	419	0.3	753	0.5
Netherlands	54	0.1	97	0.2
Portugal	97	0.6	175	1.0
Spain	819	1.0	1,474	1.8
Sweden	89	0.5	160	0.8
United Kingdom	477	0.2	858	0.4
Liechtenstein	0	0.4	0.5	0.7
Monaco	0	0.0	0	0.0
Switzerland	43	0.3	77	0.5
Norway	29	0.2	51	0.4
Iceland	62	8.8	112	15.9
United States of America	11,386	0.7	20,494	1.2
Canada	2,034	1.2	3,660	2.2
Japan	147	0.0	265	0.1
Australia	12,849	11.1	23,128	20.0
New Zealand	451	2.3	812	4.1
Countries with transition economies				
Bulgaria	169	0.4	304	0.7
Croatia	86		154	
Czech Republic	117	0.2	210	0.4
Estonia	39	0.4	70	0.6
Hungary	169	0.6	303	1.1
Latvia	68	0.7	122	1.3
Lithuania	95	0.7	171	1.2
Poland	502	0.3	904	0.6
Romania	401	0.6	723	1.0
Slovakia	67	0.3	120	0.6
Slovenia	21	0.4	38	0.7
Russian Federation	5,911	0.7	10,641	1.3
Ukraine	1,133	0.5	2,039	0.8

Table 9. Area used for bioenergy 2010 if 1 percent of the national agricultural area is used for SRLC production. Present plantation area and projected afforestation 1990-2012 is presented for comparison.

	Total new plantation area 2010 (1000 ha)	*Annual planting rate 2002-2010 (1000 ha)*	Present plantation area[i] (1000 ha)	*Average annual afforestation rate 1990-2012[ii] (1000 ha/yr)*
OECD countries				
European Union (15)	1,425	*178*		
Austria	34	*4*	0[iii]	*11*
Belgium-Luxembourg	15	*2*	294[c]	
Denmark	27	*3*	341	*2*
Finland	23	*3*	0[c]	*6*
France	299	*37*	961	*88*[iv]
Germany	174	*22*	0[c]	*7*
Greece	91	*11*	120	
Ireland	44	*6*	590	*17*
Italy	154	*19*	133	*10*
Netherlands	20	*2*	100	*0.5-2.5*
Portugal	36	*4*	834	*34*
Spain	301	*38*	1904	*54*[v]
Sweden	33	*4*	569	*11*
United Kingdom	175	*22*	1928	*18*
Liechtenstein	0	*0*	0,3[c]	
Monaco	0	*0*		
Switzerland	16	*2*	4	*0.1*
Norway	11	*1*	300	*33*
Iceland	23	*3*	12	*0.9*
United States of America	4,183	*523*	16238	*580*
Canada	747	*93*	6080[vi]	*2*
Japan	54	*7*	10682	*6*
Australia	4,720	*590*	1043	*61*
New Zealand	166	*21*	1542	*46*[vii]
Countries with transition economies				
Bulgaria	62	*8*	969	
Croatia	32	*4*	47	
Czech Republic	43	*5*	0	
Estonia	14	*2*	305	
Hungary	62	*8*	136	
Latvia	25	*3*	143	
Lithuania	35	*4*	284	
Poland	184	*23*	39	
Romania	147	*18*	91	
Slovakia	24	*3*	15	
Slovenia	8	*1*	1	
Russian Federation	2,172	*271*	17340	*70*
Ukraine	416	*52*	4425	

Table 10. Availability of land for bioenergy plantations in the European Union and the United States

Country/region and year	**Land availability / land used for SRLC plantations**		**Comments**	**Ref.**
	Mha	**Share of agricultural land**		
EU (12), 2010	15-20	-	Refers to a model exploration based on four scenarios for future diet, food trade, and productivity in agriculture [37], which found that 40-100 Mha of agricultural land could *technically* be available for other uses by the year 2025.	[38]
Europe[viii], 2010	13.5	10% of agricultural land	Based on trends in the areas in agricultural set-aside	[15]
EU (15), 2005	neg.-19		Based on an estimated availability of agricultural land for other uses at 15-21 Mha. Consideration of other land claims [ix], results in a land availability for bioenergy plantations ranging from negative (- 28 Mha) to 19 Mha	[17]
W. Europe[x], 2020	20-25		Scenario studies indicates that this amount of agricultural land will be available for non-food crops	[39]
USA	7		Based on a total 10 Mha of CRP land. Removal of areas that are most environmental sensitive (3 Mha) from consideration for bioenergy results in a potential availability of 7 Mha	[28]
USA	2 - 8		An exogenous $1-4 billion demand for switchgrass ($24/Mg) as fuel are simulated as static shocks in a general equilibrium model for the U.S. economy of 1993. The $1-4 billion demand resulted in a 2-12% increase in farm sector prices. The net farm income decreased 2-11% for livestock producers, but increased 2-13% for the farm sector as a whole. The cost of food to consumers (food CPI) increased 0.26-1.5%.	[40]
USA, 2007	6	5% of cropland	The economic impact of energy crop production on the U.S. agriculture is analyzed for the period 2000-2007 by defining alternative price levels for energy crops. At prices equivalent to $2.9/MBTU ($2.75/GJ), nearly 5% of all cropland was devoted to energy crops (mainly switchgrass). All major crops lost acreage, but this was more than offset by increasing crop prices (e.g., 2% for corn, 8% for wheat and 4% for soybeans), so that net returns were higher after the introduction of energy crops.	[41]
USA, 2008	8 - 17		Energy crops prices equivalent to $1.94/MBtu ($1.8/GJ) and $2.58/MBtu ($2.4/GJ)[xi] results in a shift to energy crops on 8-17 Mha during the simulation period 2000-2008. Compared to baseline, traditional crop prices increased 3-9% and net farm income increased 6% in the low energy crop price case. In the high price case, traditional crop prices increased 8-14% and net farm income increased 12%.	[28]

Use of forest wood for energy

A substantial share of present forest wood removals is used for energy. The wood that is used for energy can be stemwood in forest formations, and it can come from non-inventoried sources, such as tops and branches, and trees outside the forest. Wood industry residues and recovered wood waste are additional sources for energy. Such *indirect* energy use[41] makes up a large part of the total wood energy use (See Figure 3). Most of the wood products disposed of in a year were produced and sold in earlier years. Thus, the indirect use of forest wood for energy includes wood that has been extracted from the forest in earlier years. Also, part of the wood that is used for energy in a certain country may be removed from a forest in another country.

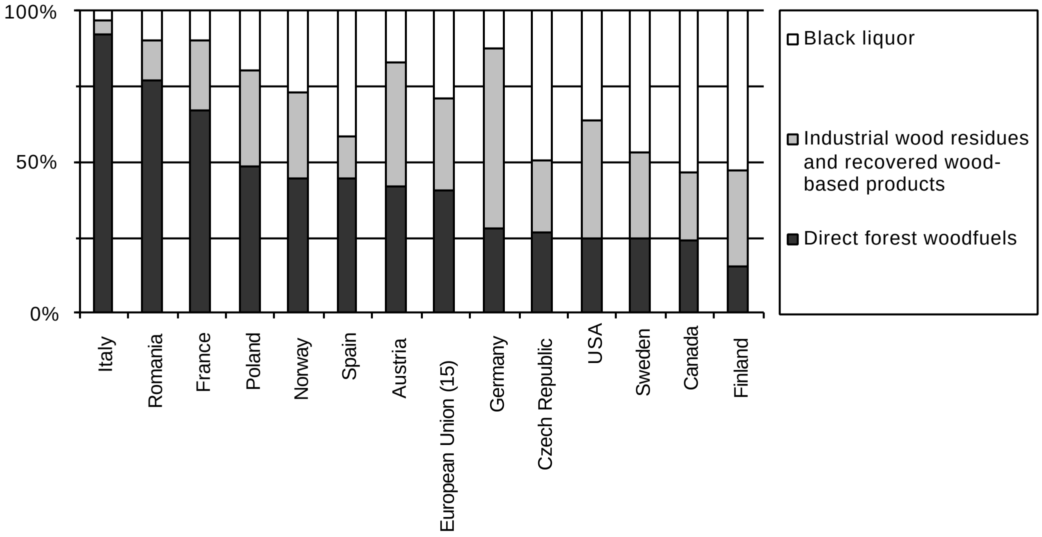


Figure 3. The division of wood energy use 1990 between direct and indirect use in a selection of Annex 1 countries. Based on [42].

