Integration of non-GHG effects and climate policy options in carbon accounting tools and bioenergy strategies

Dissertation

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Confirmation

To whom it may concern,

With this letter I, David Neil Bird, confirm as a native English speaker that the use of the English in the PhD. dissertation *"Integration of non-GHG effects and climate policy options in carbon accounting tools and bioenergy strategies"*, written by *Hannes Peter Schwaiger*, is correct.

Graz, 17.05.2012

Signature

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List of acronyms and definitions

AAUs	Assigned Amount Units
AFOLU	Agriculture, Forestry and Other Land Use
AIMES	Analysis, Integration and Modelling of the Earth System
AWG-LCA	Ad hoc Working Group on Long-term Cooperative Action under the Convention
BAT	Best Available Technology
CarboEuropeIP	Integrated project CarboEurope- Assessment of the European Terrestrial Carbon Balance
CCN	Cloud Condensation Nuclei
CDNC	Cloud Droplet Number Concentration
CERs	Certified Emission Reduction Credits
CH_4	Methane
COP	Conference of the Parties to the UNFCCC
CO_2	Carbon dioxide
dLUC	Direct Land use change
EEA	European Environment Agency
ERUs	Emission Reduction Units
ESA	European Space Agency
EUA	European Emission Allowance
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
GCM	Global Circulation Model
GDP	Gross Domestic Production
GHG	Greenhouse gas
GLP	Global Land Project
GMES	Global Monitoring for Environment and Security
GPP	Gross Primary Production
IA	Integrated Action (within in the NoE Bioenergy)
IGBP	International Geosphere-Biosphere Programme
iLUC	Indirect Land use change
IPCC	Intergovernmental Panel on Climate Change
ISCCP	International Satellite Cloud Climatology Project
IWMI	International Water Management Institute
JER	Jointly Executive Project (within the NoE Bioenergy)
JR	JOANNEUM RESEARCH Forschungsgesellschaft mbH
LUC	Land Use Change
LUCID	Land-Use and Climate, Identification of robust impacts
LRMC	Long Run Marginal Costs
MODIS	Moderate-Resolution Imaging Spectroradiometer
MPI-ESM	Max Planck Institute – Earth System Model
MS	Member State
NAMA	Nationally Appropriate Mitigation Action
NAP	National Allocation Plan

NASA	National Aeronautics and Space Administration
NBP	Net Biome Production
NEP	Net Ecosystem Production
NoE-Bioenergy	Bioenergy Network of Excellence
NPP	Net Primary Production
NREAP	National Renewable Energy Action Plan
ppm	Parts per million
RCP	Representative Concentration Pathway
RED	EU Renewable Energy Directive (RED)
REDD+	Reducing Emissions from Deforestation and Forest Degradation, plus conservation, sustainable management of forests and enhancement of forest carbon stocks
SBSTA	Subsidiary Body for Scientific and Technological Advice
SOA	Secondary Organic Aerosols
SRMC	Short Run Marginal Costs
TOA	Top of the atmosphere
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change
WMO	World Meteorological Organization

1. Summary

As the comprehensive summary of a cumulative dissertation in accordance with § 7 of the Doctoral Degree Regulations (Universität Hamburg, Germany), this report provides an overview, overall background and main outcomes of two specific papers within the research area of bioenergy, land use/land use change and climate change. Finally general conclusions are drawn and a scientific outlook for future research needs is illustrated.

Two different aspects of influencing i) the climatic impacts of land use change considering non-GHG effects such as albedo and ii) the effects of supporting climate policy instruments such as the introduction of the EU-ETS on biomass for energy purposes are assessed.

The impacts of non-GHG effects on climate change benefits of afforestation/reforestation regimes are under debate. The first paper investigates how to incorporate the changes of albedo in an existing carbon accounting tool to show the net effect of land use change on the climate. Applied on a chosen case study area in southern Europe the work combined an atmospheric and carbon accounting tool to convert albedo and carbon sequestration modelling results to a combined radiative forcing balance. The results show that afforestation/reforestation measures as human activities are no longer seen as simply positive actions fighting global warming, because most of the carbon sequestered via photosynthetic CO_2 fixation of forest growth (up to $6x10^{-6}$ Watts ha^{-1} at maturity level) is neutralized by the warming effect of albedo changes. However, sensitivity analyses lead to the conclusion that the improvement of input data like measured albedo values from satellite images (e.g. MODIS) could influence the outputs significantly. For this reason the paper points out that counting for GHG units in land use change calculations does not reflect the entire picture. It is highly recommended that in future GHG balances of land use systems and products (e.g. biomass, liquid biofuels) via LCA should also include these additional climatic effects in addition to the C balances of dLUC and iLUC.

The second paper assesses possible impacts of changes to the EU-ETS on solid and liquid biomass use in Europe. Based on these assessments, recommendations are outlined for optimising support for solid and liquid biofuels. The European Energy and Climate Package agreement contains fundamental changes to the EU-ETS, which started in 2005. With some exceptions, emissions allowances in the power sector will be auctioned starting with the third trading period of the scheme in 2013. This may have significant impacts on the sector's fuel mix and investment decisions. To the extent to which the EU-ETS results in a price on CO_2 emissions, it increases the

competitiveness of low carbon fuels. Under current regulations no CO_2 emissions are attributed to combustion of biomass, thus it functions as a zero-carbon fuel. The study shows that while the use of biomass is already viable under CO_2 prices that have been reached within the EU-ETS, investments in new biomass plants need a higher price level as well as more stable prices, conditions which cannot be predicted with any confidence. The road transport sector, which has significant scope to increase its use of biofuels is currently not part of the EU-ETS, and will not be included in the third trading period starting in 2013. However, the likely consequences of including transportation fuels under the EU-ETS are considered as well as options which involve separate trading schemes for liquid biofuels.

