The upfront carbon debt of bioenergy

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Executive Summary

In the current climate change policy framework, the use of biomass for energy is considered a carbon neutral source. According to the principle of carbon neutrality, the GHG emissions produced by combustion of plant biomass are assumed to be re-captured instantaneously by new growing plants. This assumption is acceptable when the same amount of biomass that was burned will re-grow in a very short time as for annual crops. When the raw material is wood, the time needed to re-absorb the CO_2 emitted in the atmosphere can be long, depending very much on the source of wood. This delay can create an upfront "carbon debt" that would substantially reduce the capability of bioenergy to reduce the greenhouse gas emissions (GHG) in the atmosphere in the short to medium term.

The discussion on bioenergy carbon neutrality is fundamental, since the European Union (EU) adopted ambitious policy targets on the use of renewable energy sources and a substantial share of the total renewable energy will come from biomass. Biomass resources, which would not have been used without the new policies, and could have stored carbon in the biosphere, will be used to produce energy. According to estimates used by DG TREN, the projected renewable sources' deployment in 2020 will require the use of 195 Mtoe from biomass. The energy generation from solid biomass and biowaste is projected to be 58% of the total renewable energy generation in 2020 (140 Mtoe of 240 Mtoe) and it will cover 12% of the gross energy demand in the EU.

The extent to which the use of bioenergy reduces GHG emission can be quantified with a Carbon Neutrality (*CN*) factor. The *CN* factor is defined as the ratio between the net reduction/increase of carbon emissions in the bioenergy system and the carbon emissions from the substituted reference energy system, over a certain period of time. The *CN* is time dependent and it includes emissions from carbon stock changes. This study shows that different sources of biomass for bioenergy can have very different climate change mitigation potentials according to the time horizon that is considered, by assessing the development of their *CN* over time. There is forest biomass that can produce a GHG benefit in the atmosphere from the beginning of its use but it is not carbon neutral. Other sources of woody biomass will require a long time before producing a GHG benefit in the atmosphere, while some other sources can be carbon neutral from their initiation:

- When harvest residues, previously left on the forest floor are extracted for bioenergy, there is a carbon stock loss in the dead wood, litter and soil pools. It was estimated that the mitigation potential of such bioenergy material in a 20 year time horizon is reduced by 10-40% by this loss (CN=0.6-0.9).
- Additional fellings for bioenergy can produce a decrease of the overall carbon stock in the forest that significantly affects the GHG balance of the bioenergy material. In the short-medium term (20-50 years), additional fellings could produce more emissions in the atmosphere than a fossil fuel system ($CN<0$). In such a case, the use of additional fellings would produce only very long term benefits, in the order of magnitude of 2-3 centuries.
- The GHG balance of biomass from new plantations is affected by the carbon stock change due to the conversion from the previous land use (direct and indirect). The biomass source can be carbon neutral when the carbon stock change is zero or positive (e.g. conversion from abandoned croplands). If there is an initial carbon loss

(e.g. conversion from a forest area), the biomass will produce an atmospheric benefit only after that the carbon stock change is fully compensated by the same amount of avoided emissions in replaced fossil fuels (150-200 years).

In the current accounting of GHG emissions in the climate change policy framework, there are two major gaps concerning the use of bioenergy. The first is a gap in spatial coverage. This gap resulted from adoption of an inventory methodology designed for a system in which all nations report into systems in which only a small number of countries have emission obligations, i.e., the Kyoto Protocol (KP) and the Emission Trading Scheme (EU-ETS). The second is a failure to differentiate between a system in which very long time horizons are relevant – efforts to mitigate climate change over the long term – and systems concerned with shorter-term horizons such as the EU 2020 and 2050 targets. Since the KP adopted the UNFCCC Inventory Guidelines without considering these differences, current accounting systems' difficulties in addressing the time-dependency of biomass' carbon neutrality can also be traced to this decision.

Policy approaches currently under discussion that could address the spatial or temporal gaps, at least to a limited extent, include the following:

1. More inclusive accounting of emissions from the land-use sector
2. Value Chain Approaches, including use of sustainability criteria
3. Point-of-use accounting

All of them are primarily intended to address problems that have emerged due to the difference in spatial boundaries, and point-of-use accounting can also address the time delay between use of biomass for energy and regrowth.

A more inclusive accounting of emissions from the land-use sector has been under consideration in the UNFCCC fora by widening the number of activities whose emissions must be counted in Annex-I countries and by adopting a mechanism to support REDD+ that should encourage emission reduction efforts in non-Annex-I countries. However, these approaches would only partially fill the existing spatial gap and they would be dependent on a continual series of policy agreements. A third option is a unified carbon stock accounting (UCSA) under which land-use sector emissions would be estimated across all managed lands without restriction to specific activities, but there is currently wide resistance to this approach. In addition, it would only partially resolve the accounting gap if only applied in Annex-I countries.

Under value-chain approaches GHG impacts along the entire series of steps – resource extraction or cultivation, transportation, and conversion to a final product – are taken into consideration. Under this approach bioenergy users are held responsible for the bioenergy embodied emissions and quantitative and/or qualitative criteria are set to limit the use of goods with high GHG-profiles. The EU Renewable Energy Directive's requirements for biofuel are an example of a value-chain approach. However, there is a disjunction between the Directive and the KP and EU-ETS. For the purpose of emission reduction targets, bioenergy will still enjoy zero emission status even if its GHG balance, assessed with the methodology in the Directive, is not zero. In addition carbon stock changes due to management changes are not accounted for.

Under point-of-use accounting, end-users are also held responsible for the emissions attendant on use of bioenergy and, in addition, emissions due to combustion would be assigned a non-zero multiplier (i.e., emission factor) to include the real GHG benefits due to bioenergy use. Under conditions where not all nations cap emissions in all sectors, point-of-use accounting is likely to provide better incentives and dis-incentives than other systems.

Two alternative ways to calculate emission factors at point-of-use are reviewed: calculating net value-chain emissions not covered by caps and use of Carbon Neutrality (*CN*) factors. DeCicco (2009) proposes a system in which assignment of emissions to biomass used for energy is combined with tracking the emissions occurring along its value chain that occur in non-capped sectors or nations. In such a system, the emission cap on fossil fuels serves as the incentive to lower the GHG emission profiles of biofuels.

CN factors can incorporate all emissions due to changes in carbon stocks. Moreover, they compare biomass emissions to the emissions of use of fossil-fuels in a time-relevant manner. Thus, use of *CN* factors by bioenergy users could, in principal, address both the areal gaps and timing issues. These issues have emerged as a result of the combination of the use of a 'zero emissions' factor at the point of biomass combustion under the KP and EU-ETS with the lack of accounting for land use change in Annex-I and non-Annex-I countries. The use of *CN*-factor labelled biomass would provide a straightforward way to calculate emission benefits relative to use of fossil fuels.

It is very likely that accounting systems will remain partial through the foreseeable future. Not all nations will cap emissions from their land use sector and many of those that do are unlikely to adopt a UCSA approach. During this period, a *CN* factor based only on emissions not falling under caps may be a useful approach.

1 Introduction

In the current climate change policy framework, the use of biomass for energy is considered a carbon neutral source. It is claimed that all the emissions produced by biomass burning are re-absorbed when it re-grows and therefore they are to be considered equal to zero.

A recent paper by Searchinger et al. (2009) highlighted that different bioenergy sources can have a different capability to contribute to GHG emission reduction and they are not all carbon neutral. The paper stresses that the carbon neutrality of biomass from existing forests is particularly controversial under the current accounting rules. Part of the problem is linked to the lack of a full-accounting system in the Land Use and Land-Use Change sector under the current climate policy binding agreements. Already in the past, Schlamadinger et al. (1997) came to similar conclusions and stated that the emission reduction effect of bioenergy from existing forests (logging residues, trees) has a time delay in the order of several decades. This delay can create an upfront carbon debt that would substantially reduce the capability of bioenergy to reduce the present greenhouse gas emissions (GHG) in the atmosphere in the short to medium term. The impact of this carbon debt is strongly dependent on the source of wood, the efficiency of conversion, the type of substituted fuel and the mix of final products (Schlamadinger and Marland 1996).

The discussion on bioenergy carbon neutrality is fundamental, since the European Union (EU) adopted ambitious policy targets on the use of renewable energy sources and a substantial share of the total renewable energy will come from biomass. In the current EU system, the negative GHG impact of bioenergy is partially addressed by the adoption of a sustainability criteria framework that should ensure sustainable provision and use of biofuels and bioliquids. The regulations require that biofuels and bioliquids comply with a minimum climate mitigation performance. Once the bioenergy product is accepted in the system, it is considered carbon neutral for the purpose of binding targets. Concerning the use of solid and gaseous biomass sources, the Commission produced only recommendations to Member States on the development of national sustainability schemes (COM 2010). Therefore no binding criteria are approved for biomass at this stage at the EU level. The recommended sustainability criteria for biomass are the same as those laid down for biofuels and bioliquids.

The real effectiveness of woody biomass in offsetting GHG emissions is to be discussed in order to ensure the development of policy instruments that will avoid perverse incentives to bioenergy and would increase GHG emissions instead of reducing them in the medium term.

This report summarizes the future scenarios of bioenergy demand by 2020 and the potential bioenergy production, taking into account different fuel mixes. It discusses and gives guidance to assess the real carbon neutrality of bioenergy when a medium term climate mitigation goal is considered. The main focus is on woody biomass used for bioenergy. Finally, policy options to include the bioenergy upfront carbon debt in the accounting systems are presented.

2 Bioenergy in the climate policy framework

Increased use of renewable energy is a key EU strategy for reducing emissions of CO_2 to the atmosphere. However, the Kyoto Protocol's adoption of the IPCC Inventory Guidelines results in a large fraction of emissions due to use of bioenergy not being accounted for under it or the EU-ETS. The EU Renewable Energy Directive attempts to address this gap for biofuels, but adoption of the same procedure for woody biomass would fail to address critical timing issues.

The current climate policy framework is led by the principle of differentiated responsibilities according to which industrialized countries, emitting the majority of greenhouse (GHG) emissions, are the main actors responsible for mitigating climate change.

Due to this principle, industrialized countries committed themselves to adopt policies and to take measures to limit anthropogenic emissions under the United Nations Framework Convention on Climate Change (UNFCCC). These countries, including the European Union (EU), are classified as Annex-I countries. With the ratification of the Kyoto Protocol, Annex-I countries adopted a binding target to reduce the GHG emissions of a certain percentage in comparison to a reference year (baseline).

The EU promoted a series of parallel policy actions to help comply with the Kyoto Protocol target. The emissions produced by industry are regulated by maximum emission caps in the EU-Emission Trading Scheme (EU-ETS). Most recently, the EU also approved a Directive for the promotion of the use of energy from renewable sources that establish national targets corresponding to "at least a 20 % share of energy from renewable sources in the Community's gross final consumption of energy in 2020" (EC 2009).

The increased use of renewable energies is indeed one of the strategies to reduce future emissions of CO_2 and other GHGs in the atmosphere. Woody and herbaceous biomass are considered renewable energy sources and due to the fact that re-growing plants can recapture the carbon emitted with combustion. For this reason, bioenergy (from wood and crops) is regarded as having zero emissions in accounting systems of policies with a GHG emission reduction target.

2.1 Reporting and accounting systems

There is a fundamental difference between reporting under the UNFCCC and accounting under the Kyoto Protocol (KP) and the EU-ETS. As a consequence of its more limited spatial boundaries, accounting gaps occur under the KP that do not occur under UNFCCC reporting. These gaps are spatial in nature, but timing gaps are also a problem in the case of use of woody biomass.

UNFCCC reporting covers virtually all greenhouse gas emissions due to human activities world wide[1]. Under the KP and EU-ETS, however, only GHG emissions that occur in Annex-I or EU nations, respectively, enter the accounting system. GHG emissions that occur due to land use or biomass conversion and biomass production in non-Annex-I countries are not included in either the KP or EU-ETS. As well, in many Annex-I countries the decrease of forest carbon stocks, other than deforestation, are not

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[1] None of the systems covers emissions from unmanaged lands.

included unless the country has elected forest and soil management activities in its accounts. Due to the accounting convention, the emissions that occur when biomass is combusted for energy are also not counted. Recognition of the undesirable consequences of these accounting gaps led to adoption, in the EU Renewable Energy Directive, of provisions intended to account for all emissions due to biofuel use.

Reporting under the UNFCCC as well as accounting under the KP and EU-ETS is based on the IPCC Guidelines for National Greenhouse Gas Inventories. These Guidelines were developed for UNFCCC reporting. They stipulate that each nation prepare an Inventory of "greenhouse gas emissions and removals taking place within national territory and offshore areas over which the country has jurisdiction" (IPCC 1996). Since virtually all nations are signatories to the UNFCCC, this method results in essentially complete reporting of GHG emissions due to human activities. In particular, emissions due to land use changes as well as conversion of biomass to biofuels are reported for almost all nations.

The IPCC Guidelines were subsequently adopted for preparation of inventories under the KP. "The Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol Decides… that the IPCC good practice guidance … shall be used by Parties included in Annex-I to the Convention (Annex-I Parties) in their preparation of national greenhouse gas inventories under the Kyoto Protocol". These inventories form the basis for determining compliance with targets, i.e. are used for accounting purposes. However, only a small sub-set of nations have KP targets. Thus, a reporting system designed for conditions in which virtually all nations participate is being utilized in an accounting system with different spatial boundaries: compliance with KP targets. This difference in spatial inclusiveness invalidates a key assumption underlying UNFCCC reporting: that emissions not reported in the energy sector will be reported in the LULUCF sector.

Biomass to be used for energy and biofuels are among many products that enjoy a preferential status due to this difference in the spatial boundaries of the UNFCCC and KP. Due to the "national territory" organization of inventories, the GHG emissions attributable to production of any goods imported from non-Annex-I countries are not included in KP compliance. The extent to which this eases EU compliance with targets is illustrated in Figure 1. The difference between imported and exported embodied carbon measures the extent to which the EU does not account for, and therefore does not take responsibility for, the CO_2 emissions caused by products it uses.

Biomass-used-for energy enjoys an additional advantage. This extra 'advantage' is due to the IPCC Guidelines specific to bioenergy. "Reporting is generally organized according to the sector actually generating emissions or removals…There are some exceptions to this practice, such as CO_2 emissions from biomass combustion which are reported in AFOLU (Agriculture, Forestry and Other Land Uses) Sector as part of net changes in carbon stocks" (IPCC 2006). Due to this provision, in addition to excluding emissions due to production and conversion in non-Annex-I nations, Annex-I nations also do not account for emissions that occur when they use bioenergy[2].

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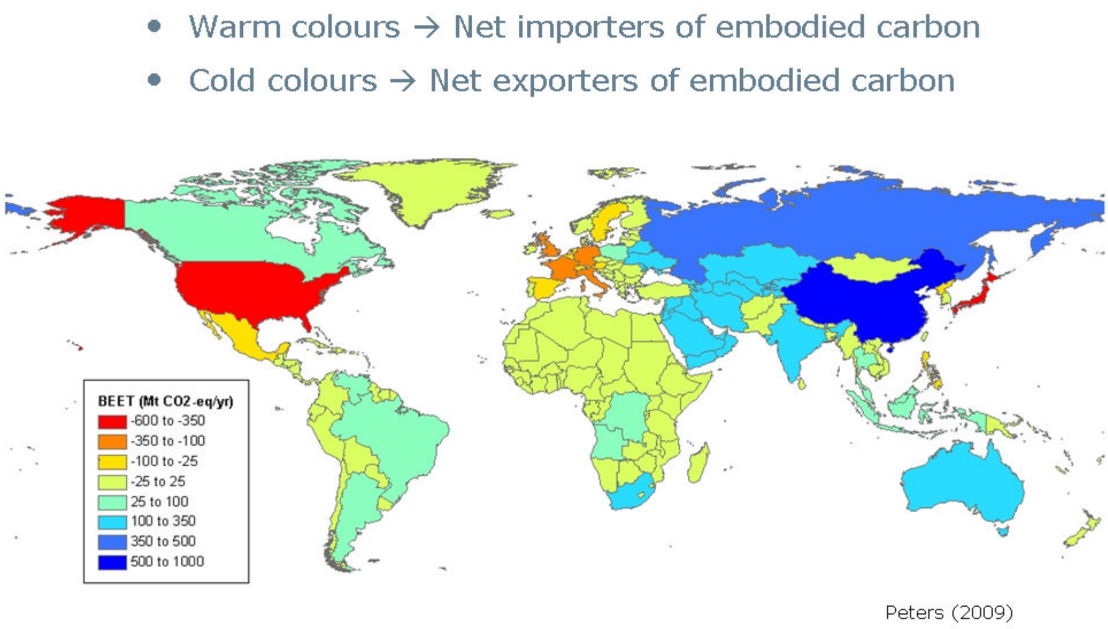
[2] In Table 1, Appendix III to Decision 20/CMP.1, which provides emission factors for the energy sector, CO_2 emissions from biomass are classified as N/A: Not Applicable, because Parties are either not required to report this source in the GHG inventories or not required to include it in their national total (UNFCCC 2006a).