The wood energy use differs in character among the countries. In France —which was the largest wood energy consumer in EU-15 in 1990— total wood energy use corresponded to about 80 percent of forest wood removals, with half of this being direct woodfuels[42]. This can be compared to the case of Sweden, where total wood energy use corresponded to slightly more than half of removals. The direct woodfuel share of total wood energy in Sweden was only half that in France (about 25 percent). Instead, black liquor dominated, contributing about half of total wood energy use.

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[41] Here, the designation "Direct use of forest wood for energy" refers to woodfuels that are removed from the forest with conversion into energy as the most important driving factor

[42] One explanation to the high ratio of forest wood energy use to forest wood removals in France in 1990 is likely that the household sector dominated the wood energy use (over 80 percent), and that about 60 percent of direct woodfuels came from non-inventoried growing stock. In Sweden, where industry, district heating, and grid-connected power and CHP production constituted almost 70% of total wood energy use in 1990, only 16 percent of direct wood use for energy came from non-inventoried sources. In the EU-15 as a whole, the household sector used 50-60 percent of total wood energy use in 1990 [42]. According to [42], the quality of available data for other regions were of too low quality for making estimates of sectoral consumption.

The role of wood energy demand as a driver behind forest wood harvest is outlined in Figure 4, where the total forest wood removals, and also the ratio of direct forest woodfuel use to total forest wood removals, are presented. As can be seen, the direct use of forest wood for energy is a major driver behind wood extraction. This is especially true for countries that do not have large wood product industries.

The use of forest wood for energy can be increased by (i) increasing the extraction of forest wood (removal of residues from industrial stemwood harvest and from silvicultural treatments such as thinning, harvest of stemwood[43] for energy), and (ii) increasing the share of industrial forest wood removals that ultimately is used for energy. The first option directly influence the carbon store in forests, while the second option does not directly influence the carbon store in forests. However, if the energetic use competes for wood presently used as raw material for other purposes, then increased industrial roundwood production may be required in order to produce the demanded wood products.

The second option is linked to the material use of forest wood, and the supply of wood for energy is therefore ultimately limited by the demand for wood products. The first option is in principle not restricted by wood product demand, but when bioenergy competes on an energy market, a rational expansion of forest wood use for energy utilizes wood residues as long as such sources are available. In such cases, also the first option can be expected to operate in concert with wood removals for material purposes, and stemwood extraction for energy will be of limited extent as long as there is cheaper biomass available from other sources. However, as was noted above, the household sector is a large consumer of wood for energy, and the dynamics in this sector can be expected to be less tied to the development in the forest industry.

Figures 5-6 provide perspectives on the potential contribution from forest wood to meeting the national emissions commitments in Annex 1 countries. In Figure 5 , the net annual increment[44] (NAI) in forest and other wooded land is presented in terms of the amount of C in wood. The NAI is also given in terms of percentages of the C equivalent of the aggregate net GHG emissions 1990, excluding LULUCF. As can be expected, Figure 5 indicates ample opportunities for using forest wood for energy in order to fulfill national emissions commitments in countries with large *per capita* forest resources. However, from a climate change mitigation point of view, the *absolute* NAI is of higher interest. For example, EU countries like France and Germany have larger absolute NAI than countries like Austria and Finland, but they also have much larger GHG emissions. Consequently, the possibilities appear to be larger in Finland and Austria in Figure 5.

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[43] In conventional forestry stemwood is harvested in diameter classes, where larger diameter classes are used for sawnwood production and smaller diameter classes are used for pulp production. Wood with a diameter below a certain limit (branches and tops of trees) constitute forest residues. “Stemwood harvest for energy” is here used for operations where stemwood of diameter classes suitable for sawnwood or pulp production is harvested and used for energy purposes.

[44] NAI can be considered a useful first approximation of the potential sustainable wood harvest level. It should be noted however, that the NAI data here reflect the current age class distribution of the forest and the current level of forest management. Especially where there is a dominance of old growth timber, where growth rates are low although there a large volumes of wood available for harvest, the use of NAI as an indicator of wood availability for harvest can be misleading. If the old growth inventory is harvested, NAI can be expected to increase as new stands replace the present mature and over-mature stands.

The NAI used in Figure 5 can be considered indicative of the *ultimate* wood energy potential (given present age class distribution of the forest and the current level of management), and the actual potential of forest wood supply for energy is of course much lower. In part of the forest, legal, economic, or environmental restrictions prevent any significant supply of wood. In addition, a substantial part of the forest wood potential is already used in conventional industrial roundwood production.

Figure 6 presents an estimate of the potential forest wood supply in excess of what is already used in the forest industry. The potential wood supply is indicated by the difference between NAI and annual fellings on growing stock in forest available for wood supply (FAWS)[45]. Also, the amount of C in wood corresponding to the difference between NAI and fellings on growing stock in FAWS is compared with the C equivalent of the aggregate net GHG emissions 1990, excluding LULUCF. As can be expected, the potential contribution to national emissions commitments (indicated by the bars in Figure 5-6) is reduced to much lower levels when legal, economic, or environmental restrictions —and competition from traditional forestry— is considered.

At a glance, the same countries appear to stand out as having potentially large forest wood availability for energy in Figure 5 and Figure 6. However, the reductions due the restrictions introduced vary substantially among the countries. In Canada the potential wood supply is 30 times lower and in Portugal the reduction is a factor 9. The potential wood supply in Switzerland is 6 times lower and several countries (Belgium-Luxembourg, Finland, Sweden, USA and Australia) experience a 4-5 fold reduction in potential wood supply.

The amount of wood corresponding to the difference between NAI and fellings on growing stock in FAWS is large compared to national emissions commitments in several countries. In the European Union, Sweden, Finland and Austria stand out. In Annex 1 countries outside the European Union, Norway, Russia, New Zealand, Latvia, Slovakia, and Slovenia appear to have a large non-used wood increment relative to the national emissions commitments. Once again, the *absolute* level of potential wood supply (indicated by the gap between NAI and fellings in Figure 5) is distributed somewhat differently among countires. From this perspective, Russia is in a class by itself, but also the United States have a large NAI in excess of fellings. The level in the European Union as a whole is about 60 percent of the level in United States. Japan, Australia, Germany, France, Sweden, Finland also have a large NAI in excess of fellings.

As already discussed, the extraction of forest wood for energy will influence both the C assimilation and the amount of stored C in the forest. Also the energetic use of industrial wood residues can lead to C stock decreases since a substantial share of such wood residues presently are incorporated in products with potentially long lives. In order to make estimates of the full carbon benefits of using forest wood for energy, explicit modelling of the C dynamics would have to be employed for each country,

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[45] Forests where any legal, economic, or specific environmental restrictions do not have a significant impact on the supply of wood. Areas where harvesting is not taking place at present, but where there are no restrictions, is included. This can be, for example, areas included in long-term utilization plans or intentions.

considering specific national characteristics. Such an approach is beyond the scope of this project[46].

Table 11 and Table 12 complement the figures in this section.