Both papers underline that on the one hand looking beyond GHG effects when assessing carbon balances and on the other hand taking into account additional monetary climate policy options in improving bioenergy strategies may complement already established pathways fighting global warming in a significant manner.

2. Introduction

In this report the overall context and basic background as well as the scope, results, discussion and outlook of the scientific papers “Schwaiger and Bird, 2010 [1], Integration of albedo effects caused by land use change into the climate balance: should we account in greenhouse gas units?” and “Schwaiger et al., 2011 [2], The future European Emission Trading Scheme and its impacts on biomass use”, are described (see Annex). Both papers refer to the research areas of bioenergy, land use/land use change and global climate change issues that depict a triangular research umbrella covering the scientific assessments.

There is a huge amount of links and interfaces among these research areas, but also interactions in the context of climate change policies combined with mitigation and adaptation strategies fighting climate change.
Over the last two centuries GHG concentrations have been increasing due to the energetically use of fossil fuels like coal, oil and gas, but also due to land use change in terms of deforestation.

In 1987 the International Council of Scientific Unions launched the IGBP [3] to support research on global climate change via various projects such as GLP and AIMES to assess the global carbon cycle and impacts of land use on climate change. Results of existing GCM model runs (e.g. MPI-ESM) indicate the importance of considering also the interface of the atmosphere with the terrestrial biosphere.

Specifically, the terrestrial carbon cycle with different land use management options such as forestry and agriculture, bioenergy generation and wood products by using biomass resources plays a significant role in climate research activities. The use of energy out of biomass resources influences also the carbon cycle.

On the other hand, not only global climate change issues but also regional and local impacts such as pollutions to air and water, nitrogen emissions caused by fertilizer inputs, fine dust etc. are highly related to land use strategies and bioenergy generation.

Several instruments and methods are applied to investigate the relevant mechanisms to develop also mitigation strategies in the energy and product sector for the reduction of emissions affecting the climate or the environment.
Environmental impacts are analysed by carrying out Life Cycle Assessments (LCA) of energy services (heat, power) but also products. By using biomass as feedstock

removed from various land use management types carbon accounting tools and models are applied to calculate the carbon and GHG balances. Carbon models and LCA tools are appropriate to cover the GHG balances of land use and service/material options, but various scientific papers show also the requirement of including other investigation areas such as impacts of non-GHG effects – e.g. albedo. Bonan, 2008 [4] points out that afforestation/reforestation regimes attenuate global warming through carbon sequestration, but biogeophysical feedbacks such as albedo can enhance or diminish this negative climate forcing. Montenegro et al., 2009 [5] also conclude that by not considering albedo effects the KP carbon accounting rules grossly overestimate the cooling caused by afforestation drawdown.

The European Union currently imports almost 60 % of its primary energy consumption and over 75 % of oil (IEA Statistics, 2007) [6]. These shares are likely to increase because of the EU's declining production and increasing consumption. High dependency of oil prevents climate change mitigation and exposes the EU to volatility of prices and political risks. The EU has chosen ambitious goals in renewable energy, greenhouse gas reduction and energy efficiency to overcome these troubles.

The energy sector and bioenergy generation and utilization in general are highly influenced by technical biomass potentials, market availability and fuel prices, because most of them are in strong competition with other sector demands such as the food and production sector.
The main target of all investigations in the field of bioenergy, land use and climate change is to provide technical and political solutions improving our national and international climate policy. For the ongoing post Kyoto and climate policy discussions these research activities may contribute to help policy makers and stakeholders in defining

- new agreements to incorporate the AFOLU (Agriculture, forestry and other land use) sector into future post Kyoto mechanisms (e.g. REDD+, CDM and JI projects, carbon credits etc.).

- new aspects in the assessment of biomass resource utilization to mitigate climate change (e.g. LCA, carbon footprints of products, liquid biofuel production with respect to dLUC, iLUC).

3. Background

3.1. Atmospheric and biogeochemical backgrounds

3.1.1. The atmosphere, greenhouse effect and global warming

Climate change is one of the greatest environmental, social and economic threats facing our planet. The concentrations of atmospheric greenhouse gases (GHG) have now reached their highest rates for more than several hundred thousand years. The increase is assumed to be human induced mainly due to fossil fuel consumptions, but also deforestation, burning of forest land, as well as degradation of cropland and soils.

As a consequence, the warming of the climate system is evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global mean sea level.