- Warm colours → Net importers of embodied carbon
- Cold colours → Net exporters of embodied carbon

Peters (2009)

Figure 1 Trade balance of emissions calculated as the difference between imported and exported carbon

While the gap in accounting for emissions due to production of biomass-for-energy is most problematic where the biomass is imported from non-Annex-I nations, there is also an accounting gap where biomass is produced in Annex-I nations. In the case of Annex-I countries, the KP only requires accounting for emissions due to afforestation, reforestation and deforestation (ARD). Emissions from lands remaining in forests, grasslands, and agricultural lands are included only on a voluntary basis.

The consequence of all of these provisions is that bioenergy enjoys a status under the KP that is not warranted, in general, by its actual emission profile. Use of biomass for heat and power or biofuels produced outside of Annex-I nations is, with the exception of transport emissions, essentially “GHG-free energy” under KP accounting. Use of biomass from such sources results in an apparent 100 percent reduction of the GHG emissions of the fossil fuels it replaces in electric power plants and petroleum products. If deforestation is avoided, the only emissions that must be accounted for in Annex-I nation sourced biomass are those from energy used in biomass conversion and transport. Thus, the KP accounting system encourages Annex-I countries to use bioenergy even in cases where it causes considerable GHG emissions globally.

The EU-ETS was designed in large part to assist in meeting the target established for the EU under the KP. Therefore it is not surprising that the EU-ETS adopted the accounting rules of the KP, with all of their consequences. The EU also, partly to assist in GHG reduction goals but also for energy security and other reasons, adopted a Directive setting mandates for renewable energy, including renewable transportation fuels (EC 2009). However, by the time the Directive was developed, a range of stakeholders had become concerned about the consequences of encouraging use of biofuels when emissions, particularly emissions due to land use change outside of the EU, were not accounted for. Consequently, the Directive includes provisions that attempt to hold EU bioenergy users responsible for emissions along the biomass production and delivery value chain.

The Directive includes mechanisms intended to cover emissions from both direct and indirect land use change. To address direct land use change, raw materials used for biofuels cannot be obtained from primary or undisturbed native forests, land converted from forests or wetlands since 2008, or peatlands drained after 2008. Further, to qualify for compliance with the Directive, a biofuel's GHG emissions per MJ must be at least 35% lower than those of the fossil fuel they replace. In calculating whether a biofuel meets this requirement, emissions due to cultivation of the biomass and direct land use change must be included. Two provisions address indirect land use change. First, if the biomass is produced on degraded or contaminated land, a specified amount (29 gCO_2 MJ^{-1}) can be subtracted[3]. In addition, the Directive charges the EC to submit a report by 2010 accompanied, if appropriate, by a proposal "…containing a concrete methodology for emissions from carbon stock changes caused by indirect land use changes…" (EC 2009). Recently, the EU Commission decided to postpone the decision whether similar regulations should be adopted at the EU level for forest biomass used for heat and power. The Commission only made recommendations to Member States on the development of national sustainability schemes that are consistent with the regulations in the Directive (COM 2010).

The attempt of the Directive to account for emissions due to use of biofuels is only partially successful. First, although the Directive attempts to prevent EU biofuel demand for biomass-for-energy from causing emissions due to land use change, it will fail to do so unless its provisions encouraging use of degraded land are successful. Without sufficient increases in use of degraded land and productivity, increased demand for biomass will trigger land use change and accompanying emissions. If land use change is 'prohibited' for biomass for energy, instead of producing this biomass on converted land, biomass to meet other needs (e.g. food) will be produced through conversion.

A second problem results from the disjunction between Directive and KP and EU-ETS rules. Although the Directive ensures that only biofuels with an emission profile better than petroleum products can be used to meet renewable energy targets, this does not impact their contribution to EU-ETS and KP targets. Under both of these regimes, substitution of biomass for fossil fuels reduces emissions accounted by close to 100 percent (i.e. except for emissions due to conversion of biomass, transport, and deforestation in the EU). Consequently, under these regimes, combustion of biofuels whose GHG balance, assessed with the methodology in the Directive, is not zero, will still enjoy zero emission status and bioenergy use will still be attractive well beyond what justified by its GHG profile.

A final consideration, with regard to the Directive in the context of use of woody biomass, lies in its approach to timing issues. Just as the adoption of an inventory approach to systems with different spatial boundaries led to problems, adoption of the current approach to biofuels for all bioenergy applications would introduce anomalies. The time horizon over which woody biomass sources provide carbon neutrality compared to the use of fossil fuel varies significantly depending on the source of biomass and the fuel-substitution pathway. In particular, the degree to which increased use of woody biomass

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[3] This provision attempts to reduce indirect land-use change impacts of bioenergy demand by providing an incentive to produce the biomass on land not in use to satisfy, e.g. food, feed, or fibre demand. In this way, the food, feed, and fibre demand can continue to be met on land already in use, avoiding further land use change.

for energy lowers or increases GHG emissions compared to fossil fuels by a given date depends on the source of the biomass as well as the fossil fuel for which it is substituted. Within the time horizons of the 2012, 2020, 2030, and even 2050 GHG emission targets, increased use of woody biomass may increase GHG emissions or may make small, medium, or significant contributions to lowering them. Another way to view this is that the carbon neutrality concept of sustainably produced biomass, which underlies the acceptance of the UNFCCC inventory approach for the KP, is true only over time periods which, in some cases, exceed the time horizons of the targets for whose achievement biomass is being recommended. Particularly cases where management change rather than land use change is involved, adoption for other bioenergy pathways of the Directive approach to biofuels would not resolve near-to-medium term targets concerns. The following sections explore this timing issue for a range of biomass sources in further detail.

3 Bioenergy deployment in Europe

According to estimates used by DG TREN, the projected RES deployment in 2020 will require the use of 195 Mtoe from biomass. The 195 Mtoe will be produced mainly from domestic biomass, i.e. 173 Mtoe of domestic solid biomass will be used in 2020, which is equal to 78% of the domestic EU potential. The remaining 22 Mtoe will be imported, divided into 5 Mtoe of forest products and residues and 16.9 Mtoe of biofuels. The energy generation from solid biomass and biowaste is projected to be 58% of the total renewable energy generation in 2020 (140 Mtoe of 240 Mtoe) and it will cover 12% of the gross energy demand in the EU.

The promotion of climate mitigation policies and the establishment of a renewable energy target are strong drivers for the demand of bioenergy in Europe. Several studies have analysed the possible deployment of the renewable energy market in the next decades, taking into account different policy scenarios, energy prices and technology development.

In this study we considered the demand projections based on the *PRIMES* modelling and the renewable energy source (RES) deployment based on the *GREEN-X* model to be consistent with scenarios and assumptions considered by the European Commission. We analysed the most recent studies that take into account the current policy target in the Renewable Energy Directive (D on RES) (EC 2008, Resch et al. 2008, Ragwitz et al. 2009).

a) Energy demand

The PRIMES projections forecast the future energy demand in Europe under different policy scenarios and energy prices (EC 2008) (Table 1).

Among the PRIMES projections, there are:

- A *baseline* scenario that includes current trends, policies already implemented and moderate energy prices. The share of renewable energy on the final energy demand is projected be around 13% in 2020. Even with high oil prices, the percentage of renewables is estimated to be 15% of the final energy demand; and
- A *new energy policy* scenario that assumes the implementation of new energy efficiencies policies to reach energy and climate targets. Under this scenario and moderate energy prices, the final demand for renewables will be 20% of the final energy demand. Therefore, it is necessary to implement new policies to reach the 20% target set in the D on RES.

The total primary energy demand for renewables is today covered mainly by the domestic primary production in the EU. The net imports of RES in 2005 were only 1% of the primary energy demand. However, the imports need to increase to 9% of the primary energy demand in 2020 to comply with the 20% target (*new energy policy* scenario).

Table 1 Energy production and demand in 2005 and 2020 according to PRIMES

Year	2005	2020			
Scenario		Baseline		New Energy Policy	
Oil price		61$ bbl^{-1}	100$ bbl^{-1}	61$ bbl^{-1}	100$ bbl^{-1}
EU primary production (Mtoe)	**896**	**725**	**774**	**733**	**763**
Oil	133	53	53	53	52
Natural gas	188	115	113	107	100
Solids	196	142	146	108	129
Nuclear	257	221	249	218	233
Renewables	122	193	213	247	250
Net imports (Mtoe)	**975**	**1,301**	**1,184**	**1,033**	**962**
Oil	590	707	651	610	569
Natural gas	257	390	330	291	245
Solids	127	200	194	108	124
Renewables	1	3	8	23	24
Primary energy demand (Mtoe)	**1,811**	**1,968**	**1,903**	**1,712**	**1,672**
Oil	666	702	648	608	567
Natural gas	445	505	443	399	345
Solids	320	342	340	216	253
Renewables	123	197	221	270	274
Nuclear	257	221	249	218	233
Final energy demand (Mtoe)	1,167	1,348	1,293	1,185	1,140
% Renewables on final energy demand	*8.9%*	*13.1%*	*15%*	*20%*	*21%*

Source: EC 2008

b) RES deployment

The future deployment of renewable energy in EU-27 has been quantified by several projects with the *GREEN-X* model that forecasts the deployment of RES in a real policy context. The potential supply of energy from each technology is described at country level analysed by means of dynamic cost-resource curves (http://www.green-x.at).

In this study, we considered the final results of the "Employ-RES" project up to 2020 (Ragwitz et al. 2009). The RES deployment is projected under the PRIMES policy scenario and high energy prices (100$ bbl^{-1} in 2020), because, under these conditions, the demand for renewable energy matches the 20% RES target. As a term of comparison, in a business as usual (BAU) scenario the RES share in the final gross energy demand would be 13.9% in 2020. In the *policy* scenario, improvements of the support conditions for RES are preconditioned for all EU countries, including a removal of non-financial deficiencies and the implementation of feasible energy efficiency measures.

In the *policy* scenario, the RES will reach a 20.4% of final (gross) energy demand in 2020[4] (239.5 Mtoe, Table 2). The D on RES includes an additional target for biofuels that will have to reach 10% on the demand for diesel and gasoline. In the projections the share of biofuels will reach 8% of transport fuel demand in 2020, corresponding to a 10% of diesel and gasoline demand.

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[4] The final energy demand used in the Employ-RES report is slightly different but fully comparable to the data presented in EC 2008.

Concerning biomass, the allocation of biomass resources to the various sectors and technologies is based on feasible revenue streams under a specific policy scenario. The projections to 2030 show a saturation of the bioenergy growth due to limitations of domestic resources and the presumed limitation of alternative imports from abroad (Ragwitz et al. 2009).

Table 2 RES deployment in EU-27

Generation category	Mtoe			% on generation category
	2006	2010	2020	2020
RES-E - Electricity generation				
Biogas	1.5	2.2	7.1	7%
Solid biomass	4.9	8.3	15.6	16%
Biowaste	1.2	2.0	2.9	3%
Geothermal electricity	0.6	0.6	0.7	1%
Hydro large-scale	26.0	27.2	28.0	29%
Hydro small-scale	4.0	4.5	5.3	5%
Photovoltaics	0.2	0.3	1.7	2%
Solar thermal electricity	0.0	0.1	1.2	1%
Tide & wave	0.0	0.2	0.5	1%
Wind onshore	8.4	14.0	24.9	25%
Wind offshore	0.3	0.8	10.1	10%
RES-E total	**47.0**	**60.2**	**98.2**	
RES-E CHP	*5.2*	*8.3*	*16.2*	*16%*
share on gross demand (%)	***16.4%***	***19.6%***	***32.4%***	
RES-H - Heat generation				
Biogas (grid)	1.5	1.6	1.9	2%
Solid biomass (grid)	5.3	9.2	20.8	19%
Biowaste (grid)	2.4	3.6	5.2	5%
Geothermal heat (grid)	0.8	0.9	1.5	1%
Solid biomass (non-grid)	49.7	53.8	65.7	59%
Solar therm. heat.	0.8	1.6	8.3	7%
Heat pumps	0.8	1.3	8.2	7%
RES-H total	**61.3**	**72**	**111.6**	
RES-H CHP	*7.1*	*10.7*	*18.2*	*16%*
RES-H distr. heat	*2.9*	*4.7*	*11.2*	*10%*
RES-H non-grid	*51.3*	*56.7*	*82.2*	*74%*
share on gross demand (%)	***10.4%***	***11.9%***	***21.7%***	
RES-T - Biofuel generation				
Traditional biofuels	3.7	6.8	11.4	39%
Advanced biofuels	0	0	1.3	4%
Biofuel import	0.4	2.5	16.9	57%
RES-T total	**4.1**	**9.3**	**29.7**	
share on gross demand (%)	***1.1%***	***2.4%***	***8.3%***	
share on diesel and gasoline demand (%)	***1.4%***	***2.9%***	***10.0%***	
RES TOTAL	**112.4**	**141.5**	**239.5**	

Source: Ragwitz et al. 2009

c) Biomass potential

The RES deployment in Employ-RES is based on a domestic availability of biomass of 221 Mtoe yr^{-1} in 2020[5]. The types of domestic fuels are: agricultural products and residues, forestry products and residues and biowaste. The share of domestic fuels is divided in: 30% of agricultural products, 32% forestry products, 14% of agricultural residues, 16% of forestry residues and 8% of biowaste. In addition, forestry imports equal to 5% of the domestic available biomass are included.

In 2006, the EEA estimated the environmental potential of bioenergy in Europe. The total potential was estimated to be 234.2 Mtoe in 2020 (Table 3). The potential in the different sectors is: 41% from agriculture, 17% from forestry and 43% from waste. The differences with the potential in the RES deployment studies are mainly due to a different classification of biomass. In the EEA study agricultural residues, demolition wood, waste wood and black liquor, manures and sewage sludge are included in the waste sector. In the RES deployment studies, only the biodegradable fraction of municipal waste is considered a biomass source from waste. When a similar classification is adopted in the EEA study, the biomass potential in Europe in 2020 is 39-47% from agriculture, 45-53% from forestry and 8% from waste, i.e. the share is comparable to the RES deployment studies.

Other studies report similar estimates. For instance, a study by Siemons et al. (2004) reports a total bioenergy potential of 210.3 Mtoe in 2020 in EU-27.

Table 3 Environmental bioenergy potential in Europe

Sector		2010	2020	2030
		Mtoe		
Agriculture		47.0	95.0	144.0
Forestry	Total without comp.	42.6	39.2	39.0
	Regular felling residues	*14.9*	*15.9*	*16.3*
	Additional fellings and their residues	*27.7*	*23.3*	*22.7*
	Competitive use of wood		*2.0*	*16.0*
Waste		99	100.0	102.0
TOTAL		**188.6**	**234.2**	**285.0**

Source: EEA 2006

According to the estimates of the Employ-RES project, energy generation from solid biomass and biowaste is projected to be 58% of the total renewable energy generation in 2020 (140 Mtoe of 240 Mtoe). Therefore biomass will cover 12% of the gross energy demand in the EU. The biomass energy generation will require 195 Mtoe that will be mainly produced from domestic biomass, i.e. 173 Mtoe of domestic solid biomass will be used in 2020, which is equal to 78% of the domestic EU potential. The remaining 22 Mtoe will be imported, divided into 5 Mtoe of forest products and residues and 16.9 Mtoe of biofuels.

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[5] “Biomass data has been cross checked with DG TREN, EEA and the GEMIS database” (Ragwitz et al. 2009)

When looking at global biomass potentials, Howes et al. 2007 report that biomass production potential varies between 33 and 1,135 EJ yr^{-1} (786-27,024 Mtoe yr^{-1}). The high variability is due to the assumptions that are made of land availability and yields. The actual biomass resource depends on several factors (accessibility, costs, etc.). The global technical potential of land-based biomass supply in 2050 is estimated to be 60-1,100 EJ yr^{-1} (1,430-26,190 Mtoe yr^{-1}) (Bauen et al. 2009). A significant contribution to the total biomass use in developed countries is given by biomass imports. In North-West Europe and Scandinavia biomass imports are 21-43% of the total use, including intra-European trade. In the longer term, the total traded biomass commodities could reach a total amount of more than 100 EJ, with Europe as a net importer (Bauen et al. 2009). These data suggest that the contribution of biomass imported from non-European countries could play a more relevant role than what suggested by the projections considered by the European Commission.

4 The mitigation potential of bioenergy

According to the principle of carbon neutrality, the GHG emissions produced by combustion of plant biomass are assumed to be re-captured instantaneously by new growing plants. When the raw material is wood, the time needed to re-absorb the CO_2 emitted in the atmosphere can be long, depending very much on the source of wood. Therefore bioenergy can create an atmospheric "carbon debt".

The research studies on bioenergy potential and the potential deployment of RES calculate the CO_2 emissions avoided by renewables based on the amount of displaced fossil fuels. The assessment is usually based only on the conversion efficiency of RES technologies.

An exhaustive GHG emission estimate should apply the principles of a Life Cycle Assessment (LCA) that take into account both direct and upstream emissions, like transport and the use of materials and energy for manufacture at all stages (EEA 2008). The calculations are made for both the original fossil fuel system (reference system or baseline) and the renewable energy system and the results from the two systems are compared to assess the GHG benefits or costs. Such an analysis should consider the emissions at all stages (Figure 2).