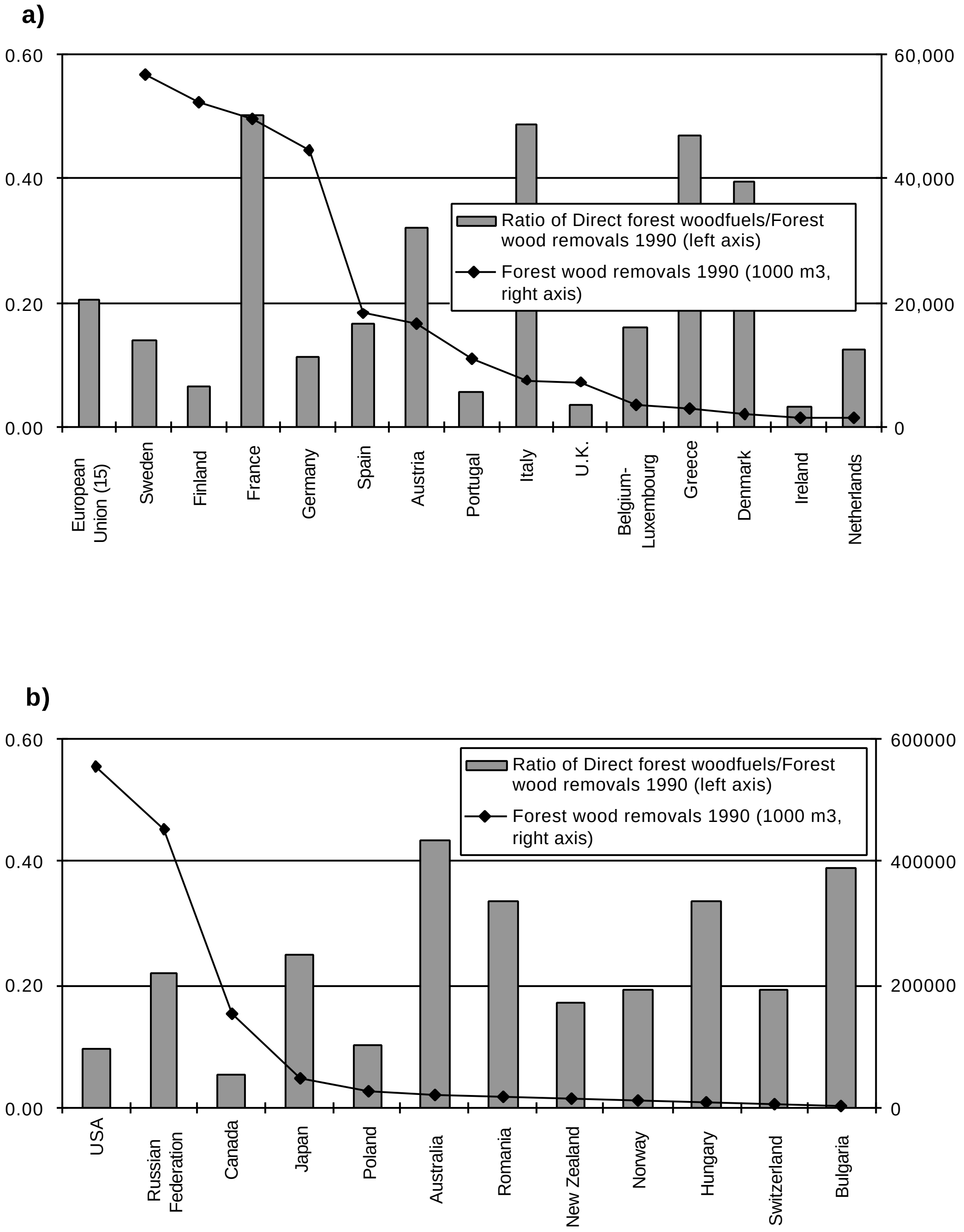

Figure 4. Direct forest woodfuel use compared to total forest wood removals in 1990. Based on [42-44]

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[46] See [43] for an impressive attempt to a full carbon account for Russia

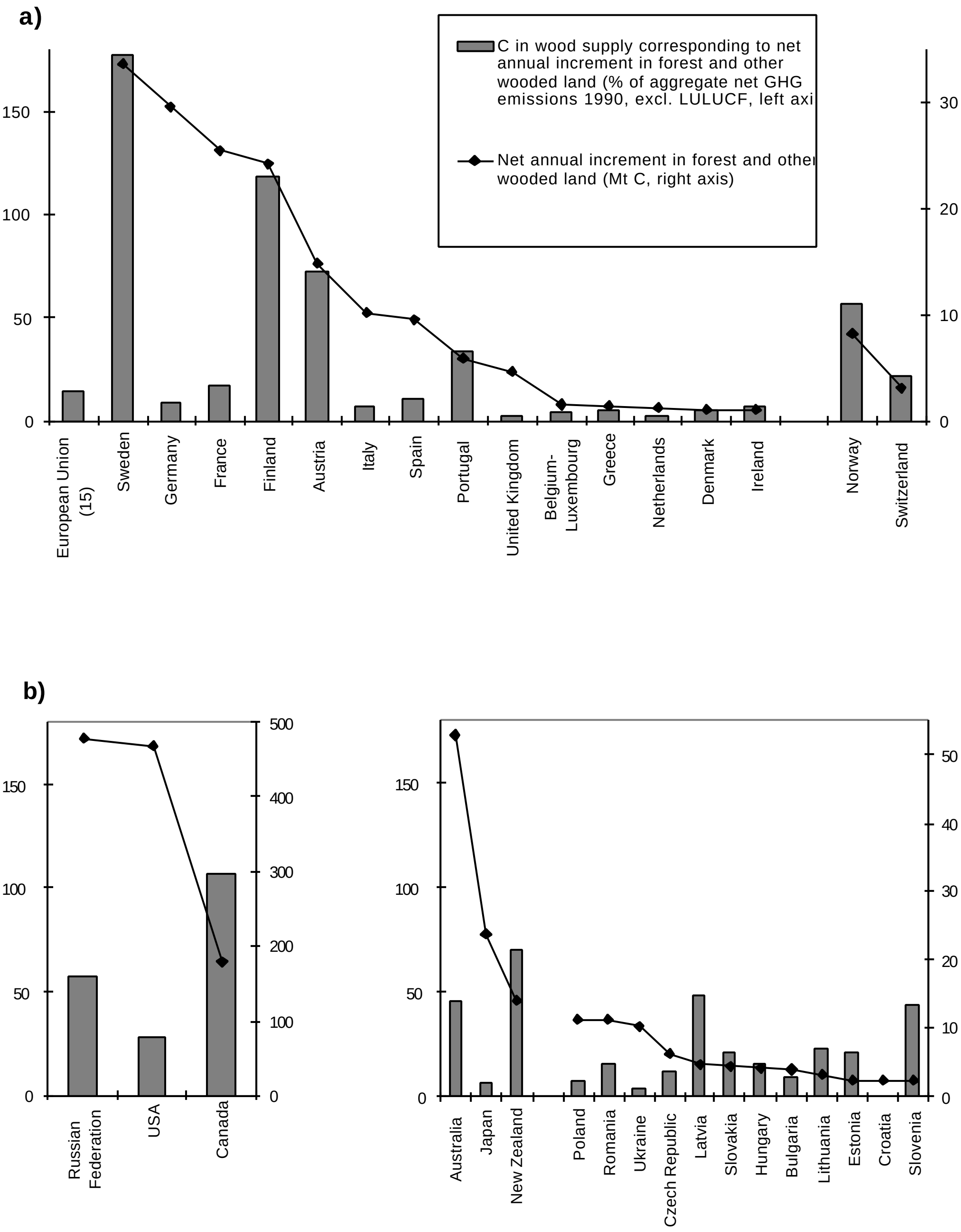

Figure 5. An indication of the ultimate contribution from energetic use of forest wood to national emission commitments in a selection of Annex 1 countries. The diagrams show the net annual increment (NAI) in forest and other wooded land (Mt C in wood, right axis), and a comparison of NAI with the C equivalent of the aggregate net GHG emissions 1990, excluding LULUCF (%, left axis). Note that the scales on the right axes differ.