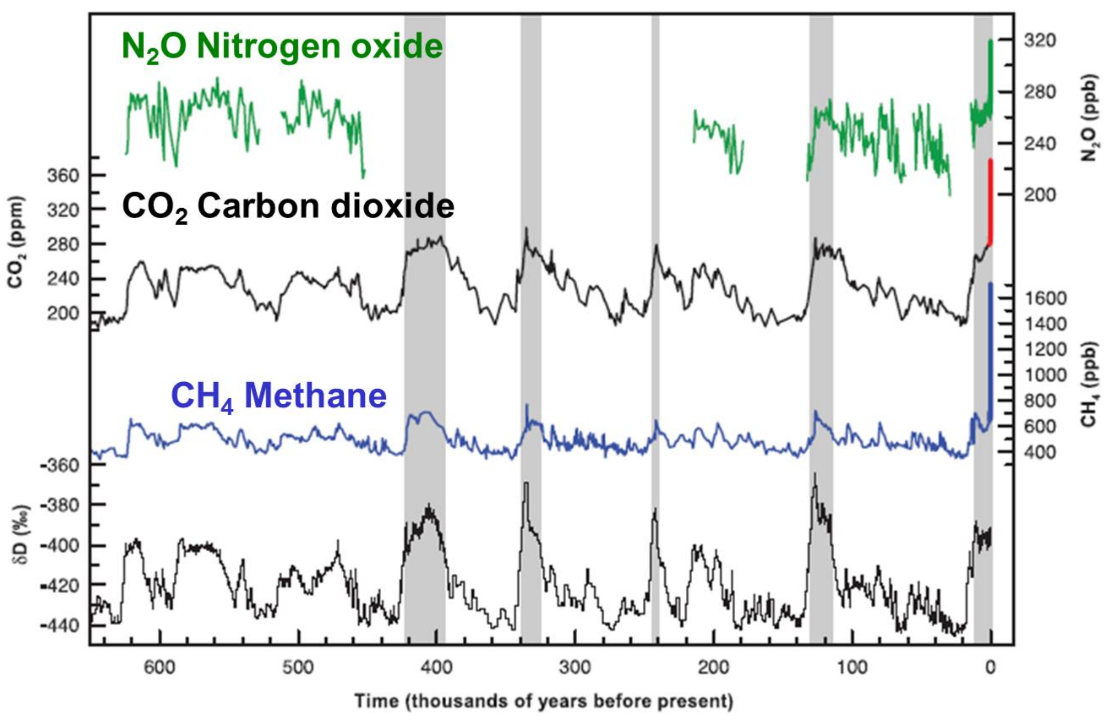

Figure 1: Global Greenhouse gas (GHG) concentration in the atmosphere based on Glacial – Interglacial ice core data IPCC, 2007 [7].

Recognizing the problem of potential global climate change, the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP) established the IPCC in 1988. In its Fourth Assessment Report, published in February 2007, the IPCC projects that, without further action to reduce greenhouse gas emissions, the global average surface temperature is likely to rise by a further 1.8-4.0°C this century. Even the lower end of this range would take the temperature increase since pre-industrial times above 2°C, the threshold beyond which irreversible and possibly catastrophic changes become far more likely [8]. There is a strong relationship between the atmospheric CO_2 concentration and average temperature of the earth surface. Petit et al., 1999 [9] showed the correlation between the atmospheric concentrations of CO_2 and CH_4 with Antarctic air-temperatures.

Figure 1 depicts the variation and development of the most relevant GHG concentrations in the atmosphere, here representative for the raising average GHG concentration over the last 600,000 years. Younger measurements depict no changes in the ongoing increase of the average concentration with CO_2 levels up to 386 ppm in spring 2007 and growth rates between 1.5 and 3.0 ppm per year.

However, Friedlingstein et al., 2006 [10] coupled eleven climate–carbon cycle models to simulate atmospheric CO_2 concentrations and land uptake by the end of the 21st century. Results (Figure 2, left) show concentration ranges between 730 and 1020 ppm in the year 2100 with high variations according to the land carbon budget changes (between – 6 and +11 Gt y^{-1}, see Figure 2, right).

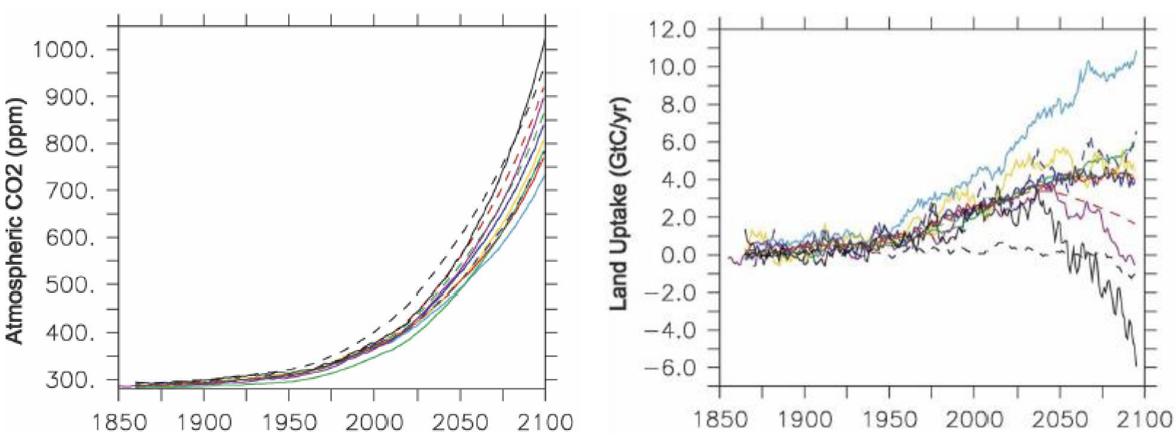

Figure 2: Development of atmospheric CO_2 concentration (left) and differences of land carbon uptake (right) by simulating coupled for climate and carbon cycle models (Friedlingstein et al., 2006 [10]).

This can be seen as another indicator of the importance to include carbon accounting tools into the climate change modelling.

The unique source of energy driving all life and atmospheric cycles on earth is the sun. Figure 3 illustrates the global annual energy balance, where the incoming radiation of the sun (342 Wm^{-2}) is absorbed by the earth atmosphere and surface (69%), but also directly reflected back to space (31%). The radiation absorbed by the surface (168 Wm^{-2}) is returned back via thermals and evapotranspiration (102 $Wm^{-2)}$, but also long wave infrared radiation. The atmosphere absorbs most of this back radiation and itself emits radiation to space, but also emits radiation back to the earth which causes the greenhouse effect, highly influenced by the existing GHG concentrations.