A type of emission that has been rarely taken into account is the carbon that is released in the atmosphere when the biomass is combusted. These emissions are usually neglected because they are only temporarily released in the atmosphere and later recaptured by re-growing biomass. Therefore biomass is considered carbon neutral. According to the principle of carbon neutrality, the GHG emissions produced by combustion of plant biomass are assumed to be re-captured instantaneously by new growing plants. This assumption is acceptable when the same amount of biomass that was burned will re-grow in a very short time as for annual crops. When the raw material is wood, the time needed to recover the CO_2 emitted in the atmosphere can be quite long, on the order of magnitude of decades. It is the same principle valid for a bank loan. The borrowed money is used in the first year to buy a product, but it is repaid to the bank in a certain time frame. The time needed to re-absorb the "carbon debt" from woody biomass depends very much on the source of wood. Factors to be considered are: the previous land use and management, the productivity of the trees that influences the time needed to biomass re-growth and the previous use of the raw material, if any.

The new climate change policies and the EU Renewable Energy Directive (D on RES) could be a strong driver for an increased use of biomass. Biomass resources, which would not have been used without the new policies, will be used to produce energy. This means that carbon that would have been stored in the biosphere in a 'without policy' baseline scenario will be released into the atmosphere as CO_2 as soon as the biomass is combusted. In the very short term, this amount of emissions going to the atmosphere would be the same as the emissions produced by a fossil fuel based energy system with similar conversion efficiency (C_{eff}) and similar emissions per unit of energy. The fossil fuel with emissions per unit of energy most similar to biomass is coal.[6]

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[6] However, most of the fossil fuel systems are more efficient than biomass energy systems, i.e. for the same amount of fuel used they produce more energy. In addition, fossil fuels other than coal produce more emissions per unit of energy derived from the fuel. Oil produces 20% less emissions than biomass to produce the same amount of energy (C_{eff}=0.8), while natural gas produces 40% less emissions (C_{eff}=0.6).

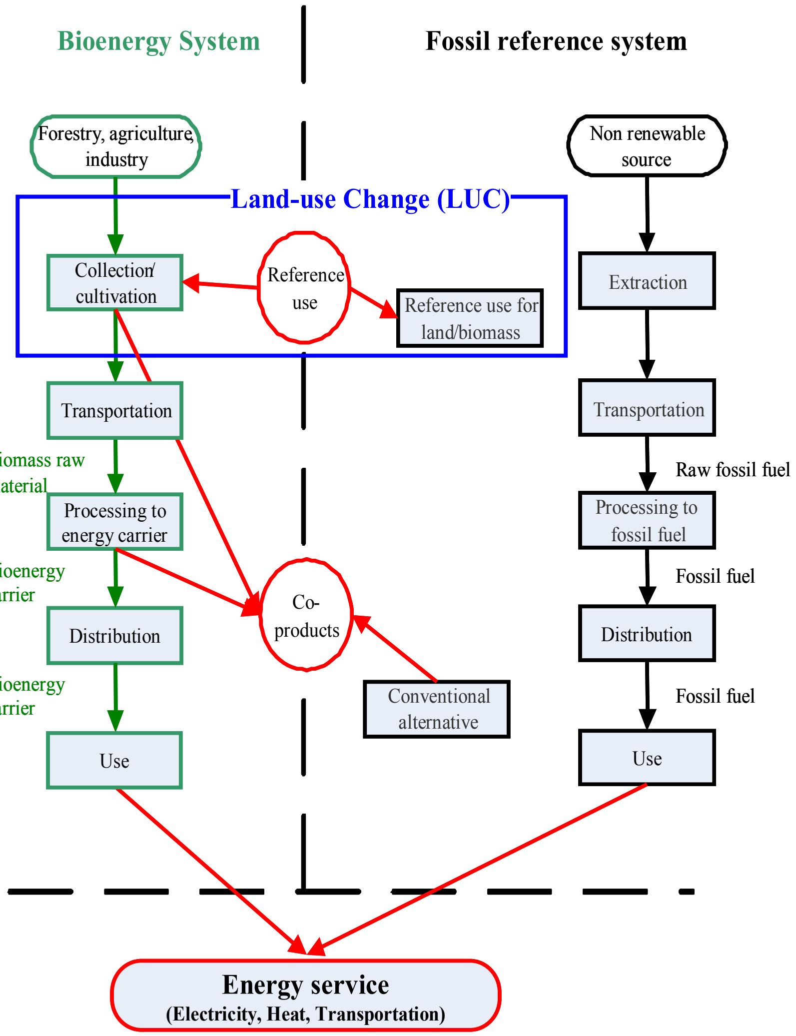

Figure 2: Processes in bioenergy and fossil reference systems

With time the emissions may be recaptured by re-growing biomass, but in the context of EU and KP climate change targets, a short term benefit, in terms of emission reductions, needs to be achieved.

It is estimated that the RES deployment considered by the European Commission will require 173 Mtoe of domestic solid biomass and 22 Mtoe of imported biomass in 2020. The sources of biomass will vary a lot, from agricultural residues to additional fellings from forest. In the short and the medium term, the real climate mitigation potential of the different materials will depend a lot on the time frame needed to recapture the emissions released from the combusted biomass.

4.1 Carbon neutrality factor

The extent to which the use of bioenergy reduces GHG emission can be quantified with a Carbon Neutrality (*CN*) factor. The *CN* factor is defined as the ratio between the net reduction/increase of carbon emissions in the bioenergy system and the carbon emissions from the substituted reference energy system, over a certain period of time. The *CN* is time dependent and it includes emissions from carbon stock changes.

Schlamadinger and Spitzer (1994) introduced 15 years ago the concept of a Carbon Neutrality Factor (*CN*) to quantify to the extent to which the use of biomass for energy reduces GHG emissions.

A similar approach is used in the D on RES. The D on RES provides instructions on how to calculate the GHG emission savings from the use of biofuels (EC 2009). The D on RES simplifies the calculation of emissions due to carbon stock changes in the biosphere. For one thing, it takes into account only emissions from land use changes, but not from management changes. In addition, it assumes constant land use change emissions over a 20 year period and therefore an unchanging relative improvement over use of fossil fuels, regardless of the time horizon of targets.

The *CN* factor is defined as the ratio between the net reduction/increase of carbon emissions in the bioenergy system and the carbon emissions from the substituted reference energy system, over a certain period of time:

[1]
$$CN(t) = \frac{[E_r(t) - E_n(t)]}{E_r(t)} = 1 - \frac{E_n(t)}{E_r(t)}$$

Where:
$E_r(t)$: carbon emissions of the fossil energy reference system, between 0 and *t* years
$E_n(t)$: carbon emissions of the new bioenergy system, between 0 and *t* years.

a) *CN* <0, if the emissions from the bioenergy system are higher than the emissions from the fossil fuel system.
b) *CN* =0, if the emissions from the new bioenergy system are equal to the emissions from the reference system.
c) *CN* =1, if the bioenergy system produces zero emissions in comparison to the reference system.
d) *CN* >1, when the bioenergy system produce a carbon sink in the biosphere.

Production chain emissions (e.g. cultivation, transport, processing, etc.) are not included in the *CN* concept. In the *CN*, the emissions produced by changes in carbon stocks (E_C) when biomass is removed are compared to the emissions produced by the fossil fuel burnt.

The E_C component ($tCO_2eq.$) is given by the difference in C stock in living biomass, both above and below ground[7], and in non-living biomass (dead wood, litter and soil) over a specified time period. Carbon stocks are measured before removal of biomass (C_0, tC -

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[7] Live fine-roots are normally considered part of the soil pool because they can not be distinguished from soil carbon.

baseline) and then after removal at some specified time *t* (C_t, tC – bioenergy system)[8]. A constant factor is used to convert the carbon into CO_2 emissions (*a*=3.664)

[3] $$E_C = (C_0 - C_t) \times a = \Delta C_t \times a$$

When carbon in biomass replaces the same amount of carbon in fossil fuels (biomass replacing coal), the *CN* factor is equal to:

[4] $$CN(t) = 1 - \frac{\Delta C_t \times a}{E_r(t)} = 1 - \frac{\Delta C_t}{C_{bioenergy}}$$

Where $C_{bioenergy}$ is the amount of carbon in the biomass used for bioenergy after *t* years.

The E_C is time dependent. When a new management – such as increased harvesting or removal of residues – is introduced or a land-use change occurs, the C stock in the system is modified until a new equilibrium is reached (Figure 3). The long-term E_C is the difference of carbon stock in biomass and soil between the baseline and the new equilibrium. However, most of the emissions due to management or land-use changes occur in the initial years. In a forest system, where additional biomass is harvested and burnt to produce bioenergy, there is an immediate loss of biomass carbon stocks equal to the amount of biomass extracted ($\Delta CB_t = C_{bioenergy} = CB_0 - CS_0$) as shown in Figure 3. The re-growth of biomass reduces, over time, the initial carbon loss (at year t_1, $\Delta CB_t = CB_0 - CB_1$). At the same time the reduced dead wood and litter inputs results in a loss of carbon in the soil and litter pools (ΔCS_t). The total E_C at time *t* is equal to the total carbon loss in the biomass and the soil at time *t* in comparison to the baseline ($\Delta CB_t + \Delta CS_t$) .

The time-dependency of E_C results in a time dependent *CN* factor (Figure 4):

1) $CN(t_0) = 1 - \frac{C_{bioenergy}}{C_{bioenergy}} = 0$

2) $CN(t_1) = 1 - \frac{\Delta CB_{t1} + \Delta CS_{t1}}{C_{bioenergy}}$

If in Figure 3 at time t_1, the carbon stock loss compared to the baseline ($\Delta CB_{t1} + \Delta CS_{t1}$) is assumed to be 40% of the amount of biomass used for bioenergy ($C_{bioenergy}$), *CN* at time t_1 is equal to 0.6.

3) If the carbon stock change, $\Delta CB_{t1} + \Delta CS_{t1}$ is equal to or less than zero (no change or a carbon sink), *CN* would be equal to or greater than 1:

$$CN(t) \geq 1 \text{ if } \Delta CB_t + \Delta CS_t \leq 0$$

In the following sections the principle of bioenergy carbon neutrality is discussed with examples that will illustrate the development in time of the *CN* factor for different bioenergy sources. The following examples will be described:

- Residues from managed forests
- Additional fellings from managed forests
- Bioenergy from new tree plantations

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[8] Normally the litter is considered a separate pool, but for the purposes of this discussion we will consider litter as part of the soil carbon pool

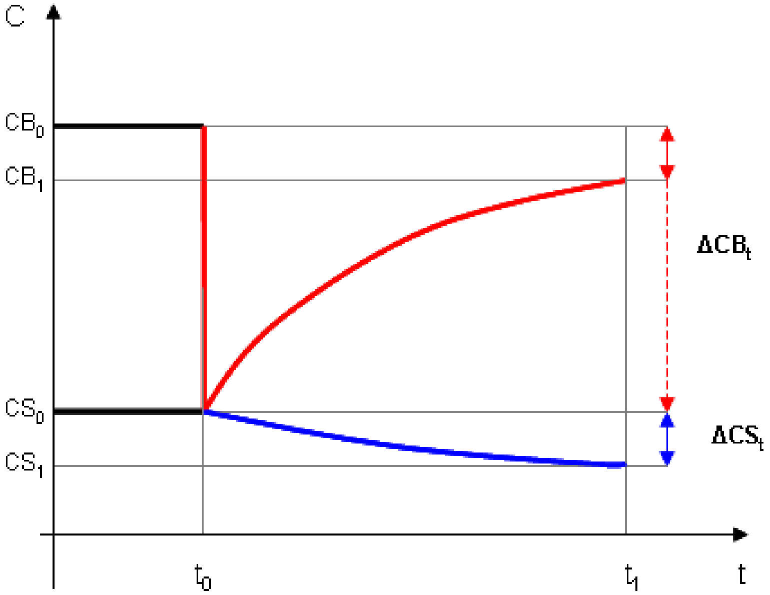

Figure 3 Carbon stock changes in biomass (*ΔCB_t*) and soil (*ΔCS_t*) due to additional biomass extraction and their change over time. Black lines: baseline carbon stock; Red lines: carbon stock in biomass when additional biomass is extracted; Blue line: carbon stock in soil and litter when additional biomass is extracted. *CB_0*=biomass C stock in the baseline; *CB_1*= biomass C stock after biomass re-growth at year *t_1*; *CS_0* = soil C stock in the baseline; *CS_1*= soil C stock after *t_1* years.

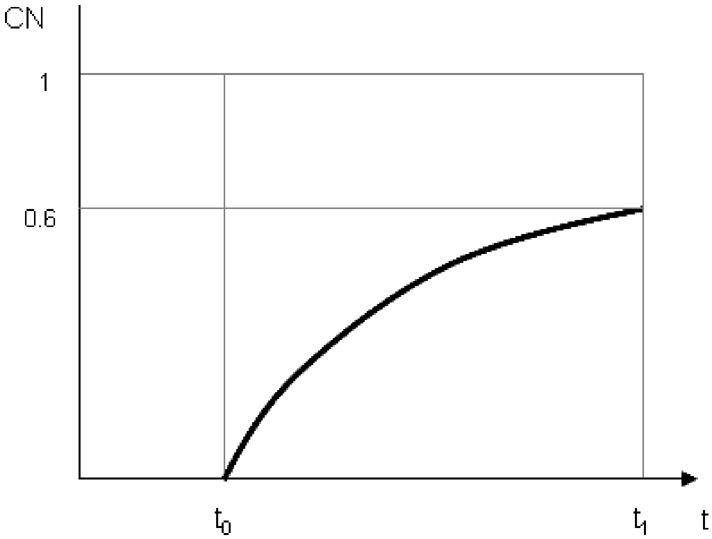

Figure 4 Development of the carbon neutrality factor (*CN*) over time, based on Figure 3

4.1.1 Residues from managed forests

When harvest residues, previously left on the forest floor, are extracted for bioenergy, there is a carbon stock loss in the dead wood, litter and soil pools. It was estimated that the mitigation potential of such bioenergy material in a 20 year time horizon is reduced by 10-40% by this loss (*CN*=0.6-0.9).

The following analysis is based on Schlamadinger et al. (1995) and Palosuo et al. (2001).

One of the possible strategies to increase the biomass available for bioenergy is to collect the forest residues that are usually left in the forest after harvesting. Depending on the site, a certain amount of residues can be extracted from the forest without compromising soil fertility and therefore forest production (EEA 2006). If this amount of residues is utilized as bioenergy source, the emissions due to the management change are limited to the carbon stock changes in the dead wood, litter and soil pools (Schlamadinger et al. 1995, Palosuo et al. 2001).

When residues are left on the forest floor, they gradually decompose. A great deal of the carbon contained in their biomass is released over time into the atmosphere and a small fraction of the carbon is transformed into humus and soil carbon. When the residues are burnt as bioenergy, the carbon that would have been oxidized over a longer time and carbon that would have been stored in the soil is released immediately to the atmosphere. This produces a short term decrease of the dead wood and litter pools that is later translated into a decrease of soil carbon.

The following paragraphs present two published studies that analysed the effect of removing harvest residues from forests where the residues were previously left on site:

1) A constant annual removal of harvest residues from selective logging (Schlamadinger et al. 1995)
2) Removal of residues from clear cut at the end of a 100 year cycle (Palosuo et al. 2001)

In Schlamadinger et al. (1995) the effect of annual residue removal from a temperate or boreal forest was analysed. Every year 2/3 of harvesting residues (0.3 tC $ha^{-1}yr^{-1}$) are extracted from a forest where selective harvesting has been taking place. The soil carbon is assumed to be in equilibrium when removal of logging residues starts at time 0.

Figure 5 compares the carbon in the residues removed annually and used to replace fossil fuel to the annual loss of carbon in the litter and soil due to these removals. At time 0 the removed biomass for bioenergy corresponds to an equal loss of carbon in the litter (0.31 t ha^{-1}). With time the soil and litter carbon tends to reach a new equilibrium and the losses tend to zero.

Based on this figures, the Carbon Neutrality factor (*CN*) of logging residues used for bioenergy was calculated (Figure 6). The *CN* factor at a certain time (*t*) represents the average *CN* of all the residues that have been extracted from year zero to year *t*.