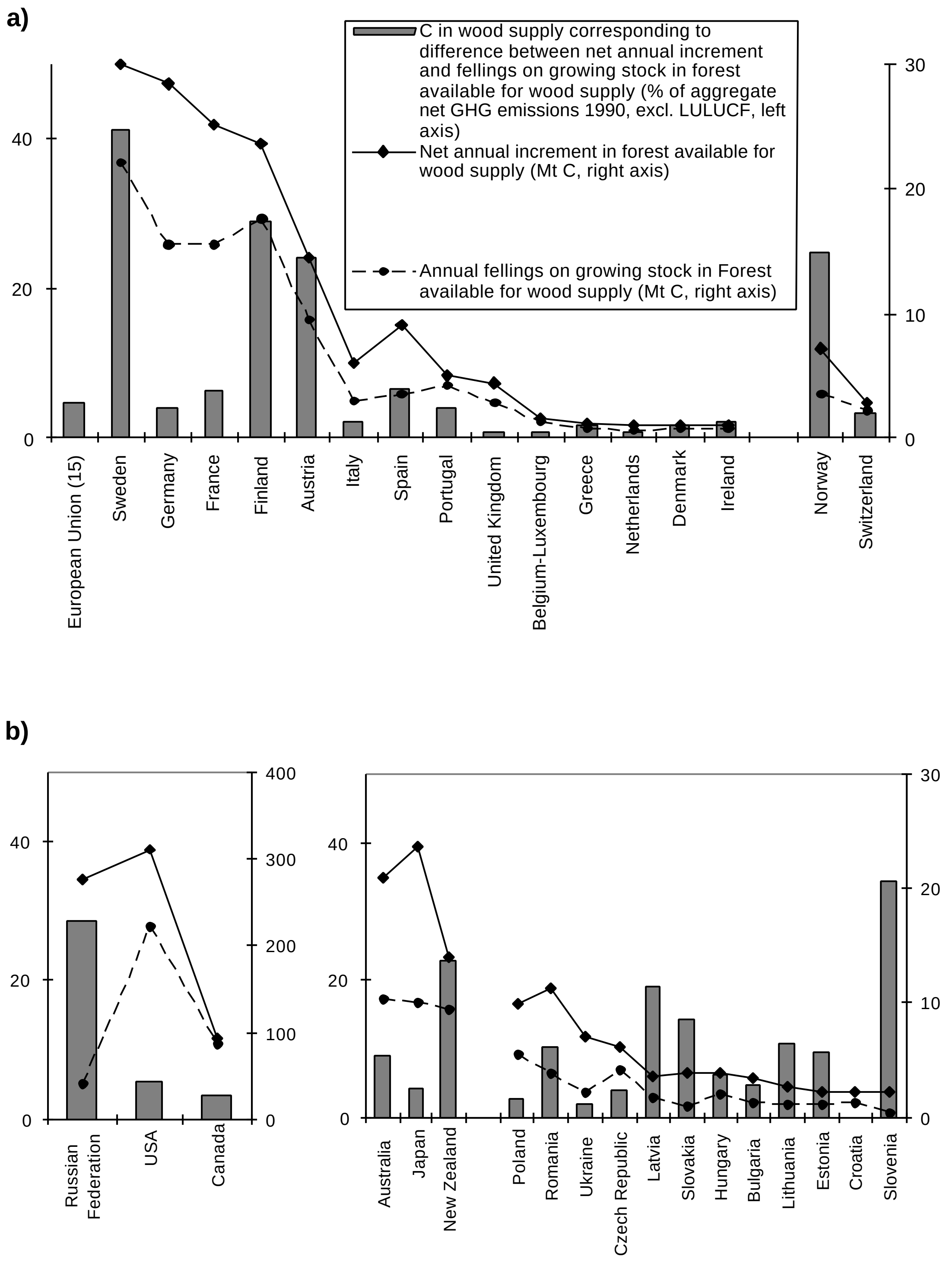

Figure 6. An indication of the potential forest wood supply in excess of what is already used in the forest industry. The diagrams show the net annual increment (NAI) and annual fellings on growing stock in forest and other wooded land (Mt C in wood, right axis). A comparison is also made of the amount of C in wood supply corresponding to the difference between NAI and fellings with the C equivalent of the aggregate net GHG emissions 1990, excluding LULUCF (%, left axis). Note that the scales on the right axes differ.

Table 11. Wood energy use and forest wood removals in 1990.

	Total wood use for energy 1990		Share of total wood energy use		
	(1000 tC) [xii]	(% of total forest wood removals) [xiii]	Direct wood energy (%)	Indirect wood energy (%)	Black liquor (%)
OECD countries					
European Union (15)	41,343		40	31	29
Austria	3,730	74	41	41	17
Belgium-Luxembourg	379	38	42	20	38
Denmark	472	64	52	48	0
Finland	6,241	37	15	32	53
France	10,719	77	67	23	10
Germany	5,208	42	28	60	13
Greece	402	41	97	3	0
Ireland	36	8	40	60	0
Italy	1,161	50	92	4	3
Netherlands	164	37	34	66	0
Portugal	1,232	38	14	8	78
Spain	1,998	37	44	15	42
Sweden	9,450	54	25	29	47
United Kingdom	151	6	49	51	0
Liechtenstein					
Monaco					
Switzerland	840	50	35	56	10
Norway	1,501	41	44	28	27
Iceland					
United States of America	62,293	35	25	39	36
Canada	10,021	23	24	23	54
Japan	3,337		0	0	0
Australia	2,624	45	93	0	7
New Zealand	1,116	27[xiv]	63	0	37
Countries with transition economies					
Bulgaria	548	40	81	6	13
Croatia					
Czech Republic	1,434		26	24	49
Estonia					
Hungary	807	33	91	8	1
Latvia					
Lithuania					
Poland	1,650	20	49	32	19
Romania	2,036	42	77	13	10
Slovakia					
Slovenia					
Russian Federation	29,000 [xv]				
Ukraine	41,343				

Table 12. Potential contribution of increased forest wood removal to meeting the national emissions commitments in Annex 1 countries.

	Fellings / NAI[a]	C in wood supply corresponding to difference between net annual increment and fellings on growing stock in forest available for wood supply (% of aggregate net GHG emissions 1990, excl. LULUCF)		C in wood supply corresponding to net annual increment in forest and other wooded land (% of aggregate net GHG emissions 1990, excl. LULUCF)	
	(%)	(Gg C)	(% of aggregate net emissions of all GHG 1990, excl LULUCF)	(Gg C)	(% of aggregate net emissions of all GHG 1990, excl LULUCF)
<u>OECD countries</u>					
European Union (15)	64	53988	5	164170	14
Austria	65	4979	24	14850	72
Belgium-Luxembourg	81	290	1	1570	4
Denmark	68	310	2	1060	6
Finland	75	5974	29	24240	118
France	62	9649	6	25430	17
Germany	55	12913	4	29540	9
Greece	62	457	2	1320	5
Ireland	67	335	2	1030	7
Italy	48	3097	2	10250	7
Netherlands	61	382	1	1310	2
Portugal	86	682	4	5840	34
Spain	39	5535	7	9490	11
Sweden	74	7790	41	33600	177
United Kingdom	64	1593	1	4640	2
Liechtenstein					
Monaco					
Switzerland	82	494	3	3060	21
Norway	50	3534	25	8130	57
Iceland					
United States of America	72	88430	5	466890	28
Canada	94	5873	4	178970	107
Japan	42	13679	4	23770	7
Australia	50	10470	9	52970	46
New Zealand	67	4543	23	14170	71
<u>Countries with transition economies</u>				<u>0</u>	
Bulgaria	40	2072	5	4050	9
Croatia	56	990		2400	
Czech Republic	67	2008	4	6300	12
Estonia	53	1060	10	2420	22
Hungary	55	1742	6	4200	15
Latvia	49	1846	19	4730	49
Lithuania	43	1527	11	3240	23
Poland	56	4396	3	11370	7
Romania	35	7350	10	11300	16
Slovakia	25	2983	14	4450	21
Slovenia	19	1795	34	2300	44
Russian Federation	15	235241	28	477490	58
Ukraine	32	4799	2	10440	4

[a] Calculated based on [35].

The use of agricultural residues for energy

As illustrated in Section 3.1, the use of agricultural residues can potentially contribute significantly to climate change mitigation and fulfillment of national emissions commitments (see also e.g., [7, 15, 38, 45-48]).

The C stock change associated with the use of agricultural residues for energy depends on the present residue management and how this is influenced by the increased energetic use. Several of the present uses leads to C sequestration[47], at least temporary. If the increased energetic use of such residues results in decreased "sequestering" uses, the C stock change will be negative. However, if the "base-line" situation includes, for example, extensive straw burning without energy recovery, and the straw burned in the field instead is used for energy purposes, the C stock change can be expected to be neglible. Thus, the use of harvest residues for energy will either lead to negative changes in soil C or neglible changes, depending on what is regarded the "base-line" situation.

In the past, straw used to be removed or burned in the field, but it is becoming increasingly common in industrialized countries to return crop residue to the soil rather than removing or burning it. Conservation tillage (CT)[48], the major form of crop residue management (CRM) in the U.S., was used on over 35 percent of U.S. planted area in 1996 [29]. Accurate data for CRM (such as CT and straw incorporation into the soil) are not available for Europe, but it is evident that the introduction of regulations governing straw burning in 1983 have increased the incidence of straw incorporation. For example, the rate of straw incorporation in the UK increased from 2 percent in 1983 to 18 percent in 1988 [15].