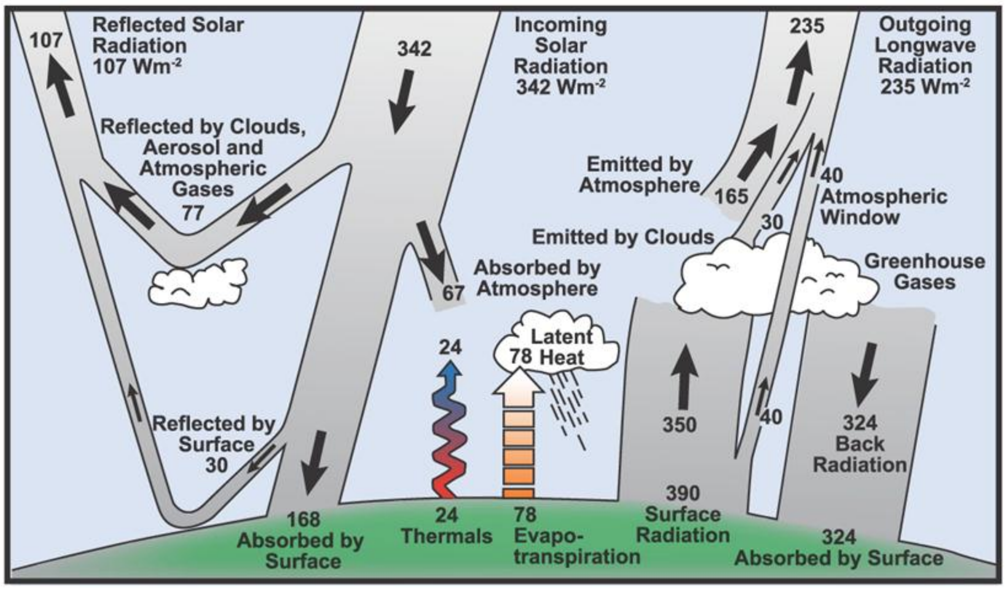

Figure 3: Earth annual and global mean energy balance (Kiehl and Trenberth, 1997 [11]).

Not only in changing the GHG concentration over time, but also changing the reflectance of the earth surface connected with higher reflection rates back to space (albedo) may influence this balance in a significant dimension. The albedo is described as the potential of diffuse reflecting back radiation for non-shining surfaces such as land use options. Planting coniferous trees as a climate mitigation measure has been questioned since the darkening of the surface (decrease in albedo) may contribute to warming and therefore diminish or counteract the climatic benefits of carbon sequestration (Thompson et al.,2009 [12]).

3.1.2. The global carbon cycle and the interface to the terrestrial biosphere

Carbon in the form of CO_2 is cycled and exchanged between the atmosphere, oceans, and terrestrial biosphere (Figure 4, see also IPCC, 2000 [15]). The largest natural exchanges occur between the atmosphere and terrestrial biota (GPP about 120 Gt C yr^{-1}, NPP about 60 Gt C yr^{-1}) and between the atmosphere and ocean surface waters (about 90 Gt C yr^{-1}). The atmosphere contains about 760 Gt C.

The oceans, vegetation, and soils are significant reservoirs or pools of carbon, exchanging CO_2 with the atmosphere. Oceans contain about 50 times as much carbon as the atmosphere, predominantly in the form of dissolved inorganic carbon. Ocean uptake of carbon is limited, however, by the solubility of CO_2 in seawater (including the effects of carbonate chemistry) and the slow rate of mixing between surface and deep-ocean waters. Terrestrial vegetation and soils contain about three and a half times as much carbon as the atmosphere, the exchange is controlled by photosynthesis and respiration (IPCC, 2000 [15]).
Land use and land use change has an important influence on the global climate system and especially on the global carbon cycle. Of all life zones forest ecosystems play the most important role influencing the global carbon cycle.