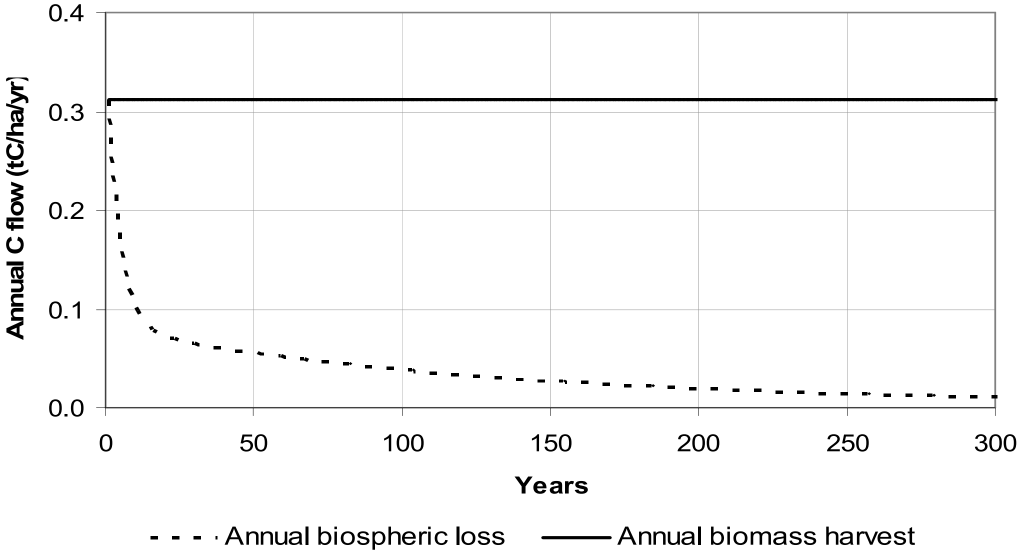

Figure 5 Carbon in removed biomass and carbon stock loss in litter and soil on a yearly basis (from Schlamadinger et al. 1995).

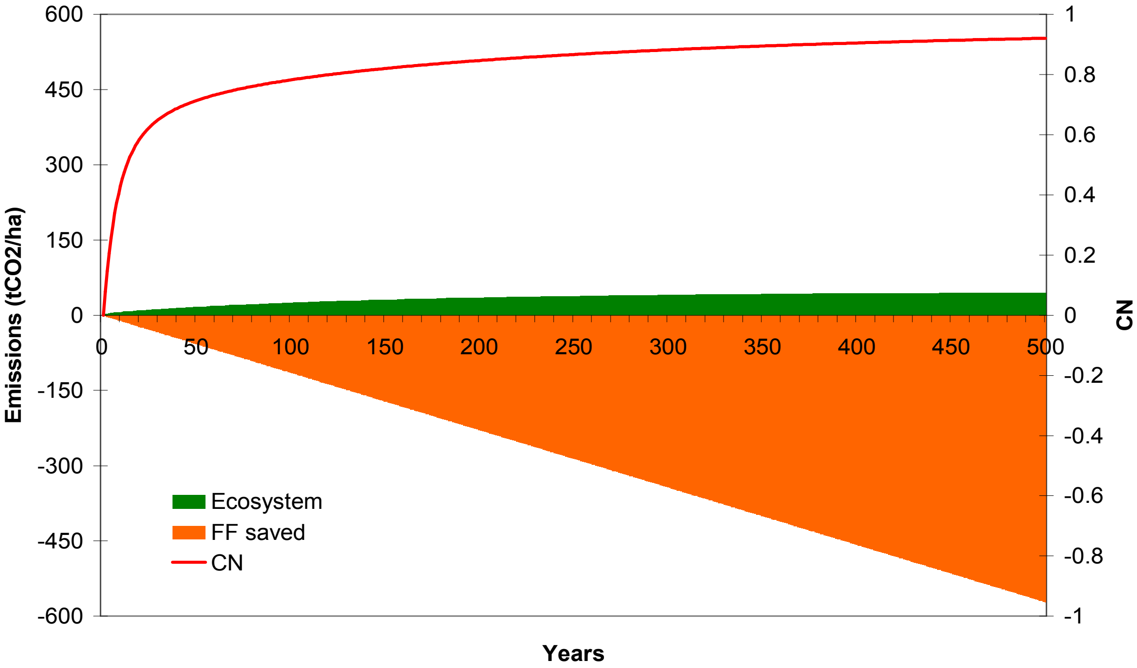

Figure 6 Carbon neutrality factor for burning logging residues for energy production (*CN*). The *CN* is calculated by comparing the carbon emissions in the soil ad litter due to the additional residue extraction (Ecosystem) to the total amount of saved emissions in the replaced fossil fuel (FF saved).

The *CN* is calculated by comparing the carbon loss in the soil ad litter due to the additional residue extraction to the total amount of carbon in the replaced fossil fuel. The replaced fossil fuel is assumed to be equal to the total biomass of residues that replaces it, i.e. the biomass replaces coal that has similar conversion efficiency and carbon emission rates. In this case,

[5]
$$CN = 1 - \frac{(C_0 - C_t)}{B_r \times t}$$

Where:
C_0= carbon stored in litter and soil at time 0 (baseline)
C_t = carbon stored in litter and soil at time t, when residues are extracted
B_r = carbon in the residues that are annually extracted

The results show that after 20-25 years the *CN* factor is about 0.6, meaning that 60% of the bioenergy used to replace fossil fuels is carbon neutral. In other words, it would be justified to assign no emissions to 60 percent of the bioenergy emissions, but in the case of the other 40 percent, an emission factor equal to that of coal would be appropriate.

The assumption used in equations [5] that the carbon emission rate or energy produced per ton of carbon of replaced fossil fuels is equal to the emission rate of residues used for energy is quite optimistic and is only approximately correct in the case of the substitution of coal. If we assume that 1 tC from residues can replace:

- 0.8 tC of oil, the *CN* of residues in the above case after 20 years would be equal to 0.5;
- 0.6 tC of natural gas, the *CN* of residues after 20 years would be equal to 0.3.

When wood waste is used for bioenergy instead of being discarded in landfills, the conclusions can be comparable if the decomposition rates in landfills are similar to the ones in forests soils. However, the wood in landfills usually decomposes slower than in the forest. In this case the *CN* of bioenergy would be lower in the short and medium term and, from the perspective of GHG emissions, it would be better to land-fill the waste wood.

A second case study was presented by Palosuo et al. (2001) for 1 ha of forest in Finland that is clear cut after a 100 year rotation cycle. The study assesses the effect of residue removal at the end of the rotation period on the litter and soil carbon. An average carbon decrease of 11% over the 100 year period was assessed, when the residues are removed. It was also calculated that 90% of the carbon in the residues left on site is released to the atmosphere after 20 years, i.e. the *CN* for a specific lot of residues removed at year 20 is equal to 0.9.

In Schlamadinger et al. the *CN* is calculated as the average for all residues annually removed over a certain period. When the *CN* is calculated for residues removed only once, by using the same modelling approach, the *CN* reaches a value of 0.8 by year 20. Therefore the figures are comparable to those presented in Palosuo et al. and they show how different chosen boundaries can influence the final results..

The calculations reported above refer to boreal or temperate forests. The decomposition rates (k) may vary substantially when the residues for bioenergy are imported from other regions. A review of litter decomposition rates shows that they increase with precipitation, temperature and latitude and they are lower for coarse dead wood than for fine litter (Zhang et al. 2008) (Table 4). In Schlamadinger et al. (1995) it was calculated that the same residue material with higher decomposition rates have a lower carbon neutrality factor.

When the residues extracted are coarse dead wood (e.g. stumps, branches), another factor needs to be considered. Part of the dead wood would not start decomposing immediately and the amount of carbon that is released in the atmosphere per year is not equal to $1-k$. Only a fraction of the carbon decomposes (e.g. 0.05 yr^{-1} for coarse dead wood, Palosuo et al. 2001) and the rest remains as a carbon pool in the forest. When the stumps are removed this slower decomposing pool must be accounted as a loss equivalent to the extraction of more logs. As a consequence the *CN* of stumps used for bioenergy will be much lower than *CN* of fast decomposing residues after the same time. The consequences of these slower rates are presented in the following section.

It is also assumed that the removal of residues does not affect soil fertility and therefore the growth of tree biomass. However, over a certain amount of residue extracted, soil fertility could be altered and negatively affect the overall forest carbon balance. Additional concerns to residue extraction are linked to the decrease of deadwood in the forest and the negative impacts that this decrease could have on biodiversity and water retention of the forest floor.

Table 4 Regression of litter decomposition with geographic, climatic factors and litter quality variables. T= mean annual temperature; P= mean annual precipitation; LAT= latitude; LIGN:N= lignin:N ratio; TN= total nutrient; C:N = carbon:nitrogen ratio

Variable/regression	N.	R^2
Climatic/geographic factors		
k = 0.0016 + 0.0447 T	163	0.288
k = -0.065 + 0.0001 P + 0.044 T	163	0.3
k = -0.4744 + 0.0081 LAT + 0.0586 T	163	0.301
k = -0.353 + 0.0063 LAT - 0.00005 P + 0.06 T	163	0.305
Litter quality variables		
k = 0.946 - 0.011 LIGN:N	141	0.131
k = -0.131 + 0.268 TN	68	0.388
k = -2.307 + 0.029 C:N + 0.524 TN	68	0.702
k = -2.132 + 0.031 C:N - 0.006 LIGN:N + 0.495 TN	68	0.733
Combination		
k = -0.308 + 0.026 T + 0.205 TN	68	0.467
k = -2.484 + 0.026 T + 0.0287 C:N + 0.461 TN	68	0.781
k = -2.935 + 0.0003 P + 0.021 T + 0.0315	68	0.805
k = -4.131 + 0.023 LAT + 0.063 T + 0.032 C:N + 0.517 TN	68	0.875

Source: Zhang et al. 2008

4.1.2 Additional fellings from managed forests

It was assessed that additional fellings for bioenergy can produce a decrease of the overall C stock in the forest that significantly affects the GHG balance of the bioenergy material. In the short-medium term (20-50 years), additional fellings could produce more emissions in the atmosphere than a fossil fuel system (*CN<0*). In such a case, the use of additional fellings would produce only very long term benefits, in the order of magnitude of 2-3 centuries.

An increased demand for biomass for bioenergy could require increasing the amount of fellings from managed forests (additional fellings). A EEA study (EEA 2006) assessed that 19.6 Mtoe of energy could come from additional fellings in the year 2020 in European forests. The potential corresponds to an additional biomass extraction of 44 Mt per year in 21 European countries (EU-21) in 2020 and takes into account environmental constraints.

European forestry statistics shows that currently the amount of annual fellings is lower than the net-annual increment (NAI). Fellings constitute on average 61% of the NAI in the EU-21 and a total amount of 433 Mm^3 was extracted in 2005 (MCPFE 2007)[9]. The FAO reported 425 Mm^3 of wood removals in EU-21 in 2005, 85% of which was industrial wood and the rest fuelwood (FAO 2006). By applying an average wood density of 0.45 t m^{-3}, 191-195 Mt of wood was removed in 2005 in EU-21 compared to a net-annual increment of about 320 Mt yr^{-1}. If an additional amount of wood, equal to 44 Mt yr^{-1}, is extracted every year, the annual fellings would increase to 75% of the NAI in EU-21.

This additional amount of extracted biomass could produce a decrease of the overall carbon stock in the forest biomass and in the soil in comparison to a “no increase in removals” baseline. The effect would be similar to the one described in the previous section for forest residues but it would be much greater. The carbon losses would not be limited to the soil and litter pools, but would include losses to the above ground live biomass pool.

The decrease of the biomass is initially equal to the amount of wood that is extracted. If we assume that every year the same amount of additional harvested wood is taken out of the forests (44 Mt yr^{-1}), forest growth and litter inputs to the soil would be modified. The forest system would slowly tend to a new equilibrium with a lower above ground biomass stock and lower soil carbon stock.

The following paragraphs illustrate what occurs when harvest thinning are increased on 1 ha of forest in Austria. The GORCAM model has been used to simulate the effects of increased thinnings against a baseline scenario. The baseline scenario is a forest on a 60 year rotation period. Wood is removed two times by thinnings at years 20 and 40. Each thinning operation extracts 18 t ha^{-1} of biomass, while the final harvest removes 270 t ha^{-1}. In the increased-thinnings scenario it is assumed that the amount of wood removed by thinnings is 30 t ha^{-1}, for a total of 60 t ha^{-1} in each rotation period. The final harvest remains the same (270t ha^{-1}).

Figure 7 presents the difference of the carbon stock in the two systems. The increase of thinnings produces a decrease of carbon stock in the forest pools. The decrease of stock

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[9] For Austria, Portugal and Spain the data of 2000 have been used

is greatest during the first 150 years and is partially and slowly compensated by the re-growth of trees. The soil is the slowest pool and it takes a very long time before it reaches a new equilibrium (approximately 300 years). In all, the total C stock is lower than in the baseline.

If the extracted biomass is used to replace fossil fuels, then there is a net benefit to the atmosphere if the cumulative emissions due to the management change are less than those would have occurred if the biomass were not used to substitute fossil fuels. Figure 8 shows the development of emissions in the forest ecosystem compared to the fossil fuel emissions avoided by using bioenergy. The first graph (A) assumes that the fossil fuel and the bioenergy system have the same conversion efficiency and the same CO_2 emissions per unit of energy produced. Even in this case, the bioenergy system will produce more emissions than the fossil fuel system for a long time. The bioenergy system will start to produce an atmospheric benefit only after 250 years ($CN \geq 0$). Bioenergy from additional fellings will produce an emission benefit even later if fossil fuels with fewer CO_2 emissions per unit of energy, like gas, are substituted (Figure 8B). In this case a benefit will be achieved only after 300 years.

Therefore in the short-medium term (20-50 years), additional fellings from already managed forests could produce more emissions in the atmosphere than a fossil fuel system and the *CN* will be negative for centuries. The use of additional fellings would produce only very long term benefits and it could be supported only when a long-term emission reduction target is considered, i.e. as an investment for future generations.

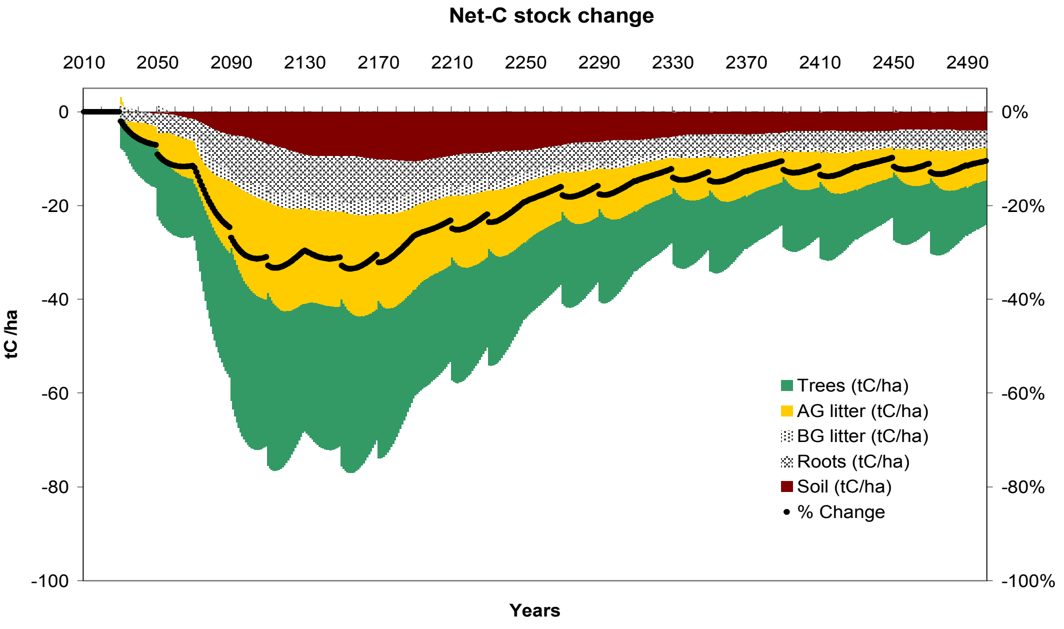
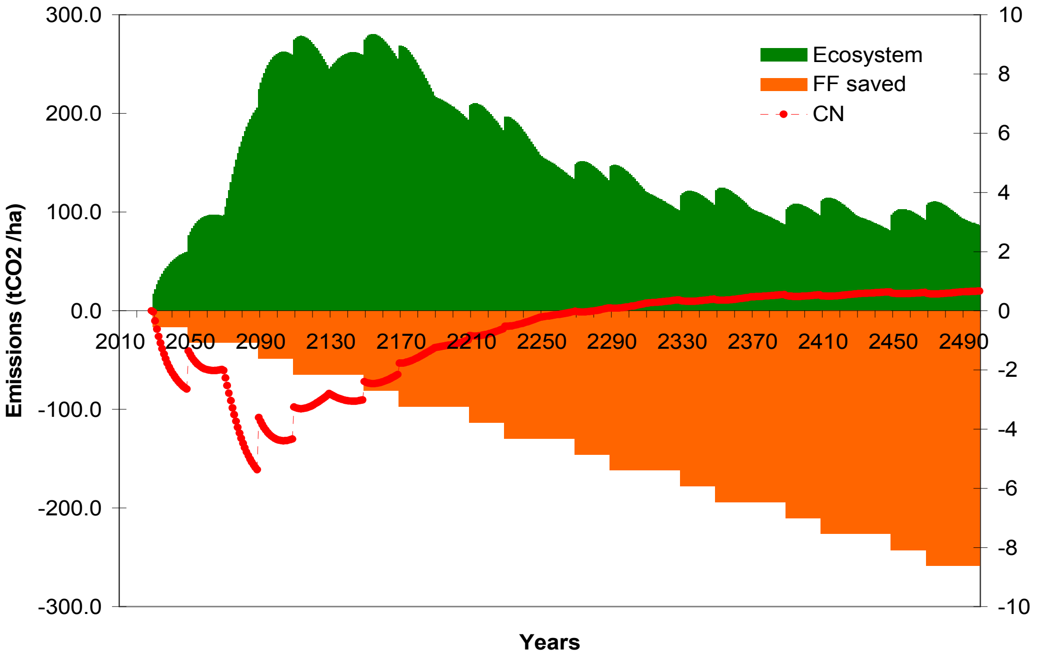


Figure 7 Decrease of carbon stock in the tree biomass, litter and soil when thinning removals are increased. Tree: aboveground tree biomass; AG litter: aboveground litter; BG litter: belowground litter; Roots: belowground tree biomass; Soil: soil carbon stock. The black line represents the percentage reduction of C stock in comparison to the baseline (% Change).