While CRM systems primarily are initiated and designed in order to protect soil and water resources, they are also considered an option for climate change mitigation since a conversion from a conventional to a CT system results in an increase of the soil C (see, e.g., [47] for United States and [15] for Europe). However, some evidence suggests than increases in N2O emissions as a result of more compact soils, which are prone to waterlogging, may negate the extra amount of C accrued in the soil. Further work on the total GHG balance from CT is needed. The amount of crop residues left in the field under CRM varies, but some of the residues can still be removed and used for other purposes. Crop residue incorporation in excess of requirements for soil and water protection may be motivated from a climate change mitigation perspective. However, such incorporation of crop residues should be weighted against other uses of residues for climate change mitigation (and for other purposes such as animal bedding).

Table 13 gives indicative data on the potential climate change mitigation of using agricultural residues for energy. Agricultural residues are here represented by cereal

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[47] For example, straw can be incorporated into soils, or used for animal bedding or non-wood pulp production

[48] A conservation tillage system is defined as "any tillage and planting system that covers 30 percent or more of the soil surface with crop residue, after planting, to reduce erosion by water. Where soil erosion by wind is a primary concern, any system that maintains at least 1000 pounds per acre of flat, smal grain residue equivalent on the surface throughout the critical wind erosion period" [29]. 1000 pounds per acre is around 1120 kg per hectare.

straw, which is one of the major potential sources of biomass for energy in the agriculture sector.

As can be seen, the use of cereal residues could potentially contribute significantly to the fulfillment of national emissions commitments in several Annex 1 countries. Notable examples in the European Union are Denmark and France where the C content in the residues assumed to be available corresponds to about 10 percent of aggregate net GHG emissions 1990. For Annex 1 countries outside the European Union, Canada and Australia appear have the largest potentials, but also in the United States the energetic use of cereal residues appear to be a potentially significant contributor to the fulfillment of emissions commitments under the first Kyoto Protocol commitment period. Of the countries with economies in transition, Hungary and Romania appear to have the largest potentials in the perspective of national emissions commitments.

The potential *absolute* contribution from cereal residues, and hence the climate change mitigation potential, correlate with the annual cereal production. From this perspective, the largest potential is found within the countries that are large cereal producer.

Note that one common harvest index is used in the calculation of residue generation rates in all countries. The harvest index used (0.5) can be expected to lead to a slight underestimate of the residue generation rates in countries outside the European Union (and also in EU countries with less intensive agricultural practices). However, given the rough assumptions made about residue availability (which varies among countries depending on soil, climate and competing uses), a variation of the harvest index among countries does not seem justified.

Detailed estimates of the net C benefit from using agricultural residues for energy is not performed here. With reference to the discussion above about possible C stock changes due to removal of residues from the fields, we emphasize that the numbers in Table 13 should be regarded as illustrative only.

Table 13. Illustrative data on potential contribution of cereal residue utilization for energy to meeting the national emissions commitments in Annex 1 countries.

	Average annual cereal production 1996-2000 (1000 tonne)[a]	C in residues used for energy if 50% of the estimated average 1996-2000 cereal residues generation is recoverable for energetic use[b] (Mt C)	(% of aggregate net emissions of all GHG 1990, excl LULUCF)
OECD countries			
European Union (15)	210,340	46.3	4.0
Austria	4,708	1.0	5.0
Belgium-Luxembourg	2,502	0.6	1.3
Denmark	9,294	2.0	10.8
Finland	3,432	0.8	3.7
France	65,210	14.3	9.5
Germany	44,392	9.8	3.0
Greece	4,504	1.0	3.4
Ireland	1,985	0.4	3.0
Italy	20,648	4.5	3.2
Netherlands	1,503	0.3	0.6
Portugal	1,646	0.4	2.1
Spain	21,369	4.7	5.6
Sweden	5,746	1.3	6.7
United Kingdom	23,400	5.1	2.5
Liechtenstein			
Monaco			
Switzerland	1,206	0.3	1.8
Norway	1,333	0.3	2.1
Iceland			
United States of America	340,227	74.8	4.5
Canada	52,823	11.6	7.0
Japan	12,791	2.8	0.8
Australia	32,827	7.2	9.2
New Zealand	900	0.2	1.0
Countries with transition economies			
Bulgaria	4,911	1.1	2.5
Croatia	2,821	0.6	
Czech Republic	6,743	1.5	2.9
Estonia	581	0.1	1.1
Hungary	11,976	2.6	9.5
Latvia	934	0.2	2.1
Lithuania	2,597	0.6	4.1
Poland	25,189	5.5	3.6
Romania	15,678	3.4	4.8
Slovakia	3,115	0.7	3.3
Slovenia	512	0.1	2.1
Russian Federation	63,858	14.0	1.7
Ukraine	26,257	5.8	2.3

[a] Data downloaded from the FAO online statistical database (http://apps.fao.org/), July 3, 2001.

[b] Cereal grain data are assumed to be reported on 88% DM basis. One uniform harvest index of 0.5 is used for all countries. The C content of cereal residues is assumed to be 50% on a DM weight basis.

Indicative fossil C substitution and C stock changes for non-Annex 1 countries

Current global commercial and non-commercial biomass use for energy is estimated at between 20 and 60 EJ/a, representing about 6 to 17% of world primary energy [49]. Most of the biomass is used in developing countries where it is likely to account for roughly one third of primary energy. As a comparison, the share of primary energy provided by biomass in industrialised countries is small and is estimated at about 3 % or less.

Biomass generally provides the largest primary energy share in rural areas and a significant share in urban areas in developing countries, mainly in the form of wood fuel or charcoal. Its use is mainly of the traditional type, for domestic heating and cooking. Part of the biomass is used in industries, for example in food processing and brick manufacture. Traditional biomass use is inefficient and often a source of environmental concern, in particular in terms of biomass resource depletion and health impacts on those exposed to combustion emissions in households (Zhang et al. 2000). Where the biomass resource is exploited sustainably it results in avoided CO_2 emissions as opposed to fossil fuel use. However, in many instances biomass resources are not sustainably exploited.

The CDM has been designed to play a double role of assisting non-Annex 1 countries in achieving sustainable development, while contributing to the objectives of the Convention, and assisting Annex 1 countries in achieving emissions reductions. Therefore, it could support a transition to more modern biomass uses and a more sustainable exploitation of biomass resources.

Global land availability estimates for energy crop production vary widely between 350 and 950 million hectares. An energy potential of about 37.4 EJ/a is estimate based on country specific lignocellulosic biomass yields and an average land availability (Figure 7).

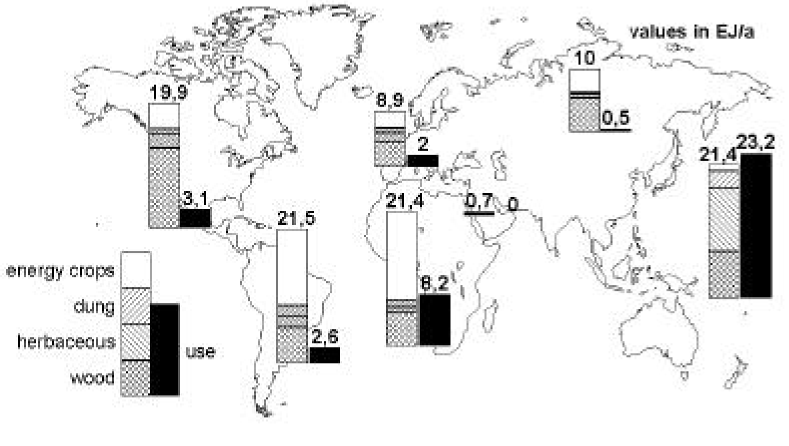


Figure 7. Global biomass potential and use [49]

Attributing an economic value to net C emissions to the atmosphere will result in an incentive to switch to low-carbon energy forms, possibly some forms of biomass energy. The removal of C from the atmosphere and its storage in the form of biomass over defined periods of time (e.g. commitment periods) could also be of economic value, especially if associated with another productive activity such as the production of biomass for energy. In such case, the economics of the system involving C storage and avoided emissions over a period of time could affect the choice of the system.