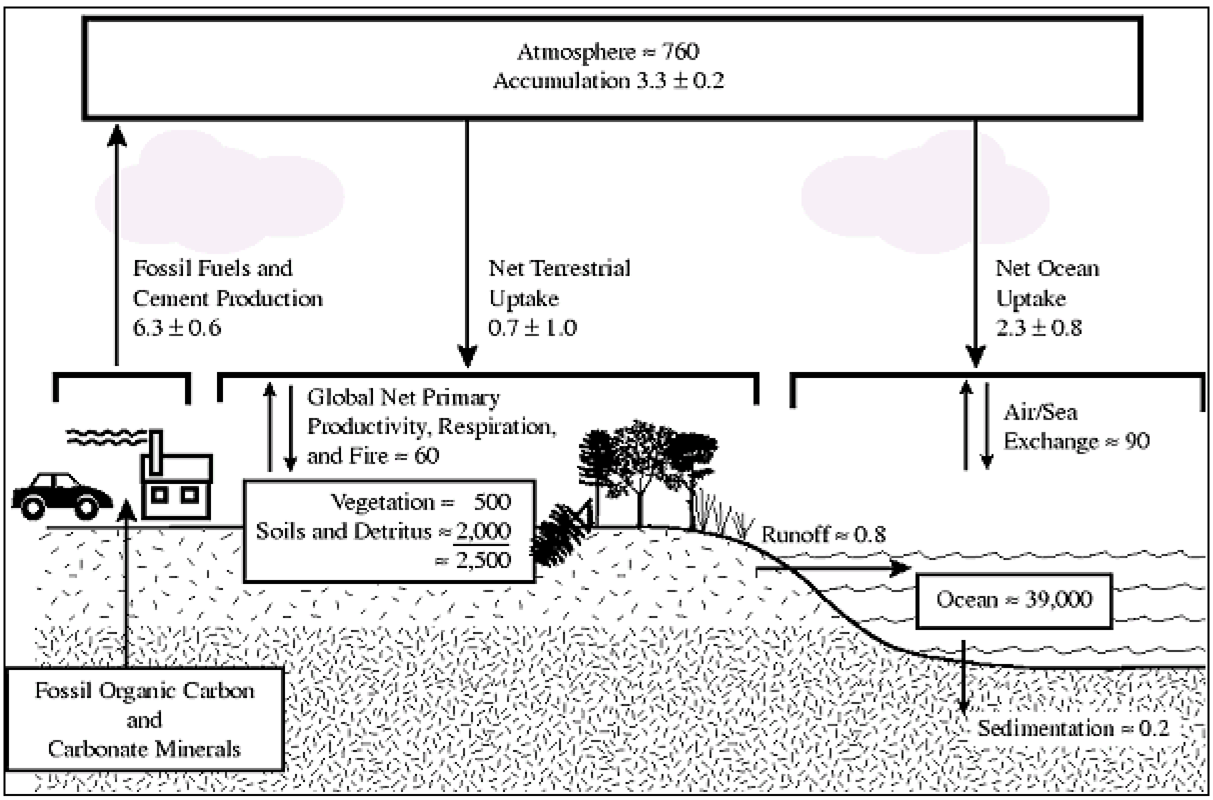

Figure 4: The global carbon cycle, showing the carbon stocks in reservoirs (in Gt C) and carbon flows (in Gt C yr^{-1}) relevant to the anthropogenic perturbation as annual averages over the decade from 1989 to 1998 (Schimel et al., 1996 [13]. Net ocean uptake of the anthropogenic perturbation equals the net air-sea input plus runoff minus sedimentation (discussed by Sarmiento and Sundquist, 1992 [14] in IPCC, 2000 [15].

Forest ecosystems as carbon sources or sinks combined with different forest management and wood utilization strategies can influence the carbon exchange processes in a decisive manner. Vegetation withdraws carbon dioxide from the atmosphere through the process of photosynthetic assimilation. Over a certain period of time plant growth coupled with the production of biomass accumulates and stores carbon in living vegetation, dead organic matter, and soil. The ability to remove carbon dioxide from the atmosphere and store the carbon in biomass provides climate-mitigation benefits in the long term.

Figure 5 provides an overview of the flows and storage capacities of the global terrestrial carbon uptake and removal. Plant respiration equal to a release of CO_2 to the atmosphere, reduces the GPP leading to the NPP and resulting in a short term carbon uptake of a forest ecosystem. Subtracting the amount of heterotrophic respiration equal to the decomposition rate of organic carbon in dead organic matter and soil pools, additional CO_2 is emitted to the atmosphere, providing the amount of NEP. This term represents the midterm carbon storage of a forest ecosystem. Finally, NBP can be derived by subtracting the anthropogenic and natural disturbances like harvest, forest clearance and fire (Schulze and Heimann, 1998 [16]).

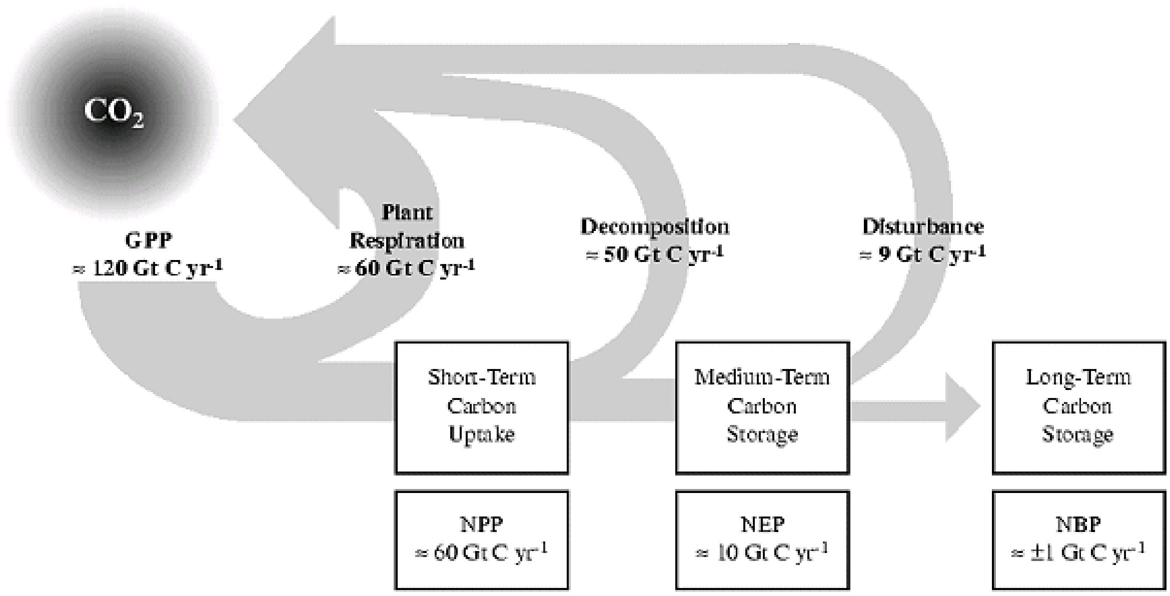

Figure 5: Global terrestrial carbon uptake. Plant (autotrophic) respiration releases CO_2 to the atmosphere, reducing GPP to NPP and resulting in short-term carbon uptake. Decomposition (heterotrophic respiration) of litter and soils in excess of that resulting from disturbance further releases CO_2 to the atmosphere, reducing NPP to NEP and resulting in medium-term carbon uptake. Disturbance from both natural and anthropogenic sources (e.g., harvest) leads to further release of CO_2 to the atmosphere by additional heterotrophic respiration and combustion-which, in turn, leads to long-term carbon storage (adapted from Steffen et al., 1998 [17]).