A



B

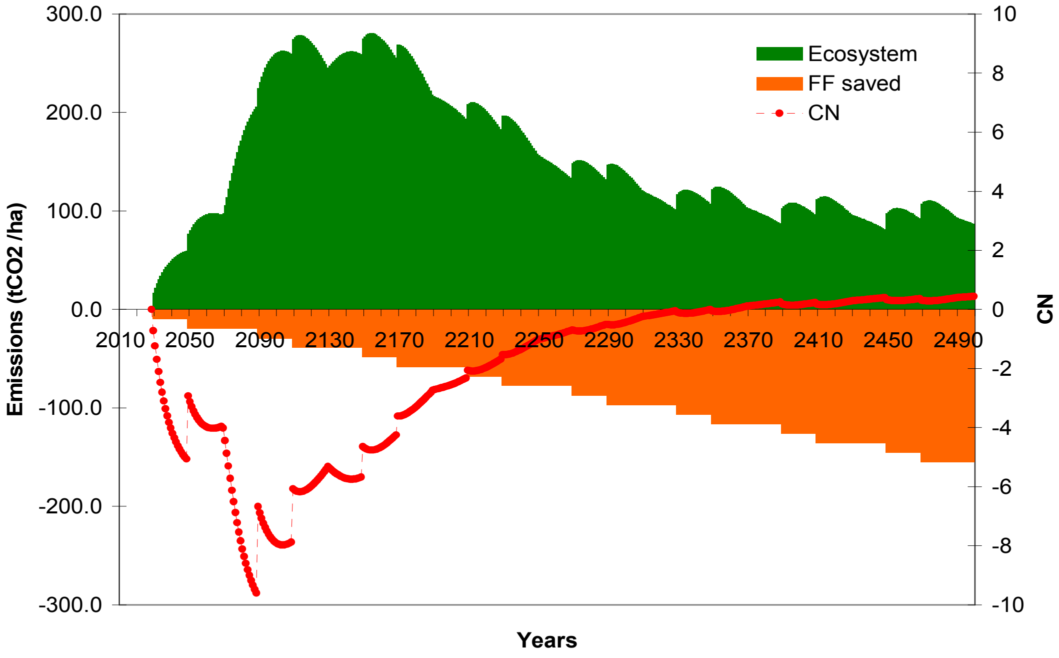


Figure 8 Additional CO_2 emissions, when additional harvesting is introduced in 1 ha of forest in Austria (Ecosystem). Cumulative emissions are shown and compared to the saved emissions in the substituted fossil fuel (FF saved). The *CN* factor shows when the emissions due to change of management are higher (*CN*<0) or lower (*CN*>0) than the baseline. (A) substitution of coal; (B) substitution of natural gas.

This example has illustrated the change of management on 1 ha of forest. When a rotation forest system is considered, each year a new patch of forest is cut to provide a constant supply of wood for bioenergy. The *CN* factor of this kind of system shows a similar development over time as the 1 hectare-system, but the *CN* is negative for a longer period. For bioenergy substituting coal, the *CN* will become positive about 25 years later (Figure 9).

This study does not take into account that the total forest carbon stock could stay unaffected when fellings are increased, because of a change of forest growth rate. To a certain extent, the forest can positively react to fellings when they reduce competition between trees and produce an increase of the net-annual increment per single tree. Additional fellings could also affect wood that, under a less intensive management, would be lost by disturbances as pests and storms and higher natural mortality rates (Nabuurs et al. 2008). It is also claimed that additional fellings can reduce forest fires. However, in European forests, where most of the fires are human-induced, it is difficult to assess to which extent this could happen.

In addition, the adoption of different management strategies in European forests could combine increased fellings for bioenergy in certain areas with afforestation and nature-oriented management in others. The result could be a shorter time period to recover the initial debt due to increased wood removals (e.g. 50 years) (Nabuurs et al. 2006).

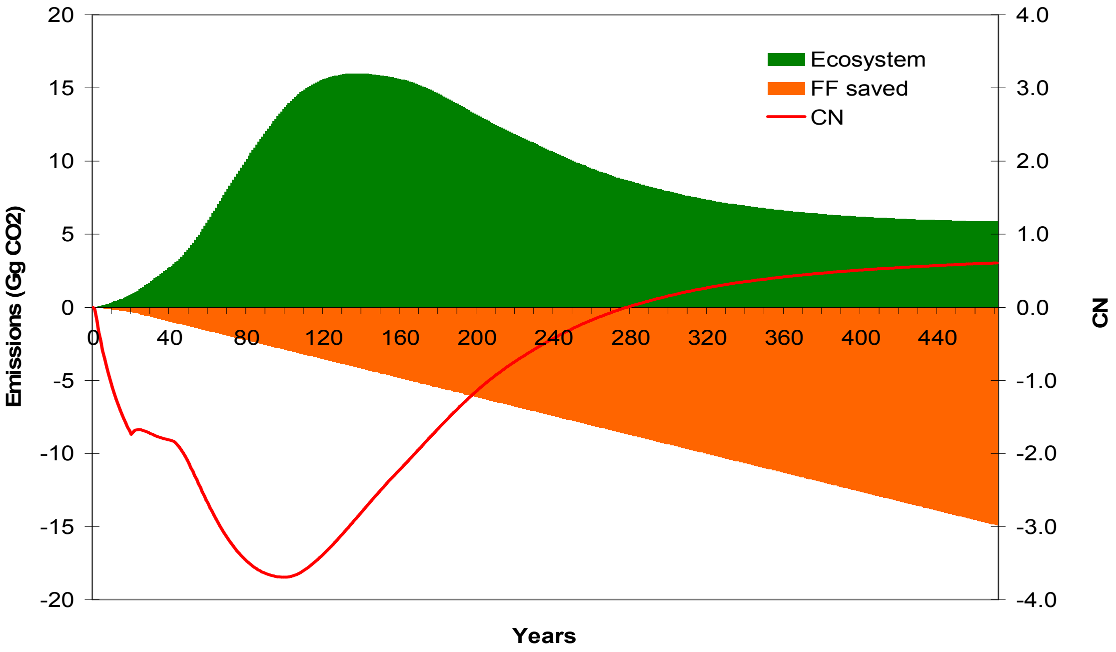


Figure 9 Additional CO_2 emissions, when additional harvesting is introduced in a rotation forest in Austria of 60 hectares (Ecosystem). In a 60 year rotation period, 1 ha of forest is cut each year to provide a constant wood supply. In comparison to Figure 8, the curve is smoothed and the *CN* line is continuous because of the constant annual wood extraction and the constant annual supply of bioenergy. Cumulative emissions are shown and compared to the saved emissions in the substituted fossil fuel (FF saved). The *CN* factor shows when the emissions due to change of management are higher (*CN*<0) or lower (*CN*>0) than the baseline. It is assumed that biomass substitutes coal.

4.1.3 Bioenergy from new plantations

The GHG balance of biomass from new plantations should include the C stock change due to the conversion from the previous land use (direct and indirect). The biomass source can be carbon neutral when the C stock change is zero or positive (e.g. conversion from abandoned croplands). If there is an initial carbon loss (e.g. conversion from a forest area), the biomass will produce an atmospheric benefit only after that the C stock change is fully compensated by the amount of avoided emissions in replaced fossil fuels.

New tree plantations established for the purpose of bioenergy production and climate change mitigation can be a third source of biomass (short rotation plantations or long-rotation forests). In this case, the trees would not have been there without the new policies and they are grown for the purpose of being used for energy at the end of the rotation period. Since the wood harvested is grown where there would not have been wood in a baseline scenario, there is no loss of biomass in comparison to the baseline when it is harvested and combusted.

On the other hand, C stock changes due to the conversion from the previous land use still occur and they can be positive (C sequestration) or negative (C loss). The C stock change assessment must include the difference between the carbon stock in the above and below ground biomass and soil before and after conversion. The effect of indirect land use changes should also be taken into account.

The C stock changes can vary a lot depending on the previous land use:

a) When cropland is converted to a tree plantation the “direct” carbon losses are limited to soil carbon losses due to site preparation. The temporary decrease of soil carbon stock, if any, is soon recovered and followed by a net increase of soil carbon due to higher litter inputs from trees than from crops (Guo and Gifford 2002). Therefore, the initial soil losses can be neglected. The belowground biomass stock increases, too. In this case, the biomass used for bioenergy will be carbon neutral or positive from the beginning ($CN \geq 1$). However, this positive “on-site” balance can be offset by carbon losses due to indirect land use change. For instance the crops previously grown on the land and used for food will be grown on other lands, possibly causing deforestation in other areas (see point c).

b) In permanent grasslands, the soil and the belowground biomass carbon stocks can be much higher than in croplands. Therefore, a few years are needed to recover the initial carbon loss (5-10 years). Depending on the initial carbon loss and the productivity of the new tree plantation, the carbon balance could be positive even during the first rotation period (e.g. conversion of degraded grassland) or it could be initially negative and then turn positive. In most of the cases, the biomass extracted to produce bioenergy will have an atmospheric benefit since the beginning ($CN \geq 0$)[10] and will become carbon neutral in a few decades ($CN \geq 1$).

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[10] An atmospheric benefit occurs as soon as the *CN* is greater than zero. When the biomass reaches, for example, a *CN* of 0.8, replaced fossil fuel emissions will be reduced by 80 percent. Full carbon neutrality – i.e., the condition where no emissions can be attributed to combustion of biomass, is not achieved until the *CN* reaches 1.

Different results could be linked to the conversion of grasslands with high carbon stocks.

c) If a forest area is clear cut to be replaced by a tree plantation used for bioenergy, an initial carbon loss equal to the forest biomass should be accounted for. The bioenergy produced from the clear cut forest and the new plantation has a GHG benefit only after that the carbon stock change is fully compensated by the same amount of avoided emissions in replaced fossil fuels. The changes in the litter and soil pools should also be added to the overall balance. In Schlamadinger and Marland (1996), the carbon loss from the conversion of 1 hectare of mature forest to short-rotation forestry (SRF) is compensated after 40 years, when natural gas is substituted. The example considers an initial forest C stock of 160 tC ha^{-1} and a new rotation period of 7 years in the SRF. Fossil fuels substituted by bioenergy and fossil fuels saved by substituting energy intensive materials with wood products are included to assess the compensation period. If only the fossil fuels substituted by bioenergy are accounted, the losses are compensated after 45 years, i.e. $CN \geq 0$ after 45 years. The paper adopts a simplified approach to calculate the carbon losses in soil (including roots) and litter. A constant decrease of soil and litter C pools for a certain time period is assumed.

   A similar case study has been developed here, using the GORCAM model, to include simple equations to simulate decomposition in litter and soil and the change of root biomass. As in Schlamadinger and Marland, the initial aboveground C stock of 160 tC ha^{-1} is harvested and used for long-lived and short-lived wood products (30% and 25% respectively) and for bioenergy (22%). The wood extracted every 7 years from the new short rotation forest is all used for bioenergy (80% of aboveground biomass). The improved simulation of the carbon stock changes in the soil, litter and roots, significantly changes the results presented in Schlamadinger and Marland (Figure 10). The bioenergy extracted from 1 ha of short rotation forest compensates the carbon losses due to the land use change after 70 years when natural gas is substituted (Figure 10A). Therefore, after 70 years, the bioenergy starts to produce an atmospheric benefit ($CN \geq 0$). When a rotation forest system is considered (each year a patch of forest is cut to provide a constant supply of bioenergy), the *CN* factor is negative for almost 80 years (Figure 10B).

   The results are strongly influenced by the assumptions made. When the conversion affects a forest with higher carbon stock, the period needed to compensate the land use change emissions is longer. For instance, if a mature forest of 275 tC ha^{-1} is cut and replaced by a SRF, the period of compensation is 170 years. Similarly, if the new plantation has a longer rotation period of 60 years, 150-200 years are needed to offset the initial C loss, depending if the wood from the plantation is all used for bioenergy (150 years) or if part of it is used for wood products (200 years).

In the Renewable Energy Directive, the sustainability criteria state that raw materials used for biofuels cannot be obtained from areas that were converted from land with high carbon stocks (forests, wetlands) or with high biodiversity values (highly biodiverse grasslands, primary forests). In addition, the land use change emissions are accounted for, when assessing the GHG emission performance of biofuels compared to fossil fuel.

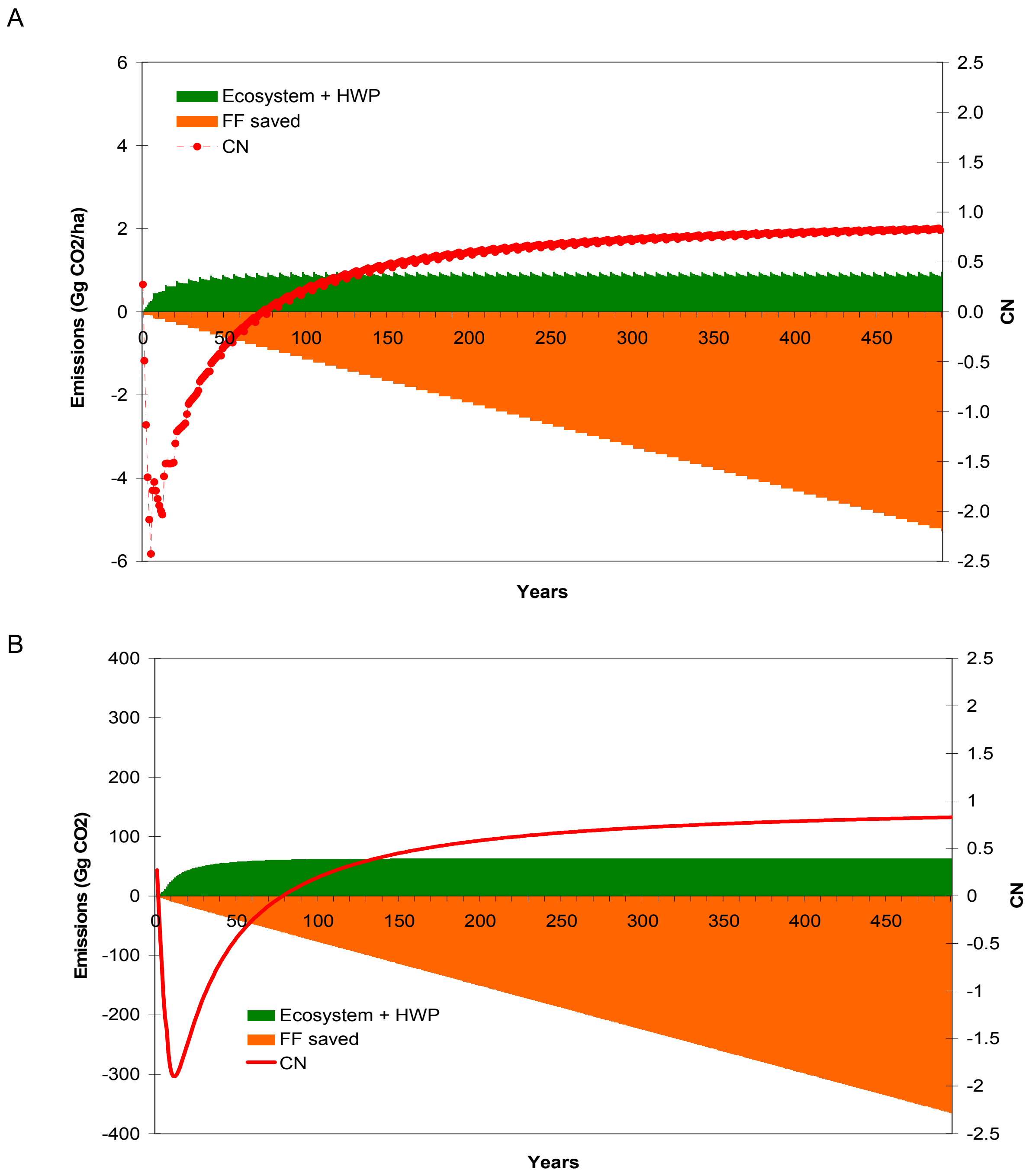

Figure 10 Cumulative CO_2 emissions when a mature forest is converted to a short-rotation forest on a 7 year rotation period (Ecosystem + HWP). The plantation follows harvest of a mature forest of 160 MgC ha·'. The wood from the initial harvest of the mature forest is used for wood products (HWP, 55%) and bioenergy (22%). Cumulative emissions are shown and compared to the saved emissions in the substituted fossil fuel (FF saved). The substituted fossil fuel is natural gas. The *CN* factor shows when the emissions due to land use change are compensated by the saved fossil fuel emissions (*CN*≥0). When *CN*>0, the bioenergy produces a net GHG benefit in the atmosphere. In diagram A, only 1 ha of forest is converted. Diagram B describes the conversion of 70 ha of forest to short-rotation plantation, when 10 ha are harvested each year.