Calculations have been performed to provide an indication of the biomass energy potential in developing regions and its implications for fossil C substitution and C stock changes over commitment periods. The basic assumptions made in the calculations are shown in Table 14.

Three different scenarios have been developed, with the only difference between the three being the energy plantation rotation length. The different scenarios have been chosen to determine the effect of the rotation length on the potential total C 'credits' and the balance fossil C substitution and C stock.

Table 14. Scenario assumptions

	Assumptions
Scenario 1	• Plantation area: 1.5% of agricultural land by 2017 • Yield: 20 dry matters tonnes/ha/yr • Rotation: 8 • Fossil C substitution ratio: 0.7
Scenario 2	• Plantation area: 1.5% of agricultural land by 2017 • Yield: 20 dry matters tonnes/ha/yr • Rotation: 4 • Fossil C substitution ratio: 0.7
Scenario 3	• Plantation area: 1.5% of agricultural land by 2017 • Yield: 20 dry matters tonnes/ha/yr • Rotation: 1 • Fossil C substitution ratio: 0.7

Tables 15 to 17 and Figures 8 to 10 illustrate the results of the scenario calculations.

Table 15. **Scenario 1 calculations**

Developing countries	Annual plantation establishment (Mha/yr)	Above ground C stock change (Mt C)		Fossil C substitution (Mt C)		Above ground C stock (5 yr avg) (Mt C)	Fossil C substitution (5 yr avg) (Mt C)	Total (Mt C)	Above ground C stock (5 yr avg) (Mt C)	Fossil C substitution (5 yr avg) (Mt C)	Total (Mt C)
		2000-2012	2013-2017	2000-2012	2013-2017	2000-2012			2013-2017		
Africa	**0.966**	**241.4**	**96.6**	**486.7**	**486.7**	**48.3**	**97.3**	**145.6**	**19.3**	**97.3**	**116.7**
Botswana	0.023	5.7	2.3	11.6	11.6	1.1	2.3	3.5	0.5	2.3	2.8
Kenya	0.023	5.7	2.3	11.5	11.5	1.1	2.3	3.4	0.5	2.3	2.7
Mozambique	0.042	10.4	4.2	21.0	21.0	2.1	4.2	6.3	0.8	4.2	5.0
Nigeria	0.064	15.9	6.4	32.1	32.1	3.2	6.4	9.6	1.3	6.4	7.7
South Africa	0.085	21.4	8.5	43.0	43.0	4.3	8.6	12.9	1.7	8.6	10.3
Tanzania	0.035	8.7	3.5	17.5	17.5	1.7	3.5	5.2	0.7	3.5	4.2
Zambia	0.031	7.8	3.1	15.7	15.7	1.6	3.1	4.7	0.6	3.1	3.8
Zimbabwe	0.018	4.4	1.8	9.0	9.0	0.9	1.8	2.7	0.4	1.8	2.2
Asia	**1.153**	**288.2**	**115.3**	**581.1**	**581.1**	**57.6**	**116.2**	**173.9**	**23.1**	**116.2**	**139.3**
China	0.469	117.2	46.9	236.3	236.3	23.4	47.3	70.7	9.4	47.3	56.6
Bangladesh	0.009	2.2	0.9	4.5	4.5	0.4	0.9	1.3	0.2	0.9	1.1
India	0.160	39.9	16.0	80.5	80.5	8.0	16.1	24.1	3.2	16.1	19.3
Indonesia	0.040	9.9	4.0	20.0	20.0	2.0	4.0	6.0	0.8	4.0	4.8
Malaysia	0.006	1.6	0.6	3.2	3.2	0.3	0.6	1.0	0.1	0.6	0.8
Philippines	0.010	2.5	1.0	5.0	5.0	0.5	1.0	1.5	0.2	1.0	1.2
Thailand	0.019	4.7	1.9	9.5	9.5	0.9	1.9	2.8	0.4	1.9	2.3
Latin Amer & Carib.	**0.659**	**164.7**	**65.9**	**332.0**	**332.0**	**32.9**	**66.4**	**99.3**	**13.2**	**66.4**	**79.6**
Argentina	0.149	37.4	14.9	75.3	75.3	7.5	15.1	22.5	3.0	15.1	18.1
Brazil	0.212	53.1	21.2	107.1	107.1	10.6	21.4	32.0	4.2	21.4	25.7
Colombia	0.040	9.9	4.0	20.0	20.0	2.0	4.0	6.0	0.8	4.0	4.8
Cuba	0.006	1.5	0.6	3.1	3.1	0.3	0.6	0.9	0.1	0.6	0.7
Mexico	0.091	22.8	9.1	46.0	46.0	4.6	9.2	13.8	1.8	9.2	11.0
Paraguay	0.021	5.1	2.1	10.4	10.4	1.0	2.1	3.1	0.4	2.1	2.5
Uruguay	0.013	3.3	1.3	6.6	6.6	0.7	1.3	2.0	0.3	1.3	1.6
Venezuela	0.020	4.9	2.0	9.8	9.8	1.0	2.0	2.9	0.4	2.0	2.4