This NBP is appropriate for the net carbon balance of a specific area. On the basis of the NBP, the development of carbon exchange rates of forests with the atmosphere is also dependent on harvesting regimes and calamities. Depending on the system boundary around a single forest ecosystem it is obvious, that forest ecosystems are not always carbon sinks, but also carbon sources, e.g. when standing stocks or large amounts of timber are removed from forest ground (e.g. wind throw or clear cut).

To assess the carbon stock and flux behaviour of different land use compartments like living above and below ground biomass, litter, dead wood and soil, several carbon accounting models can be used to assess carbon balances of land use strategies over time. The consideration of manufactured harvested wood products is of importance when dealing with LCAs and carbon footprints of forest products, but not of importance referring to the rules of CDM, JI or REDD+ and therefore not considered here.

In comparison to forest ecosystems, agricultural land use options in general show lower carbon stocks. Due to shorter harvesting periods and more frequent biomass removals, the living vegetation part under management has lower C-stocks. Therefore, as one of the mitigation strategies to fight global warming there has been interest in converting non-forest lands into both short and long rotation forests using afforestation or reforestation for bioenergy use and timber production.
However, not only forest management activities, but also the production of liquid biofuels combined with LUC activities influences the carbon cycle.

There are plenty of scientific publications underlining that the increase of activities for first and second generation liquid biofuels production and utilization have caused significant disturbances in the existing land use management regimes worldwide (see Fehrenbach et al., 2008 [18], Searchinger et al., 2008 [19], Fritsche et al. 2010 [20], Bouët et al., 2010 [21], Croezen et al., 2010 [22], Havlik et al., 2011 [23]).

3.1.3. Land management and the influence on albedo

Depending on its colour and brightness, a change in land surface could cause 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. For example, Betts, 2000 [24] concluded that the change in surface albedo due to planting coniferous forests in areas with snow cover can contribute significantly to radiative forcing. Brovkin et al., 1999 [25] found that cooling due to albedo change from deforestation was of the same order of magnitude as increased radiative forcing from CO_2 and solar irradiation. Bala et al., 2007 [26] investigated that a global-scale deforestation event could have a net cooling influence on the Earth's climate and Jackson et al., 2008 [27] concluded that ignoring biophysical interactions could result in millions of dollars being invested in some mitigation projects that provide little climate benefit or, worse, are counter-productive.

On the other hand in tropical regions, afforestation may be positively beneficial in sequestering carbon since forest trees can lead to cloud formations via higher transpiration rates resulting in global cooling. Stoy et al., 2012 [28] for example showed that temperate forests tend to cool the land surface in addition to their high CO_2 sequestration potential.

However, Thompson et al., 2009 [12] argue that in boreal areas low surface albedo exerts a positive climatic forcing that may exceed the negative forcing from sequestration. Boreal forest areas are often covered by fog and clouds particularly in winter. Therefore it seems to be obvious that a "negative" albedo effect due to changing from e.g. grassland covered with snow to dark coniferous forest is substantially reduced due to the presence of clouds, thus lowering the contribution of albedo changes accompanying land use changes to overall global warming impact. However, in areas with less frequent cloud cover, land use change from grassland to forest where on land surfaces characterized by light colour conditions (snow or bright sandy grassland) warming effects due to albedo change might be sufficient to cancel cooling effects of carbon sequestration.

Another topic that has to be discussed here is the influence of evapotranspiration and aerosols. Evapotranspiration is given as the sum of evaporation and plant transpiration from land to the atmosphere and accounts for the movement of water to the air from sources such as soil, canopy interception, and waterbodies (evaporation) plus the water within a plant and the subsequent loss of water as vapour through stomata in its leaves (transpiration). In comparison to land cover with low surface roughness and leaf area index like grasslands, forests are seen to have a higher evapotranspiration rate over the year. It is assumed here, that the latent energy included in the vapored water releases this energy back to atmosphere on its condensing level and therefore seen as neutral when focusing on a large scale such as global warming. Betts et al., 2007 [29] and Sampaio et al., 2007 [30] figured out that evapotranspiration on the other hand promotes low-level cloud cover increasing top-of-atmosphere (TOA) albedo. Spracklen et al., 2008 [31] found out, that due to emissions of biogenic volatile organic compounds forming secondary organic aerosols (SOA), forests influence their TOA albedo themself. SOA particles act as effective cloud condensation nuclei (CCN) in summer and higher concentrations lead to an increase of cloud droplet number concentrations (CDNC) accompanied by increasing albedo and life time of clouds. For boreal forests this influence has been calculated as 3-8% increase in cloud albedo.

3.2. Climate policy and economic backgrounds

3.2.1. The Kyoto Protocol (KP)

The Kyoto Protocol (KP) to the United Nations Framework Convention on Climate Change (UNFCCC) is an amendment to the international treaty on climate change, assigning mandatory emission limitations for the reduction of GHG emissions to the signatory nations (UNFCCC, 1997 [32]). Signatory countries can be divided into two groups: Annex I countries (developed countries with GHG reduction obligations) and Non-Annex I countries (without GHG reduction obligations). Annex I countries that ratify this protocol commit to reduce their emissions of carbon dioxide and five other greenhouse gases, or engage in emissions trading if they maintain or increase emissions of these gases.
At the moment there are 192 parties and 84 signatory nations to the KP. Parties signed up the UNFCCC and share the objective to stabilize GHG concentrations worldwide at a level that would prevent dangerous anthropogenic interferences (+2°C above the pre-industrial global average temperature), whereas signatory nations also ratified the KP with legally binding reduction targets. One major problem of the KP is that parties should act to protect the climate system “on the basis of equality and in accordance with their common but differentiated responsibilities and respective capabilities”. This includes the consideration of different national circumstances to contribute. In addition, the polluter pays principle should make sure that parties have to pay for their environmental pollutions [33]. Actual developments in post Kyoto negotiations and the case of Canada (pulled out of the KP after COP17) lead to the assumption that several signatory nations have ratified the KP without a serious aim to reduce emissions and take into account existing loopholes and possibilities not paying fees.