In principle, if similar criteria would be applied to woody biomass, the land-use change emissions described above could be taken into account. Therefore, biomass that comes from areas converted from forests (or other lands) with high C stock would be discouraged or forbidden. However, in practice, not all the conversions can be classified as land-use changes because of the definitions adopted under the climate policy agreements. For instance, a SRF or a palm plantation usually complies with the definition of forest under the KP. Therefore, no land-use change may have to be reported when it replaces a forest with higher carbon stock if similar definitions would be applied under the Directive. This kind of problem could be solved by including management changes in the equation.

4.1.4 Summary of the mitigation effect of different sources of wood bioenergy

The previous sections explained that different sources of biomass for bioenergy can have very different climate change mitigation potentials according to the time horizon that is considered. Table 5 summarizes the *CN* factors of the previously illustrated examples for different time horizons. There is forest biomass that can produce a GHG benefit in the atmosphere from the beginning of its use but it is not carbon neutral (forest residues or wood from new plantations on lands with low carbon stocks previous to conversion). Other sources of woody biomass will require a long time before producing a GHG benefit in the atmosphere (additional fellings or new plantations in areas converted from high C stock ecosystems). Some other sources can be carbon neutral from their initiation (new plantations in areas converted from abandoned cropland that do not produce indirect land-use change).

Table 5 *CN* factors calculated in this study for different source of wood biomass on different time horizons, when biomass substitutes coal. When biomass substitutes oil the *CN* must be reduced by 0.2 and by 0.4 when it substitutes natural gas. The reported figures assume that no indirect land-use change occurs.

Source of biomass	*CN*			
	20 years	50 years	300 years	Notes
Forest residues (constant annual extraction)	0.6	0.7	0.9	Always positive, but not C neutral
Additional thinnings	<0	<0	0.2	Atmospheric benefit after 200-300 years
New forests:				
- conversion from cropland	≥1	>1	>1	C neutral
- conversion from grassland[a]	>0 to ≤1	≥1	≥1	Positive in the short-term, becomes C neutral in 1-2 decades
- conversion from managed forest to SRC	<0	<0	0.7	Atmospheric benefit after 70 years
- conversion from mature forest to SRC	<0	<0	0.4	Atmospheric benefit after 170 years
- conversion from managed forest to a 60 year rotation plantation	<0	<0	0.3-0.7	Atmospheric benefit after 150-200 years

[a] The conversion of natural grasslands with high C stock in soil and biomass can produce more emissions and reduce the mitigation potential of the bioenergy produced after conversion.

The illustrated examples are based on various assumptions and the values of *CN* can change as assumptions change. For instance, the biomass from areas converted from a forest to a bioenergy plantation can have a worse carbon balance and therefore a lower *CN* if the initial carbon stock is higher than the assumed 160 tC ha^{-1}, as in natural or mature forests. The calculated *CN* factors are not representative for all the woody biomass feedstocks that are planned to be used to meet the renewable energy targets of the EU. A more in-depth analysis that would consider average assumptions representative for the different feedstocks should be implemented. However, this study shows that some of the feedstocks included in the RES deployment projections should not enjoy a zero emission status in the accounting systems. In the short-medium term, wood material as forest residues could have a mitigation potential that need to be discounted by 30-40%, when only carbon stock changes are considered (41% of the bioenergy potential assessed by EEA). Additional fellings from existing forests could even produce more emissions than fossil fuels (59% of the bioenergy potential assessed by EEA).

In addition, results would be improved by including the positive effect that increased fellings can have on forest growth rates and on reducing natural mortality rates. The extent to which carbon stock changes could be counteracted by combined management strategies as forest conservation or afforestation should also be assessed.

The reported figures do not take into account the emissions in the production chain and their effect on the overall mitigation potential of bioenergy. The inclusion of production chain emissions would produce a further decrease of the emissions reductions attributable to bioenergy.

The study also does not take into account the impact of the change in surface albedo on climate change. The albedo of a surface is the extent to which it reflects light from the sun. Depending on its colour and brightness, a change in land surface can have a positive (cooling) or negative (warming) effect on climate change. Planting coniferous trees as a climate mitigation measure has been questioned in areas with snow since the darkening of the surface (decrease in albedo) may contribute to warming. Sequestration due to forest growth and albedo changes may compensate each other, tending towards a slight warming effect over the very long term (250 years) (Schwaiger and Bird 2010). Therefore the albedo effect might contribute to worsen the bioenergy climate change mitigation potential when the wood feedstock would come from new planted forests.

5 Policy Options to Address Current Accounting Gaps

A number of approaches currently under discussion in UNFCCC fora, the EU, and among concerned stakeholders and experts could address the spatial or temporal gaps identified in the previous chapters.

The previous sections have suggested that there are two major gaps in current accounting of GHG emissions due to the use of bioenergy. The first, discussed in Section 2, is a gap in spatial coverage. This gap resulted from adoption of an Inventory methodology designed for a system in which all nations report into systems in which only a small number of countries have emission obligations, i.e., the KP and the EU-ETS. The second is a failure to differentiate between a system in which very long time horizons are relevant – efforts to mitigate climate change over the long term – and systems concerned with shorter-term horizons such as the EU 2020 and 2050 targets. Since the KP adopted the UNFCCC Inventory Guidelines without considering these differences, current accounting systems' difficulties in addressing the time-dependency of biomass' carbon neutrality can also be traced to this decision.

Approaches currently under discussion that could address the spatial or temporal gaps, at least to a limited extent, include the following:

1. **More inclusive accounting of emissions from the land-use sector**
2. **Value Chain Approaches, including use of sustainability criteria**
3. **Point-of-use accounting**

The following sections briefly describe and evaluate each of these. While all of them are primarily intended to address problems that have emerged due to the difference in spatial boundaries, point-of-use accounting can address the time delay between use of biomass for energy and regrowth. Both value-chain and point-of-use accounting hold end-users responsible for emissions. Since the time horizon over which emissions due to land-use and management changes should be calculated is open to debate, *CN* factors offer an attractive avenue to address the time-variance of carbon neutrality with respect to targets. Adoption of *CN* factors in both the EU-ETS and the renewable energy Directive would result in market demand matching the true GHG profile of biomass used.

In the following review of options to address accounting gaps global accounting of land-use emissions is not included as it is not considered to be a realistic option within time frames of interest to current EU policy. Further, the discussion of sustainability criteria is confined to sustainability from the perspective of GHG emissions. Criteria and issues relevant to, e.g., sustainability of water supply or biodiversity are not considered.

5.1 Account for a wider range of land-sector emissions

Inclusion of a larger portion of the earth's land base in accounting system can reduce the areal gap identified in Section 2. However, short of full global inclusion, these approaches can only make limited contributions.

Two major avenues for fuller accounting of land-sector emissions have been under consideration in UNFCCC fora.

1. Increase the types of activities whose emissions must be accounted

2. Adopt a mechanism to support REDD+

These two mechanisms are appropriate for Annex-I (or countries adopting GHG obligations that include the land sector) and non Annex-I countries, respectively.

A third option is also reviewed:

3. Replace the current activity-based approach with unified carbon accounting (referred to in some papers as land-based accounting).

This approach is included due to the significant simplifications it would bring to accounting for land-sector emissions, the current openness of the climate agreement process, and its compatibility with atmospheric accounting approaches.

5.1.1 Widen mandatory accounting of land-sector activities

Widening the land-sector emissions that must be reported by Annex-I countries would be a useful step but would have only a limited impact.

Under the current KP, Annex-I countries are only obligated to include net emissions due to afforestation, reforestation and deforestation (ARD). They may also opt-in, on a voluntary basis, to include activities named in Article 3.4, e.g., emission reductions due to management of forests, croplands and grasslands. Widening the number of activities whose emissions must be counted would be a straightforward extension of the current regime. A first step might be to render Article 3.4 mandatory as has been proposed in meetings taking place within the UNFCCC process (UNFCCC 2008a). Stakeholders have also called for inclusion of wetland management.

From the perspective of biomass-for-energy, mandatory accounting of emissions due to forest, wetlands, and peatlands management would be the important additions and would close the primary gaps in areal coverage of land-sector emissions within the EU. However, the approach involves a continual series of agreements on which activities should become mandatory. For instance, currently inclusion of emissions from wetlands faces resistance, partly due to the comparative uncertainty in measurements. Consequently while agreement on mandatory inclusion of forest management might be reached in upcoming negotiations, each new activity requires new negotiations.

If bioenergy continues to enjoy the ‘zero emissions’ accounting procedure under the KP and EU-ETS, extension of the activities whose emissions must be reported would have the advantage that carbon-stock draw-downs attendant on dedication of biomass to energy would be reported. This would result in an accounting system more consistent with the emissions actually entering the atmosphere. However, this step would only address the gap in the EU – or in other Annex-I nations participating in an extension of the KP. It would not address the much larger areal gap that is the primary concern of Searchinger et al. (2009) and other stakeholders in the biofuels community. This larger gap results from the lack of GHG emission obligations in non-Annex-I countries where the vast majority of land-sector emissions originate[11]. A step towards addressing this gap may be taken with the adoption of REDD+.

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[11] As of 2008 approximately 1.2 billion tonnes (1.2 Pg) of carbon, or 12 percent of total CO_2 emissions were due to land use change. Brail and Indonesia alone accounted for 0.9 million tonnes of these emissions (http://www.globalcarbonproject.org/carbonbudget).

5.1.2 REDD+ (Reduced Emissions from Deforestation, Degradation, and other activities)

Although REDD+ has garnered significant support and engendered considerable enthusiasm, its contribution to closing the accounting gap is likely to be limited to the reduction in biomass-for-energy demand it causes through price increases.

REDD+ is considered to be one of the few 'winners' from the recent COP-15 in Copenhagen (www.globalcanopy.org). Under the Copenhagen Agreement, Annex-I countries committed themselves to provide additional, predictable and adequate funding to developing countries, specifically mentioning REDD+ as an action to receive support (UNFCCC 2009). COP 11 in Montreal initiated a process to consider whether emissions from deforestation (RED) could be addressed within the KP. Initially focused on deforestation, in fall of 2008 a meeting of experts concluded that it would also be possible to include avoided degradation in a mechanism (UNFCCC 2008b), thus leading to the acronym REDD. As demonstrated by the text of the Copenhagen Accord (UNFCCC 2009) further stakeholder pressure, including by the United States, has led to expanding the mechanism to include forest conservation, the third activity generally understood to be designated by REDD+.

While REDD+ will encourage emission reduction efforts and lead to more robust estimates of land-sector emissions in non-Annex-I countries, its potential to reduce the accounting gap identified in section 2.1 is limited. Limitations stem from (1) the design of the mechanism itself, (2) from the unlikelihood that all developing countries will adopt or reach REDD+ targets, and (3) due to emission sources not included in the mechanism. From the point of view of bioenergy, it is also important to recognize that REDD+ will (4) directly compete with meeting bioenergy targets. REDD+ will raise both land costs and the cost of removing biomass from forests.

Looking at the first issue, the accounting gap could only be reduced to the extent that REDD+ play a role in accounting systems of nations having GHG emission obligations. That is, the carbon stock changes will have to enter into a system in which emissions are tallied. The most likely avenue for this is through issuance of credits for REDD+ achievements, credits that are then used by nations with GHG emission obligations to assist these. Such credits, even if issued and used, will only offer a 'soft' attempt to close the gap. Credits will almost certainly be based on reductions relative to a national baseline. Thus, REDD+ will, at best, only provide information about the difference between carbon stock changes at a national level under REDD+ and changes under a presumed business-as-usual case or historic emissions. There is no obvious way in which this information could be used to balance, or assess the degree of balance between, bioenergy emissions in Annex-I nations and carbon stock changes in developing countries.

Turning to issue (2), it is unlikely that REDD+ will be adopted across the globe. Consequently, international leakage will be a problem. Adoption of REDD+ in some nations can, and very likely would, be accompanied by increased deforestation and degradation, and decreased forest conservation in other nations. To the extent that this occurs, REDD+ would only address the gap in areal coverage to the extent that it lowers demand by raising prices. Since, however, both the United States and Europe drive bioenergy energy demand through mandates, it is more likely that land conversion will simply move around the globe and the cost of meeting biofuel or bioenergy mandates will increase. These mandates, in turn, will raise costs of REDD+ by increasing the opportunity costs of all lands with potential to produce biomass for energy.

Restricting imports of biomass-for-energy to nations that have adopted and achieved REDD+ goals is unlikely to reduce the leakage problem. Even if all major importing nations including, e.g., China, took part in such a ban – unlikely in itself – a ban would only lead to biomass-for-energy coming from 'REDD+' countries but increasing amounts of food, feed, and fiber would come from (with attendant land use changes) from non-REDD+ nations where land prices remain lower. The legality of such a ban under WTO regulations would, in any case, need to be established.

REDD+ will, as mentioned in (4), inevitably increase land prices (as well as costs of biomass extracted from forests). This is a direct result of money flowing into forest conservation, making conversion of forest land more expensive. Since land for food and feed often comes from conversion of forestlands, REDD+ will compete directly with meeting these, increasing, demands as well as with meeting bioenergy demand. The more successful REDD+ is, the more it will raise costs of these products. Similarly, the more countries adopt bioenergy goals or mandates, and the higher these are, the more expensive REDD+ itself will become.

If sufficient money flows into REDD+, the consequent food cost increases due to restrictions in conversion of forest land to agricultural land could render the cost increases attributed to U.S. ethanol mandates trivial in comparison. However, and particularly as land and food costs rise, nations are likely either to refuse to adopt REDD+ or will simply fail to achieve the targets unless these are set sufficiently low to accommodate rising food, feed, fiber and bioenergy demand. If set at such low levels, the targets will be meaningless. Thus, at best, REDD+ will dampen demand or supply of biomass-for-energy from developing countries. However, this dampening will most likely be due to rising prices.

Turning finally to (3), as currently understood, REDD+ falls well short of bringing the full range of land sector emissions into climate agreements. Key activities that are not covered include activities that cause emissions (or emission reductions) in wetlands, peatlands, and agricultural lands. Emissions from peatlands in non-Annex-I countries are a particular source of concern. Emissions from peatlands drained to grow palm trees or other crops are particularly high. A study by peatland expert Hans Joosten, for example, concluded that 580 million tonnes CO_2 were emitted from drained peatlands in Southeast Asia (Joosten 2009)[12]. Emissions from peatland drainage occur for decades to centuries once inaugurated. Consequently, this is another instance where taking account of emissions due carbon losses from lands remaining in a current use would be critical.

5.1.3 Unified Carbon Stock Accounting (UCSA)

Under unified carbon stock accounting, land-sector emissions would be estimated across all managed lands without restriction to specified activities. While having considerable advantages over the current approach, if only applied in Annex-I countries it will suffer the same major limitation as widening mandatory activities.

Currently, as mentioned in subsection 5.1.1, emissions from the land-use sector are calculated only insofar as they are linked to specific activities which cause them. This

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[12] Total CO_2 emissions in 2008 were 31.9 billion tonnes.

activity-based approach was, to a large extent, the result of the late acceptance of land use in the KP. The decision to allow reductions in emissions from land use to contribute to targets was made after targets had been set based only on emissions from other sectors. Due to the widely differing contributions that nations could expect from their land bases, it was agreed that only emissions and removals due to specified human activities were to be included. As a result, unlike all other emissions sources, the land sector is not listed as a Sector/Source in Annex A of the KP.

An alternative to the current activity-based accounting system would be to estimate, and include in accounting, all stock changes on managed lands without regard to the activity resulting in the emissions. Under this approach, carbon stock changes would be treated in the same manner regardless of whether they result from a land use or a management change. In effect, Articles 3.3 and 3.4 of the KP would be removed and the land sector would become a sector source as is the case for all other emission sources (UNFCCC 2008b). This approach is referred to hereafter as unified carbon stock accounting.

There is currently wide resistance to unified carbon stock accounting. However, it has a number of important advantages that, in the long run, might outweigh current resistance. From a bioenergy perspective, the most important advantage is that it would automatically, with one agreement, close the areal gaps in Annex-I countries. Other advantages include its relative simplicity and its high compatibility with atmospheric accounting (see section 5.3). Resistance seems to be grounded in the understandable reluctance to change from the current system as well as in the difficulties in, or rather range of uncertainties among, making estimates of emissions from the full use of land management and change options. That is, there is, for example, considerably greater ability to measure emissions due to deforestation than to do so for emissions due to draining wetlands or re-wetting them or to some agricultural land management changes.