Figure 8. Above ground C stock and fossil C substitution, Scenario 1

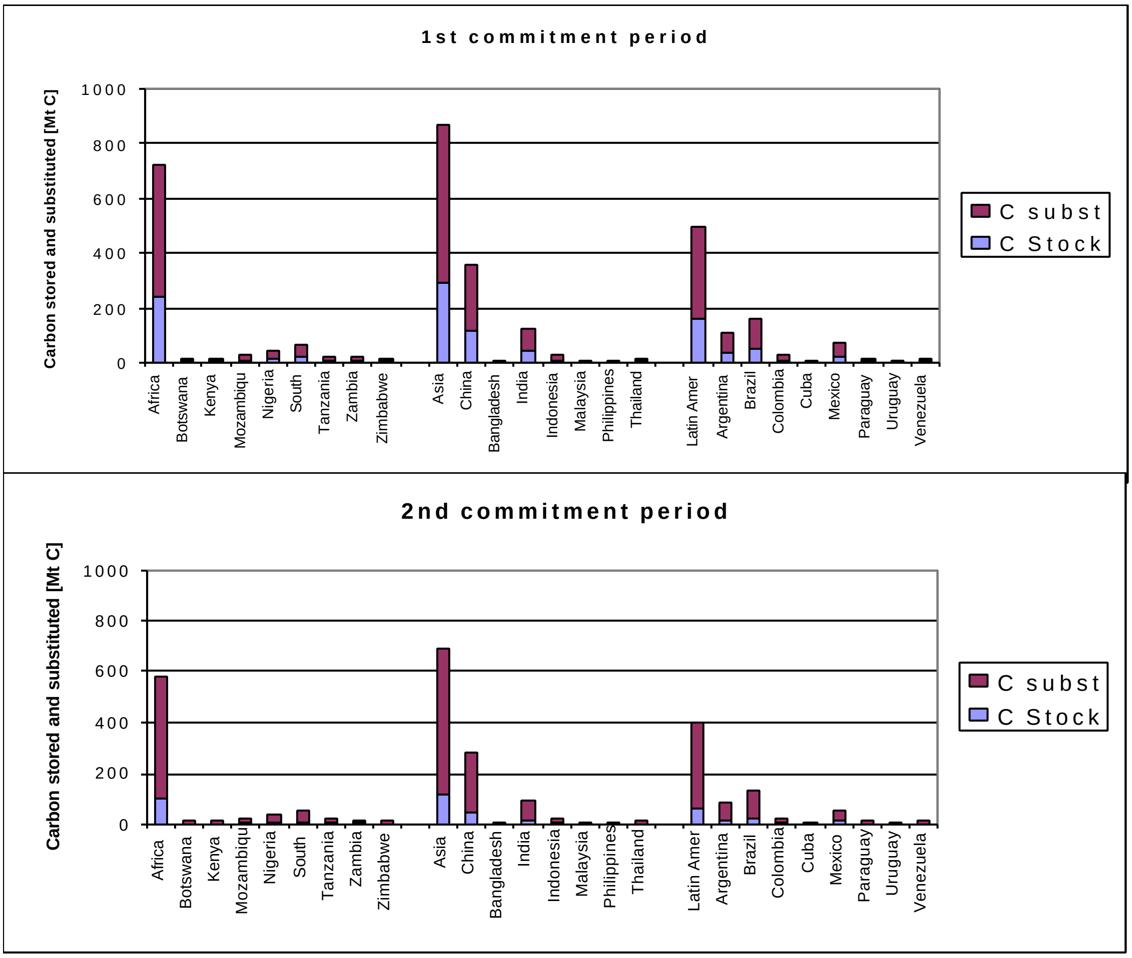


Table 16. **Scenario 2 calculations**

Developing countries	Annual plantation establishment (Mha/yr)	Above ground C stock change (Mt C)		Fossil C substitution (Mt C)		Above ground C stock (5 yr avg) (Mt C)	Fossil C substitution (5 yr avg) (Mt C)	Total (Mt C)	Above ground C stock (5 yr avg) (Mt C)	Fossil C substitution (5 yr avg) (Mt C)	Total (Mt C)
		2000-2012	2013-2017	2000-2012	2013-2017	2000-2012			2013-2017		
Africa	**0.966**	**453.9**	**193.1**	**324.5**	**432.6**	**90.8**	**64.9**	**155.7**	**38.6**	**86.5**	**125.2**
Botswana	0.023	10.8	4.6	7.7	10.3	2.2	1.5	3.7	0.9	2.1	3.0
Kenya	0.023	10.7	4.6	7.6	10.2	2.1	1.5	3.7	0.9	2.0	3.0
Mozambique	0.042	19.6	8.3	14.0	18.7	3.9	2.8	6.7	1.7	3.7	5.4
Nigeria	0.064	29.9	12.7	21.4	28.5	6.0	4.3	10.3	2.5	5.7	8.2
South Africa	0.085	40.1	17.1	28.7	38.3	8.0	5.7	13.8	3.4	7.7	11.1
Tanzania	0.035	16.3	7.0	11.7	15.6	3.3	2.3	5.6	1.4	3.1	4.5
Zambia	0.031	14.6	6.2	10.5	13.9	2.9	2.1	5.0	1.2	2.8	4.0
Zimbabwe	0.018	8.4	3.6	6.0	8.0	1.7	1.2	2.9	0.7	1.6	2.3
Asia	**1.153**	**541.9**	**230.6**	**387.4**	**516.5**	**108.4**	**77.5**	**185.8**	**46.1**	**103.3**	**149.4**
China	0.469	220.4	93.8	157.5	210.1	44.1	31.5	75.6	18.8	42.0	60.8
Bangladesh	0.009	4.2	1.8	3.0	4.0	0.8	0.6	1.4	0.4	0.8	1.1
India	0.160	75.1	31.9	53.7	71.6	15.0	10.7	25.8	6.4	14.3	20.7
Indonesia	0.040	18.7	8.0	13.4	17.8	3.7	2.7	6.4	1.6	3.6	5.2
Malaysia	0.006	3.0	1.3	2.1	2.8	0.6	0.4	1.0	0.3	0.6	0.8
Philippines	0.010	4.6	2.0	3.3	4.4	0.9	0.7	1.6	0.4	0.9	1.3
Thailand	0.019	8.9	3.8	6.3	8.5	1.8	1.3	3.0	0.8	1.7	2.4
Latin Amer & Carib.	**0.659**	**309.6**	**131.7**	**221.3**	**295.1**	**61.9**	**44.3**	**106.2**	**26.3**	**59.0**	**85.4**
Argentina	0.149	70.3	29.9	50.2	67.0	14.1	10.0	24.1	6.0	13.4	19.4
Brazil	0.212	99.9	42.5	71.4	95.2	20.0	14.3	34.3	8.5	19.0	27.5
Colombia	0.040	18.7	8.0	13.4	17.8	3.7	2.7	6.4	1.6	3.6	5.2
Cuba	0.006	2.9	1.2	2.1	2.8	0.6	0.4	1.0	0.2	0.6	0.8
Mexico	0.091	42.9	18.2	30.7	40.9	8.6	6.1	14.7	3.6	8.2	11.8
Paraguay	0.021	9.7	4.1	6.9	9.2	1.9	1.4	3.3	0.8	1.8	2.7
Uruguay	0.013	6.1	2.6	4.4	5.9	1.2	0.9	2.1	0.5	1.2	1.7
Venezuela	0.020	9.2	3.9	6.6	8.8	1.8	1.3	3.1	0.8	1.8	2.5

Figure 9. Above ground C stock and fossil C substitution, Scenario 2

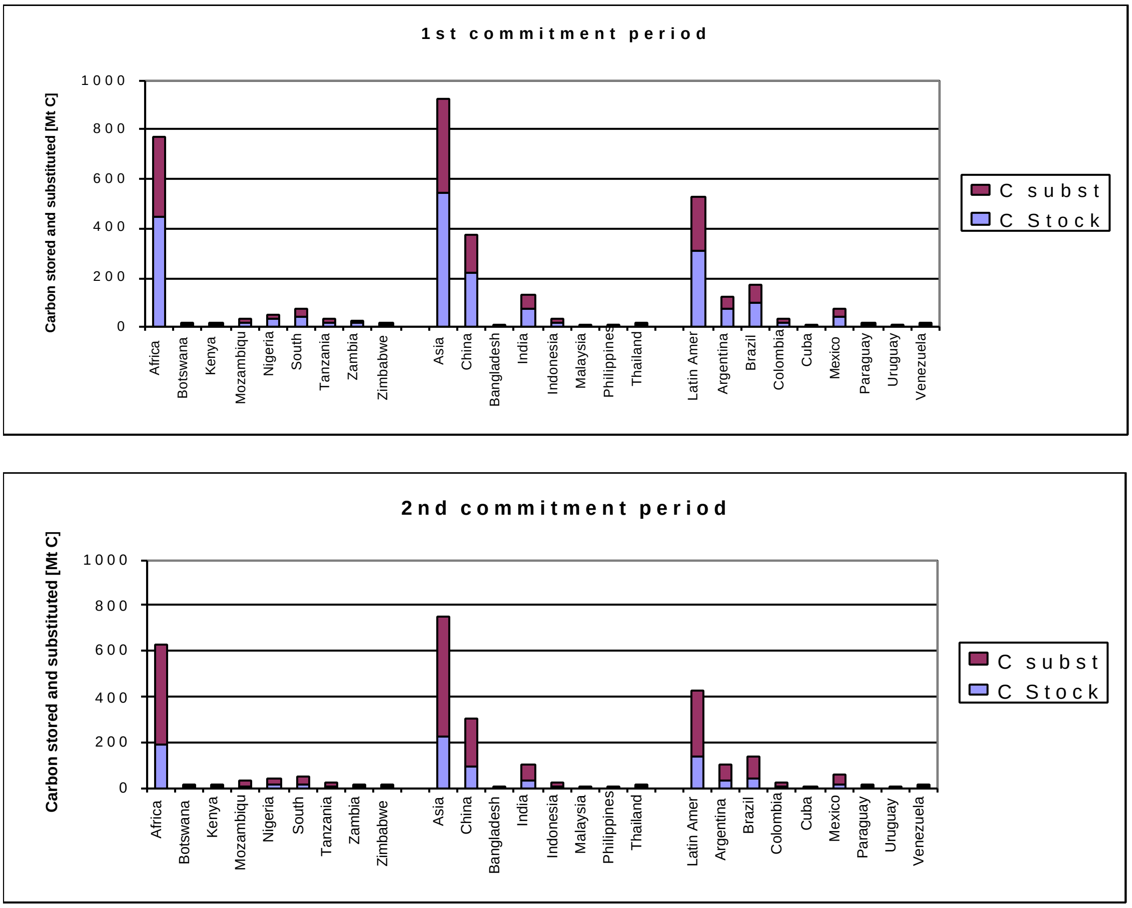
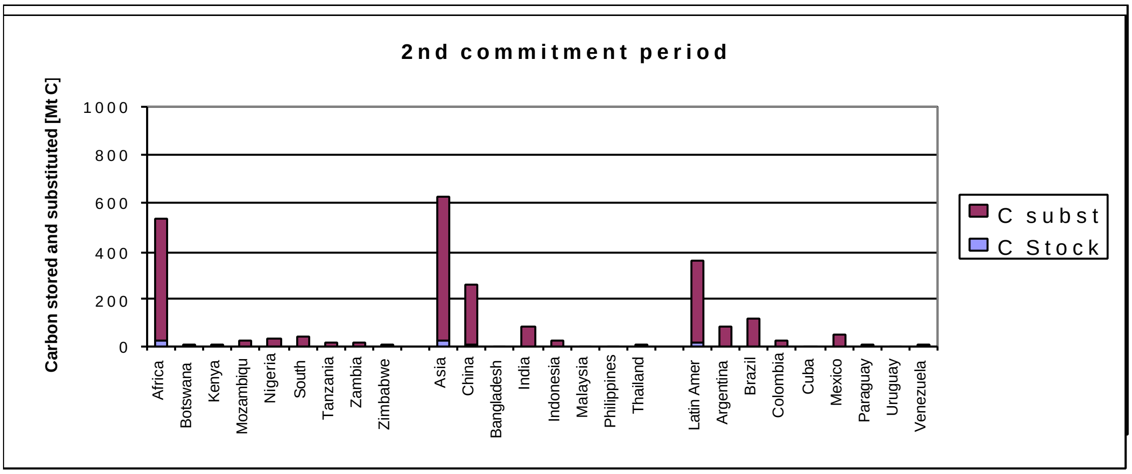