However, with respect to AFOLU sector the KP establishes that human–induced land use change and forestry activities - limited to afforestation, reforestation and deforestation (Article 3.3) since 1990 - can be used to meet the Annex 1 countries commitments. This limited inclusion of AFOLU activities can be taken into account for the first commitment period between 2008 and 2012, but also for the new period starting in 2013.
Article 3.4 allows to consider “additional human-induced activities” related to changes in GHG gas emissions by sources and removals by sinks in the agricultural soils and the land-use change and forestry categories. At COP 17 in Durban parties agreed that forest management accounting is considered by the so called “reference level approach”, where a baseline is defined to which the reported numbers are compared.

A party would gain credits if reported removals were higher than the reference level net removal, but limited by a cap of 3.5%. If removals were lower, the party would be debited. For the next commitment period, starting in 2013 – 2017 or 2020, this flexible mechanism is mandatory [34].

Another flexible mechanism of the KP, the Clean Development mechanism (CDM) allows industrialized countries with a GHG reduction commitment to gain credits for financing emission reduction projects in countries without Kyoto targets. The flexibility mechanism, defined under Art. 12 of the Kyoto Protocol permits the acquisition by Annex I Parties of certified emission reduction credits (CERs) accruing from project activities in developing countries. AFOLU projects carried out under the CDM could also earn credits as CERs, without the emission limitation commitments that are applied to Annex 1 countries. It does not specifically mention forest or other land use, but allows any project that fulfills the requirement of being real, measurable and of long-term benefits related to the mitigation of climate change. However, CDM calls for additional and cost effective ways to reduce carbon emissions.

Therefore, the CDM offers possibilities for project-based emission reduction "credits," referred to as "certified emission reductions" for transfer of credits from Non-Annex I countries envisioned in CDM. A second, similar scheme called "Joint Implementation" or "JI" applies in transitional economies mainly covering the former Soviet Union and Eastern Europe (Art. 6 of the Kyoto Protocol). It allows Annex I countries to implement policies and measures jointly with other countries. The rationale for JI is to reduce aggregate costs of GHG mitigation and enable the transfer of efficient activities, technologies and techniques to countries that are hosting the project. Each party has been given targets by the way of issuing emission rights, called Assigned Amount Units (AAUs). An Annex-1 party can invest in a project in another host country leading to emission reductions (or enhancing removal by sinks) in exchange of credits, termed as Emission Reduction Units (ERUs). In order to transfer ERUs, JI requires both the host and buyer country to approve the projects and deduct/add an equivalent amount of AAUs from their national registries (UNFCCC, 2009 [35]).
To verify and assess changing GHG balances of land use options due to human induced KP activities C stock changes modelling is required, which is especially true for land use change activities (dLUC, iLUC), afforestation and reforestation activities, land management improvements, measures in the field of REDD etc. . As mentioned before, including albedo changes caused by LUC activities may influence the carbon stock change based GHG balance of a land use system significantly.

3.2.2. The European Emission Trading Scheme (EU-ETS)

Following the directive 2003/87/EC [37], establishing a scheme of GHG emission allowance trading within the community, in January 2005 the European Union implemented the European Emission Trading Scheme (EU-ETS) as a main instrument to reach its Kyoto commitments on Climate Change. The EU-ETS is the largest multi-country, multi-sector GHG emissions trading scheme world-wide.

The first phase comprised 3 years from 2005-2007, and included 12,000 industrial plants covering about 46 % of the EU's total CO_2 emissions or about 30% of its overall GHG emissions. For this period, the EU-ETS includes CO_2 emissions of five of the most energy intensive sectors: iron and steel, minerals, pulp and paper, refineries, and the power sector. The second phase runs from 2008-2012 and coincides with the first Kyoto commitment period. The third period runs from 2013-2020.

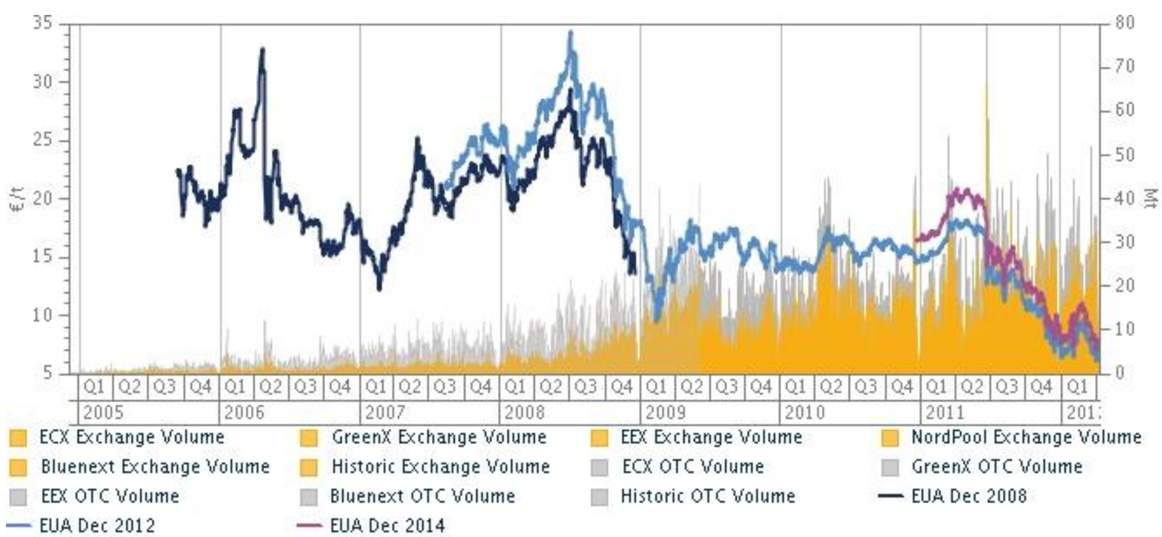

Figure 6: Development of EU allowance (EUA) prices over time in € t^{-1}[36].