UCSA simplifies accounting of land-sector emissions in a variety of ways. First it removes the need to define what constitutes specified human-induced activities such as deforestation or reforestation. Similarly it removes the need to define land categories such as forest land or wetland. All of these definitions have proved difficult and have led to the anomaly that what qualifies as deforestation in one nation does not qualify in another. Since IPCC Inventory guidelines are designed to provide for complete accounting of carbon stock changes across managed lands, the approach could be applied both in Annex-I and in developing countries. Further, a UCSA approach would provide an incentive to improve estimates of emissions from a range of sources in both Annex-I and developing countries.

UCSA would resolve the accounting gap attendant on the activity-based approach in Annex-I countries insofar as biomass originates in Annex-I countries. Emissions due to extraction of biomass can come from a very large array of activities, including activities that occur on lands remaining in the same use, and activities whose emissions are not currently included in Annex-I country accounting even within Article 3.4, e.g., peatland management. Under UCSA, emissions from all managed lands would enter the accounting system, and any land from which biomass were removed for bioenergy would automatically qualify as managed land. Thus, as long as the biomass originated in Annex-I countries, the reductions in carbon stocks would appear in accounts in the same time frame (actually before) the emissions due to their combustion. In fact, one way to tackle the gap caused by the current assignment of zero emissions to combustion of biomass is to combine UCSA in Annex-I countries with *CN* factors for biomass originating in nations not having GHG emission obligations (see section 5.3.3).

5.2 Value-chain accounting

Under value-chain approaches impacts along the entire series of steps - resource extraction or cultivation, transportation, and conversion to a final product – are taken into consideration. In the context of climate mitigation, only GHG emissions along this value chain are relevant. The EU RES Directive's requirements for biofuel are an example of a value-chain approach.

The increasing use of biofuels by Annex-I countries has, in particular, raised questions regarding of responsibility for impacts along biofuel value chains. Impacts due to land-use and management changes, including impacts on food prices, tropical forests, and GHG emissions have been of particular concern. Increased food prices in a range of developing countries in 2007 caused food riots which were attributed in part to dedication of U.S. corn to ethanol (www.environmentalgraffiti.com/business). Commodity price increases, or the reduced availability of U.S. soy due to switching from soy to corn production, were also believed to have triggered increases in land used to produce soybeans in Brazil. Production of oils for biodiesel to meet EU demand has also led to concerns. Oils often originate from drained peatlands in Southeast Asia. In this case concern stems from the very high emissions. Peatland contain up to 1,450 tonnes of soil carbon per hectare (Biello 2009),[13] carbon that is oxidized when the soils are drained. Questions about the advantage, from a GHG perspective, of ethanol from biomass other than sugar cane, have resulted in pressure to include consideration of GHG emissions that occur during conversion of biomass to fuel.

Stakeholder discussions have, as a result of these concerns, sought for ways to hold Annex-I country users of biofuels responsible for a range of impacts. As evidenced by the EU Renewable Energy Directive (D on RES) prohibitions on sourcing biomass from areas with high biodiversity, in addition to GHG emissions, stakeholders have, non-GHG concerns regarding impacts at the first step of the biofuel production chain – production or extraction of the biomass. However, as far as climate is concerned, only GHG impacts are relevant, i.e. the GHG emissions resulting from production, transport, and conversion of biomass. Holding users responsible for such 'value-chain' emissions can be referred to as end-user responsibility for embodied emissions.

End-user responsibility for embodied emissions represents a significantly different approach than the one taken in the UNFCCC Guidelines and KP. As mentioned in Section 2, under these reporting and accounting systems a nation is only responsible for emissions occurring within its borders, not for emissions embodied in imports. However, as shown by Figure 1, this approach fails to hold Annex-I nations responsible for their balance-of-trade in GHG emissions. Thus, an end-user approach potentially has application far beyond biofuels.

A system in which end-uses were responsible for emissions embodied in products might have considerable advantages. The production pathways – i.e. resource extraction or cultivation, processing, and transportation paths – with the lowest overall emissions would have an advantage in the global market and would presumably gain market share. Importing countries with GHG obligations would have a 'built-in' incentive to purchase goods with low GHG-profiles. The power of purchasers to alter production practices has been demonstrated in the forest sector. Sustainable forestry initiatives operate primarily

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[13] Some old growth forests on wetlands in the tropics and U.S. and Canadian Pacific Northwest have, for purposes of comparison some 500 to 700 tonnes per hectare.

through convincing purchasers to only buy wood certified as coming from sustainably managed forests, and some 90 percent of industrial forest land in the United States is now certified under the Sustainable Forestry Initiative (Richards et al. 2006). Placing responsibility for efficient or low-GHG production processes on the purchasers might prove an effective approach.

In spite of attractive features, there has been insufficient discussion of consumer-responsibility approaches in climate change discussions to enable a more in-depth evaluation of their pros and cons. The only products for which consumer-responsibility is currently required are bioenergy products. As yet these discussions are not occurring in the context of international climate agreements but only in the context of instruments such as the D on RES and a possible U.S. cap.

5.2.1 The EU Renewable Energy Directive (D on RES)

The Renewable Energy Directive's (D on RES) specifications regarding biofuels represent a value-chain approach. EU distributors of transportation fuels serve as the point for determining compliance with Directive specifications which prohibit use of lots that do not meet the specifications.

The Directive sets criteria with which biofuels must comply to satisfy national RES obligations. The criteria consist of a mix of prohibitions on origin of the biomass and GHG-emissions ratings which biofuels must satisfy to be eligible for use. The GHG-emission ratings include emissions throughout the value chain and entities importing and distributing biofuels are responsible for ensuring that the biofuels comply with the specifications. This is thus a system that places responsibility for emissions on the country using the product, not on the country where the emissions occur. The use of prohibitions within the D on RES – including the prohibitions on biomass origin and the specification of minimum GHG emissions – distinguishes it from value-chain approaches that simply hold end-users responsible for the emissions. Approaches that, by rendering end-users responsible, increase the price of products with high-embodied GHG emissions, but do not impose restriction on them may be more acceptable under WTO regulations. See sections 5.3.2 and 5.3.3 for further discussion of such approaches.

To be eligible for compliance with the D on RES, a biofuel consignment's GHG profile must be calculated. Emissions due to cultivation of biomass, direct land-use change, conversion to a fuel, and transportation must be included. No attempt is made to include emissions due to indirect land use change at this time. Only biofuels whose GHG emission profile is at least 35% (current) to 50-60% (2017-2018) lower than the fossil fuels they replace can be used. Emissions from direct land use change must be annualized over 20 years. This is a sufficiently short time frame so that biomass grown on land converted from forests, wetlands or recently drained peatlands would generally fail to meet the criteria as long as actual emissions are used.[14] However, this method of calculating GHG emissions does not address the problem of emissions from extraction of biomass where lands remain in the same land use. In particular, the formula does not address emissions due to increased extraction of wood from forests already used for wood supply. As shown in Section 4, the 'value' of such biomass from the perspective of its contribution to reductions in GHG emissions within the time frame relevant to the

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[14] Thus from a GHG perspective, the prohibitions on biofuels whose biomass originates from such lands, are most likely redundant with the time stipulations in the GHG emission calculation.

RES, e.g., the 2020 targets can vary greatly. Use of wood for energy from forests already in use is more likely to occur in the case of use of biomass for heat and power than for biomass for biofuels, at least in the near- to medium-term. Consequently, the formula would need to be expanded to cover emissions from lands remaining in the same use if it were to be applied more generally.

While GHG emission reductions are only one goal of the D on RES, this paper has shown that there are significant differences, from a GHG perspective, between use of forest residues, short-rotation plantations and increased harvests from forests typical of Europe. Some sources of wood, particularly increased harvests in European forests – or forests with similar growth rates – might make no significant contribution to reducing GHG emissions within the time frame of the RES targets. Thus, to the extent that GHG emissions are a concern for the EU, calculations of the GHG profiles of biomass-used-for-energy should reflect these differences. Particularly if guidelines are prepared covering use of biomass for energy more generally, i.e., for bioenergy pathways other than biofuels, inclusion of emissions from land remaining in the same use would be an important addition to the current approach. In effect, there is no justification, from a GHG perspective, of distinguishing between carbon losses, or emissions, that occur due to land use or land management changes.

5.2.2 Sustainability Criteria

One of the goals of the D on RES criteria for biofuels is to ensure the sustainability of biomass production. While theoretically attractive, application of sustainability criteria can run into hurdles due to information requirements and difficulty agreeing on specifics.

The RES applies specifications intended to insure sustainability to specific ‘lots’ to fuel. It is thus a ‘project-level’ approach. However, it is also possible to apply sustainability criteria at the national level. Both of these options are reviewed below.

GHG sustainability in the case of biomass is, essentially, a question of maintenance of carbon stocks. Except for biomass converted to extremely recalcitrant forms (e.g., fossil fuels or recalcitrant soil carbon), biomass oxidizes sooner or later, regardless of whether humans intervene or not. Thus, maintenance of carbon stocks entails sufficient biomass growth, over some time period and spatial area, to ‘make up for’ biomass oxidized. Requirements for biofuels to meet sustainability criteria consequently represent imposing responsibility for regrowth of biomass, e.g. for what occurs at the first step in a biofuel’s value chain – its cultivation.

It is important to note that the GHG sustainability of biomass is not the same as its *CN*. *CN* is determined in relation to a business-as-usual carbon stock scenario and represents the extent to which fossil fuel emissions are ‘neutralized’[15] through use of biomass. Particularly in the case of woody materials, biomass can be used in various energy pathways, substituting for fossil fuels with different emission profiles. In these cases, not only the time required for regrowth – including replacement of soil carbon losses – but also the fuel for which the biomass is substituted plays a role in its effectiveness in reducing GHG emissions. Moreover, as explained in Section 4, *CN* depends largely on time horizons. Woody biomass shipments that meet GHG

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[15] Neutralized is here used to express the concept that fossil fuel emissions are balanced by removals of CO_2 from the atmosphere, e.g., by increases in carbon stocks.

sustainability and *CN* criteria for a 2050 target might not meet similar criteria for a 2020 target. Thus, even if criteria can be employed that ensure sustainability, they will fail to ensure carbon neutrality.

Determining whether or not carbon stocks have been maintained depends, as mentioned, on the spatial and time boundaries selected. Globally, as has been the case at least since 1860 (Schlamadinger and Marland 2000), there is a net loss of terrestrial carbon stocks. While this loss is among the drivers for stakeholder interest in adoption of sustainability criteria, sustainability criteria that are being proposed do not operate at the global level. The two primary ‘areal’ boundaries most often proposed are project-level or national-level. Each of these has pros and cons.

Project-level Criteria

Requiring sustainability at the project level is attractive from the perspective of an individual entity in the business of producing and selling biomass for energy. Such an entity can usually ensure that, within the areas over which it has control or from which it is extracting carbon stocks, regrowth, over some time period, equals extraction. There are two problems with this approach: the difficulty of establishing what will qualify as sustainable and the problem of leakage.

A very large range of plants that can be used for energy can grow under many soil, climate, and management regimes. This could render impractical establishment and verification of numerical values, such as time for regrowth – including replacement of soil carbon oxidized – which would reflect the GHG sustainability of individual biomass shipments. Possibly due to partly the difficulties of numerical approaches, ‘best practice’ guidelines have been suggested for determining sustainability. Such guidelines, while often including quantitative elements, e.g., rates of fertilizer application or slope angle above which erosion control measures are required, only provides ‘qualitative’ assessments of sustainability. A best practice approach is attractive on a number of grounds, including that it forms the basis of both EU and U.S. agricultural policy. However, selection of best practices requires considerable knowledge of local conditions. Knowledge would be needed not only in regard to practices governing production of wood and crops but also in regard to removal of residues, an area in which very little reliable data is yet available even in Annex-I countries. A best-practice approach also requires regular monitoring to ensure that the practices are being employed. However, within a system in which information is required for each lot of biomass, such monitoring is likely to take place in a more systematic way than under EU cross-compliance where less than 5 percent of farmers are checked annually (Farmer et al. 2007).

Although best-practice approaches are not yet part of the KP, REDD+ discussions have highlighted the need to address underlying causes of deforestation and degradation (UNFCCC 2006b). Addressing such causes is likely to require policy changes or national measures, i.e. Policy & Measures (P&M) approaches. While best practices can be required at the project level, they also would fit well within national-level approaches including P&M, sectoral approaches, and NAMAs. All of these are under discussion and evaluation for inclusion in international climate agreements.

National-level criteria

National-level approaches have the primary advantage of being able to address the problem of leakage within a nation[16]. Criteria that would insure sustainable growth in a given project area – i.e. criteria applied at the project level – do not guarantee that carbon stocks will not be drawn down elsewhere. This problem – particularly in the case of forests where conservation in one area tends to lead to harvesting elsewhere – was a factor in not accepting avoided deforestation as eligible for crediting under the Clean Development Mechanism (CDM). The CDM is a project-level approach and acceptance of a national-level approach was an important element in building support for a mechanism to address emissions from deforestation in the KP.

Leakage is equally relevant where woody biomass that would have been used for some other purpose is to be used for bioenergy. Under these circumstances, the current RES criteria will not prevent leakage. The criteria in place – those that prevent biomass-for-energy from originating in primary forests or from conversion of forests, wetlands, or peatlands – are likely to simply shift the purposes for which lands are converted. Forests that would have been converted to produce biomass for energy can, instead, be converted to agricultural land to provide food and feed. Imposing sustainability criteria at the project level can not address this problem. Thus, a national-level approach to sustainable criteria for biomass-for-energy may also be appropriate.

Measuring sustainability at the national level is attractive both from the perspective of addressing domestic leakage[17] and from the perspective of an importing country. An importing nation would only need to know the national situation in order to assign a *CN* factor to imports. This would be equivalent, for example, to use of national averages to determine the GHG emissions of imported electricity or to determine the improvement over current emission rates represented by a new power generation station. However, as suggested above, land-uses are interchangeable and biomass-for energy is only one source of reductions in carbon stocks. In fact, in many developing nations the vast majority of carbon stock draw-down is to obtain land to meet internal food security or food export goals. Such draw-down is occurring on a considerable scale.

In the past decade, globally the area harvested for crops increased by some 70 million hectares while forest and pastureland decreased by over 100 million hectares (http://faostat.fao.org; http://www.fpl.fs.fed.us/documnts/pdf2000/young00a.pdf). Over the past decade world population increased by some 770 million and caloric intake per person is rising at some 0.35 percent per year. Demand for timber products has also increased in step with increasing population (http://faostat.fao.org.). It is thus reasonable to conclude that land use changes, and the resultant carbon stock reductions in many developing countries, are primarily a result of these drivers, not biofuel demand. Under these conditions, it can be questioned whether use of a national factor representing the carbon stock balance of a country to determine whether biomass-for-energy qualifies as sustainable is appropriate. The contribution of bioenergy demand to carbon stock reductions may be minor compared to other demands affecting land use. If the biomass for bioenergy comes from short rotation plantations established on lands that would not be used for agriculture it would in fact be contributing to carbon-stock increases.

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[16] A mechanism that addresses leakage within a nation is currently considered adequate because under the KP Annex-I nations are only held accountable for emissions within their borders.

[17] Since currently GHG emission obligations are confined to those occurring within national boundaries, proposed requirements to account for leakage are also confined to national boundaries.

5.3 Point-of-use Accounting (PoU)

Under point-of-use accounting, emissions due to combustion of biomass would be assigned a non-zero multiplier (i.e., emission factor). Under conditions where not all nations cap emissions in all sectors, point-of-use accounting is likely to provide better incentives and dis-incentives than other systems.

Just as inclusion of land use as a Sector/Source, i.e., UCSA, would bring the land-use sector into accord with how all other sectors are treated, assigning emissions from combustion of biomass their full CO_2 value when determining target compliance would bring emissions from use of biomass-for-energy into line with other energy-sector emission sources. In the form usually proposed, combustion of biomass would result in emissions based on an emission factor close to that of lignite coal, e.g. 2.47 kg CO_2 toe^{-1} (Hong and Slatick 1994). The resulting emissions would be counted in a GHG target in the same manner as emissions from combustion of coal, petroleum products, natural gas, and waste materials. After reviewing this approach, two alternative ways to calculate emission factors at point-of-use are reviewed: calculating net value-chain emissions not covered by caps and use of *CN* factors. While not currently being discussed in climate negotiations, the attention to problems that have arisen due to the 'zero emission' approach raised by recent papers, e.g., Searching et al. 2009 and DeCicco 2009, is likely to reopen the question of whether the 'zero' emission factor assigned to biomass approach should be abandoned.

Under an approach that assigns emissions to combustion of biomass, removals of CO_2 from the atmosphere by plants can continue to be tallied in the land-use sector. However, carbon stock losses due to use of biomass for energy would no longer be counted in the land-use sector. Under simple point-of-use, all biomass emissions and removals are counted where they occur. Under point-of-use plus, removals of CO_2 that are reported to end-users get credited in the energy sector, reducing the emission obligation for energy users. If *CN* factors are used, the time-pattern of both losses and removals is reflected in the factor.