Table 17. **Scenario 3 calculations**

Developing countries	Annual plantation establishment (Mha/yr)	Above ground C stock change (Mt C)		Fossil C substitution (Mt C)		Above ground C stock (5 yr avg) (Mt C)	Fossil C substitution (5 yr avg) (Mt C)	Total (Mt C)	Above ground C stock (5 yr avg) (Mt C)	Fossil C substitution (5 yr avg) (Mt C)	Total (Mt C)
		2000-2012	2013-2017	2000-2012	2013-2017	2000-2012			2013-2017		
Africa	**0.966**	**67.6**	**24.1**	**527.3**	**507.0**	**13.5**	**105.5**	**119.0**	**4.8**	**101.4**	**106.2**
Botswana	0.023	1.6	0.6	12.5	12.1	0.3	2.5	2.8	0.1	2.4	2.5
Kenya	0.023	1.6	0.6	12.4	12.0	0.3	2.5	2.8	0.1	2.4	2.5
Mozambique	0.042	2.9	1.0	22.8	21.9	0.6	4.6	5.1	0.2	4.4	4.6
Nigeria	0.064	4.5	1.6	34.7	33.4	0.9	6.9	7.8	0.3	6.7	7.0
South Africa	0.085	6.0	2.1	46.6	44.8	1.2	9.3	10.5	0.4	9.0	9.4
Tanzania	0.035	2.4	0.9	19.0	18.3	0.5	3.8	4.3	0.2	3.7	3.8
Zambia	0.031	2.2	0.8	17.0	16.3	0.4	3.4	3.8	0.2	3.3	3.4
Zimbabwe	0.018	1.2	0.4	9.7	9.3	0.2	1.9	2.2	0.1	1.9	2.0
Asia	**1.153**	**80.7**	**28.8**	**629.5**	**605.3**	**16.1**	**125.9**	**142.0**	**5.8**	**121.1**	**126.8**
China	0.469	32.8	11.7	256.0	246.2	6.6	51.2	57.8	2.3	49.2	51.6
Bangladesh	0.009	0.6	0.2	4.8	4.6	0.1	1.0	1.1	0.0	0.9	1.0
India	0.160	11.2	4.0	87.2	83.9	2.2	17.4	19.7	0.8	16.8	17.6
Indonesia	0.040	2.8	1.0	21.7	20.9	0.6	4.3	4.9	0.2	4.2	4.4
Malaysia	0.006	0.4	0.2	3.5	3.3	0.1	0.7	0.8	0.0	0.7	0.7
Philippines	0.010	0.7	0.2	5.4	5.2	0.1	1.1	1.2	0.0	1.0	1.1
Thailand	0.019	1.3	0.5	10.3	9.9	0.3	2.1	2.3	0.1	2.0	2.1
Latin Amer & Carib.	**0.659**	**46.1**	**16.5**	**359.6**	**345.8**	**9.2**	**71.9**	**81.1**	**3.3**	**69.2**	**72.5**
Argentina	0.149	10.5	3.7	81.6	78.5	2.1	16.3	18.4	0.7	15.7	16.4
Brazil	0.212	14.9	5.3	116.0	111.5	3.0	23.2	26.2	1.1	22.3	23.4
Colombia	0.040	2.8	1.0	21.7	20.9	0.6	4.3	4.9	0.2	4.2	4.4
Cuba	0.006	0.4	0.2	3.4	3.2	0.1	0.7	0.8	0.0	0.6	0.7
Mexico	0.091	6.4	2.3	49.8	47.9	1.3	10.0	11.2	0.5	9.6	10.0
Paraguay	0.021	1.4	0.5	11.2	10.8	0.3	2.2	2.5	0.1	2.2	2.3
Uruguay	0.013	0.9	0.3	7.1	6.9	0.2	1.4	1.6	0.1	1.4	1.4
Venezuela	0.020	1.4	0.5	10.7	10.3	0.3	2.1	2.4	0.1	2.1	2.1

Figure 10. Above ground C stock and fossil C substitution, Scenario 3



The scenarios clearly show that the above ground biomass C stocks are largest for the energy plantations with the longest rotations. Assuming that the different energy plantations had the same annual yield and the same fossil C substitution ratio, it appears that the longer rotations result in larger total C benefits in terms of C substituted and stored. However, they will result in lower C substitution and higher C stocks, in particular during plantation establishment periods. Once no more land is destined to energy plantations, the total C benefits will converge (this is valid for the particular examples chosen, which have the same yield), but the longer rotations will achieve larger total C benefits because the above ground biomass that is not used for biomass energy will provide a greater C credit since the ratio of fossil C avoided to biomass C used is less than 1. This discussion is purely illustrative and it needs to be noted that energy plantations with different rotations are likely to have different yields and different types of biomass will result in different fossil C substitution ratios.

Synthesis

The quantitative examples in this section should be regarded as *illustrative* only of the potential contribution of biomass to meeting the national emissions commitments in Annex 1 countries and of the potential of biomass for carbon mitigation in developing countries, based on the linking of carbon sink crediting to biomass energy. It is clear that there exist ample opportunities for using biomass for climate change mitigation in the energy sector, and also for meeting the national emissions commitments in Annex 1 countries. It is also clear that those biomass potentials are unevenly distributed among countries, and they do not correlate well with national emissions requirements related to the Kyoto Protocol for Annex 1 countries. Thus, cross-boundary mechanisms may be very important in realising the exploitation of biomass potentials.

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[i] Unless specified otherwise, data are taken from Forest Resources Assessment 2000, http://www.fao.org/forestry/fo/fra/index.jsp

[ii] Unless specified otherwise, data are calculated from FCCC/SBSTA/2000/9/Add.1. Table 2 (a), IPCC/FAO definition.

[iii] [35]

[iv] 10% artificial (i.e., by planting or seeding) and 90% natural (i.e., by natural seeding of land where previous non-forest use has been discontinued)

[v] Average 1990-99.

[vi] Cumulative area of annual plantation available since 1975 [36].

[vii] Includes grassland to planted forest and shrublands to planted forests

[viii] All of the European land area as far east as the Baltic States, excluding the former Soviet Union except for Belarus and Ukraine

[ix] Replacement of agricultural imports (0-8 Mha), new non food outlets (0,3-3 Mha), extensification of agriculture (0,5-13 Mha), expansion of forest area (0-15 Mha), nature development (0,5-3,3 Mha), built-on area (0,7 Mha).

[x] EU (15), Norway and Switzerland

[xi] The two cases differ also in management practice. The low energy crop price case assumes management practices intended to achieve high environmental benefits on CRP program lands, while the high price case assumes high productivity management practices. Around 3 and 5 Mha of the 7 Mha CRP land available was used for energy crops production in the low and high energy crop price cases respectively.

[xii] [42]

[xiii] Calculated based on [42, 44]

[xiv] Approx. 97 percent of removals are from plantations

[xv] [43]