5.3.1 Point-of-use

Under circumstances where many nations do not adopt emission caps, point-of-use accounting provides a straight-forward way to avoid undue encouragement of the use of biomass for energy. It can also provide advantages to countries which export more biomass for energy or wood products than they use domestically.

The pros and cons of accounting for biomass emissions and removals where they occur (referred to in the literature as the atmospheric flow approach in the context of harvested wood products) versus accounting for changes in carbon stocks (carbon stock approach) were investigated by a group of experts in 1997 (Apps et al. 1997). As long as a global perspective is adopted (i.e., stock changes are accounted for globally) and a long enough time horizon is contemplated, both approaches yield accurate accounts of emissions due to biomass oxidation and growth. This group of experts recommended use of the carbon stock change approach both on grounds of simplicity and because it seemed to result in a more desirable incentive system. They also recognized that selection between these two approaches determines in whose account emissions and removals would appear. At least partly due to their recommendation, the stock change approach was adopted. It is important to bear in mind that the recommendations were based on global accounting i.e., the assumption shared by the IPCC Reporting Guidelines.

Both the Searchinger and DeCicco papers focus on the real-world situation which has emerged since 1997. Under global accounting, Apps et al. showed that the stock-change approach would discourage deforestation, which was seen as one of the advantages of the stock-change system. However, since accounting does not, and in the foreseeable future will not, take place globally, the incentive system functions contrary to expectations. Since deforestation is primarily occurring in nations where accounting is not required, the system is failing to discourage it. Since, in addition, under the carbon-stock system no emissions are assigned at the point of combustion, the carbon-stock system encourages nations with accounting obligations to import and use of biomass to replace fossil-fuels. In contrast, the point-of-use as also recognized by Apps et al., discourages bioenergy use. Under partial accounting this may be preferable to a system that not only fails to discourage deforestation but actually incentivizes it by encouraging bioenergy use.

Moving to a point-of-use system would have both benefits and drawbacks. First, approach would have benefits for non Annex-I countries which grow more biomass than they use domestically. If point-of-use were adopted in conjunction with crediting in the land-use sector, developing nations could receive credits for the total amount of the biomass grown less the portion they use domestically. Loss of carbon stocks, and attendant emission, due to biomass exported would be the responsibility of the nation in which the biomass was combusted or otherwise oxidized. Thus, the system would represent a partial move toward user responsibility for emissions attendant on use of bioenergy. It is not a complete system because emissions due to processing, conversion, and transport outside of Annex-I countries would not be covered.

There are some consequences of adoption of a point-of-use approach about which little is yet known. In particular more information is needed regarding the distribution of benefits and losses. Point-of-use accounting would have impacts on international trade in biomass, but modelling will be necessary to determine, for instance, whether there would be negative impacts on EU nations currently exporting significant amounts of wood. Considerations are that point-of-use accounting would encourage reuse of wood but also sale of wood to other countries both for bioenergy and as waste after its final use to avoid responsibility for emissions due to oxidation. Again, the GHG balance of these effects is unknown.

Apps et al. pointed out one problem with a point-of-use approach. No system accounts, or envisions accounting, for CO_2 respired by people or animals. Thus, in the case of biomass used for food and feed – including in the case of food and feed exported from non-Annex-I to Annex-I nations – credits would accrue even for annual sequestration resulting from plant growth but the emissions due to its oxidation in the digestive-respiratory cycle would not be counted. Thus, statistics on food and feed consumption would need to be used to correct for this imbalance.

One drawback of a point-of-use system is that it does not, by itself, distinguish between biomass whose conversion and transportation emissions are high or low. That is, it only accounts for carbon stock losses. Insofar as conversion, processing, and transportation occur in nations without caps, these emissions would continue to lie outside of the accounting system. Further, the emissions due to combustion of a tonne of wood will be the same regardless of whether the wood is residues, from short-rotation plantations, from deforestation, or from increased harvests in forests already used for wood. In effect, there is no direct link between the user of biomass and source of carbon stock or other value-chain emissions. Thus, individual users of bioenergy – e.g., power plants or fuel blenders or distributors – have no incentive to select biomass with low embodied emissions or short regrowth cycle. The alternatives in the following two sections address these problems.

5.3.2 Point-of-use-plus

DeCicco (2009) proposes a system in which assignment of emissions to biomass used for energy is combined with tracking the emissions occurring along its value chain that occur in non-capped sectors or nations. One of his primary objectives is to create a system in which the emission cap on fossil fuels serves as the incentive to lower the GHG emission profiles of biofuels.

DeCicco (2009) proposes a system that combines:

1. An obligation on fuel distributors to submit permits to emit (allowances) based on the carbon content and use of biofuels.
2. The opportunity to use a lower emission factor to calculate obligations if it can be justified by net removals (removals minus GHG emissions) along the entire value chain.

For example, a distributor of biodiesel would calculate his obligation on the basis of 77 $gCO_2\ MJ^{-1}$ distributed. Reductions in this factor are allowed to the extent justified by net removals of CO_2. Net removal calculations must take into account GHG emissions at all steps along the value chain in addition to the carbon sequestered by plant growth. Emissions due to cultivation, land use change[18], conversion or other processing and transportation must be calculated. However, only those GHG emissions not covered by caps enter into reducing the emission factor.

DeCicco's paper is focused on transportation fuels but the system he proposes would be applicable to any bioenergy pathway. He starts by pointing out that under cap-and-trade systems some fuel-related emissions fail to be counted because "markets cross the boundaries of capped and uncapped sectors both domestically and internationally." He mentions that missed emissions include not only many biofuel-related emissions but also fossil fuel production and refining emissions insofar as these occur in developing countries. His proposal is directed at encouraging accounting, under a cap, for the all uncapped emissions and emission reductions along the biofuel value chain. His system encourages rather than requires such accounting because he proposes that the submission of value-chain information be voluntary.

DeCicco's exclusive use of uncapped emission and sequestration emission sources to adjust the emission factor avoids double counting of both emissions and removals. Table 6 below illustrates how this works. In this example it is assumed that the agricultural sector is not part of a cap-and-trade system, so with respect to obligations under that cap, sequestration and emissions in agriculture play no role. However, fossil fuels, including both those used in transportation and electricity are capped, as well as most of the emission due to production of fertilizer. Thus, from the original credit (737 x 10^3

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[18] DeCicco does not provide information on how emissions due to land use change would be calculated. He does suggest a fund to purchase forestland to address indirect land use change. Since this is a form of REDD+, this is not further addressed here.

tonnes), after accounting for uncapped emissions, 637 x 10^3 credits remain at the first step in the value chain or 31.2 kg CO_2 per bushel.

Table 6: Example of credits for corn from some farm

Item	10^3 tonnes CO_2-eq.	
	all	uncapped
CO_2 absorbed	(737.0)	(737.0)
Conservation tillage	(12.7)	(12.7)
Fertilizer production	22.6	3.8
Diesel fuel	10.0	-
Propane	3.9	-
Electricity	4.0	-
N_2O emissions	97.6	97.6
Direct land-use	10.5	10.5
Totals	**(601.1)**	**(637.8)**
kg CO_2-eq. per bushel	(29.4)	(31.2)

Source: DeCicco, 2009.

Uncapped emissions from the conversion as well as from transportation, to the extent that this occurs in nations without caps, are further deducted. Table 7 shows the results for corn processed in a nation with caps on fossil fuels.

Table 7: GHG emission balance after refining

Item	10^3 tonnes CO_2-eq.	
	all	uncapped
Corn feedstock	(637.8)	(637.8)
Electricity	24.9	-
Natural gas	90.2	-
CO_2 from fermentation	240.5	240.5
Totals	**(282.2)**	**(397.3)**
kg CO_2e MJ^{-1} (LHV)	(63.0)	(88.8)

Source: DeCicco, 2009.

As shown, the net credits are converted into grams per MJ. In a final step, emissions due to use of biomass for ethanol at the rate of 71.5 gCO_2 MJ^{-1} are subtracted, leaving a credit of 17.3 gCO_2 MJ^{-1}. Credits equal to 17.3 gCO_2 MJ^{-1} in the ethanol he has purchased (i.e., 80.2 MJ $gallon^{-1}$) can then be used to reduce the fuel distributor's obligation for petroleum products he sells.

Since in DeCicco's system the submission of value-chain information is voluntary, only pathways where there would be a net credit would submit the information. However, a system could require submission of value-chain information.

DeCicco considers that this system has the following advantages:

- ✓ The cap itself functions to drive emission reductions along the entire chain.
  This occurs because distributors will offer higher prices for lower GHG-pathways as it reduces the number of allowances they need to submit.
- ✓ Biofuels suffer no market disadvantage compared to other fuels under the cap.

This is because biofuels 'non-reduced' emission factor is equivalent to their carbon content, on an energy equivalent basis, to the fuels they substitute.

- ✓ The rating system proposed avoids the need for full life-cycle analysis or information about multiple feedstock-fuel pathways.
  Information is only needed on GHG emissions throughout the value chain that are not accounted for elsewhere.
- ✓ There is no need to distinguish between acceptable or unacceptable fuels or pathways.

The system basically adds to the point-of-use approach an incentive to lower the GHG consequence of use of bioenergy. Since the system is voluntary it only closes the gap created by lack of caps in developing countries and lack of accounting across all managed lands in Annex-I countries to the extent that bioenergy pathways result in credits. However, if it were mandatory and if emissions due to indirect land use change were included, it would close the areal gap. Details of how carbon stock losses due to land use and management change were to be calculated would determine its completeness and impacts in relations to achievement of targets.

5.3.3 Mandatory *CN* factors

Use of a *CN* factor in Directives on renewable bioenergy could align bioenergy with its GHG consequences with respect to specified targets. *CN* factors could also be used to calculate biomass emissions within the EU-ETS, thus removing the undesirable effects of lack of coordination between the two systems.

A *CN* factor incorporates all emissions due to changes in carbon stocks. Moreover, it compares the biomass emissions to emissions resulting from combustion of fossil-fuels in a time-relevant manner. Thus, use of *CN* factors by bioenergy users could, in principal, address both the areal gaps and timing issues that have emerged as a result of the combination of the use of a 'zero emissions' factor at the point of biomass combustion under the KP and EU-ETS with the lack of accounting for emissions due to land use change both in some instances in Annex-I countries and to the lack of emission obligations in developing countries. A *CN* approach also includes the following elements not included in the D on RES approach:

- Emissions from land remaining in the same use
- The relative advantage over fossil fuels at any specified point in time

Currently neither *CN* factors nor the D on RES calculations incorporate emissions due to indirect land use change. If, or when, credible methodologies to estimate these become available, either approach could do so.

Under the current bioenergy accounting systems of the KP and EU-ETS, emission reductions appear in calculations determining target compliance well beyond those supported by the *CN* factors of the biomass. The compliance regime registers a 100 percent reduction in emissions compared to use of fossil fuels to produce the same amount of energy. As shown in Section 4, in the case of woody biomass, 100 percent reductions could occur only for certain types of biomass, namely from new plantations, or only occur in the case of fairly long time horizons. Where wood is used to replace petroleum or natural gas, emissions can actually be higher than they would be if the fossil fuel were used, at least in the short or medium term. Since *CN* factors calculate the relative emission savings for all sources of biomass, use of *CN*-factor labelled biomass – together with mandatory use of the factor to determine emissions that need to be covered by allowances – would provide a straightforward way to calculate emission benefits relative to use of fossil fuels. This could then be translated into a bioenergy user's allowance obligation. A user of bioenergy with a *CN* of 0.8, for example, would need to submit 20 allowances per 100 tonnes of CO_2 emitted.

As explained in Section 4, biomass removed for energy today will have a different *CN* factor in relation to a 2020 or 2030 target than biomass removed in 2018 or 2028. To address this problem within a *CN*-based system, one might use average *CN* factors over the time between the present and a selected target date for distinct sources of biomass. This would require reaching agreement on both the target date and what constituted a distinct biomass source. One problem that might arise, even if a single target date were agreed on within the EU, is that the acceptability of the date might be contested internationally.

Use of the same target date to assess the *CN* of biomass sources from Annex-I and developing countries would raise a set of difficult issues, issues shared by the D on RES requirement to average emissions from land use change over 20 years. Annex-I nations converted their native forest in the past. Consequently they can, in many cases, produce and extract biomass from lands whose land-use-change emissions no longer enter into either a *CN* or 20-year calculation. Thus, to use the same annualization period or target date can be viewed as a reversal of the normal interpretation of the 'differentiated responsibilities' concept: Annex-I countries do not have to account for emissions that developing countries do.

Since Annex-I lands that were converted from natural forests have been producing crops and wood products for hundreds of years, the same could be expected on lands currently being converted from natural forests or peatlands in developing countries. Particularly if forests are converted to short rotation plantations, positive *CN* factors can emerge within reasonable time spans (e.g., 60-70 years). This would support allowing annualization periods longer than the 20 years allowed in the EU-RED, or more distant dates for calculating annual emissions or *CN* factors. However, since such an approach within the D on RES would enable the EU to use biomass resulting from deforestation in developing countries it likely to be highly controversial.

Stakeholders may argue that short-term annualization periods are needed because GHG emissions must be reduced in the near term. REDD+, as well as prohibitions on extraction from currently high-carbon stock lands are also supported by this argument. Another common claim is that the objective of such mechanisms is to prevent developing countries from following the undesirable development path taken by the northern hemisphere. However, GHG emissions from land use change are an increasingly small percent of total GHG emissions, currently 12 percent (Marland 2009). The percent will almost certainly continue to fall as fossil fuel emissions from China in particular escalate. Lowering GHG emissions significantly within the next 50 years can thus only be accomplished by substantial reductions in the close to 90 percent of emissions due to combustion of fossil fuels. Until stakeholders concerned with deforestation also actively support carbon capture and sequestration (CCS), the only technology known today with this capability, the sincerity of their concern for near-term reductions is open to question. Similarly, the EU has shown no inclination to itself undertake to reforest a substantial portion of its agricultural land and thus both reduce emissions and undo the damage of its development path. Until it does so, the position that retaining large percents of land in forests is an attractive way to reduce GHG emissions and avoid the negative aspects of development represents an asymmetrical standard across nations. An alternative way for stakeholders advocating retention of forests in developing countries to increase their credibility would be to focus serious effort on the most critical contributors to deforestation: the low per hectare productivity of food and inefficiency with which biomass for food is used and the lack of robust growth in the industrial and service sectors.

As noted above, a further problem is that the *CN* factor as presented above does not incorporate emissions from indirect land use change. Further work would be necessary to do this. Use of *CN* factors could however, with this exception, close the current areal gap and address the time problem attendant on the lag between emissions due to combustion of biomass and the replenishment of carbon stocks. For the timing feature to function, however, the *CN*s will have to be related to specified time horizons or target dates.

It is very likely that accounting systems will remain partial through the foreseeable future. Not all nations will cap emissions from their land use sector and many of those that do are unlikely to adopt a UCSA approach. During this period a *CN* factor based only on emissions not falling under caps may be a useful approach. *CN* factors could be calculated under both the D on RES and the EU-ETS. Under both systems bioenergy users could use whatever mix of biomass sources enabled them to most cost-effectively meet their obligations. Under the EU-ETS, bioenergy users would have to submit allowances to emit for the fraction, if any, of fossil fuel emissions not neutralized. Such a system could be implemented as soon as agreements were reached on target dates. When methodologies for calculating indirect land use change were considered sufficiently well-established, these emissions could be incorporated. However, this is a new concept that has not as yet undergone discussion and review by experts and stakeholders. Such a review process is vital to identify problems and weakness that, in this first presentation of the concept, have not come to light. The authors encourage interested parties to inaugurate and support such a review process.

Table 8 Summary of the policy options to address emissions from the use of biomass for energy

Policy option	All direct LU emissions	iLUC emissions in:		non-LU emissions included	C stock recovery time	Market incentives to lower GHG pathways	Independent from WTO rules	Political Readiness	Cap neede
		Annex-I	Non-Annex I						
Expanded Activity Approach	-	F	-	-	-	-	✓	M	✓
UCSA: within Annex-I countries	✓	✓	-	-	✓	-	✓	L	✓
UCSA: all nations	✓	✓	✓	-	✓	-	✓	L	✓
Value-chain (basic)	✓	F	F	TP	-	✓	✓	H	-
• EU directive on RES	-	F	F	TP	-	-	-	H	-
• Sustainability criteria									
- Project level	✓	F	F	TP	-	-	-	H	-
- National level	✓	✓	F	TP	-	-	-	H	-
Point-of-use Accounting	-	-	-	C	-		✓	?	✓
Point of use Plus (voluntary)	✓	F	F	CTP	-	✓	✓	?	✓
Point of use Plus (mandatory)	✓	F	F	CTP	-	✓	✓	?	✓
Mandatory CN factors	✓	F	F	CTP	✓	✓	✓	?	✓

✓ yes, includes; or meets criteria
\- no, does not include; fails to meet criteria
F: Future (i.e., when a credible method is available)
C, T, P: Combustion, Transport, Processing emissions
WTO: World Trade Organization
H, M, L: high, medium, low (high: already employed, medium: politically realistic in the near- to mid-term, low: unlikely to be politically accepted in the near term)
LU: land use
iLUC: indirect land use change

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