The trading scheme allows companies to buy and sell certificates to release CO_2 into the atmosphere, so called allowances. In the National Allocation Plans (NAPs) the number of allowances allocated to companies (cap) and the method to allocate them is determined on EU member state level. Companies exceeding their individual CO_2 emissions targets can purchase allowances from others who over fulfill them. While in the first and second period allowances were allocated based on historical emissions (grandfathering) and free of charge – (at least 95% in the first period, and at least 90% in the second phase), in the 3rd phase all allowances will be auctioned at least in the energy sector (EC, 2009 [37]). For "new entrants" (installation that are included into the EU-ETS for the first time) the EU-ETS uses benchmarks. These can be either the Best Available Technology benchmark (BAT) where the benchmark of emission

allocation refers to the “best” available technology in each sector, or benchmarks based on the carbon intensity of the fuel used, on capacity or on output.
Figure 6 shows the development of European Emission allowances over the last years for allowances including traded volumes that expired in 2008 (1st trading period) and the still valid EUAs 2012 and 2014 (2nd and 3rd trading period). All CO_2 price performances in the chart depict a strong correlation to the mix of commodity prices worldwide. Prices declined from over 30 € per ton to CO_2 prices below 7 € at the moment [36]. Main reasons for that is the current economic crises and its negative impacts on the affected industry sectors under the EU-ETS.

The philosophy behind the system is to create incentives for the affected sectors to reduce their specific CO_2 emissions. The cap on the allowances allocated should create scarcity, a precondition for a market. If companies manage to keep their CO_2 emissions below their cap, they are able to sell their excess allowances at the price determined by the market. As a result emissions reductions are carried out where they are cheapest and measures to reduce CO_2 emissions, such as switching to a low emission fuel mix and investments in new “climate friendly” technologies, are encouraged. Emissions trading ought to ensure that emissions are reduced in a most cost-effective way. As the EU-ETS sets a price on CO_2 emissions it increases the competitiveness of low carbon fuels. Biomass is regarded as carbon neutral in the scheme causing no additional CO_2 costs. The scheme thus has the potential to increase biomass use. Several studies such as Buchner et al., 2006 [38] support that the EU-ETS so far has motivated companies to investigate internal reduction measures, and that abatement has occurred even if the CO_2 price was very volatile and the reduction requirements were modest.
In the first trading year, 2005, ca. 260 millions of allowances were traded making up 5.3 billion Euros. The market is expanding to more than 700 million of allowances traded in 2006. Thus, the ETS has evolved as the engine of the global carbon market. In the EU business is learning to work in a carbon-constrained environment and to lower its GHG emissions at the lowest price.

3.2.3. The EU Directive on renewable energy (RED)

In 2009 the European Parliament and of the Council endorsed a new directive (EC, 2009 [39]) on the promotion of the use of energy from renewable sources (hereinafter referred to as “Renewable Energy Directive” or “RED”).

This directive poses a binding target of 20 % renewable energy share in the EU’s final energy consumption by 2020. As part of the overall target, a binding minimum target for each Member State (MS) to achieve at least 10 % of their transport fuel consumption from renewables is set, provided that production is 'sustainable' and the second generation biofuel share commercially available is included. In order to reach the 20% target, each member state should increase its share of renewable energies by 5.5% from 2005 levels, with the remaining increase calculated on the basis of per capita gross domestic production (GDP).

In terms of reaching the mandatory national targets, the directive provides the flexibility to use support schemes and measures of cooperation between different MS and with third countries in accordance with Articles 5-11 of the Directives. The purpose of such cooperation is to allow MS to partly fulfill their renewable energy target through relatively cheaper renewable energy sources from other member states or countries that have higher potentials and thus lower production costs. The new flexible mechanisms included in the directive are (i) statistical transfer, (ii) joint projects and, (iii) joint support schemes (e.g. common feed in tariffs etc.).

The RED requires each MS to adopt, publish and notify to the Commission their National Renewable Energy Action Plan (NREAP) to meet the objectives of the directive and shall ensure that authorisation, certification and licensing procedures are simplified to remove barriers in the development of renewables markets. Every two years MS must report the share of renewables they have achieved based on the following interim targets: 20% of the final 2020 target in 2011/2012, 30% in 2013/14, 45% in 2015/16, 65% in 2017/18. Unlike the overall target, these interim targets are not mandatory.
These plans shall include (possible) co-operations between local, regional and national authorities, planned statistical transfers or joint projects. To assist MS during their NREAP preparations, the EC issued a template for a National Renewable Energy Action Plan (2009/28EC) in June 2009. This template requires renewable energy consumption related data from 2010 onwards for each consecutive year until 2020.

By June 2010 MS needed to notify their NREAPs to the Commission. However, six months before NREAP is due, each MS is requested to publish and notify its estimated excess renewable energy sources compared to the indicative trajectory that could be statistically transferred and the estimated potential for joint projects or its estimated demand for renewable energy to fulfill its 2020 renewable target.
The RED also provides a procedure for the calculation of GHG emissions of biofuels including LUC impacts and has therefore a significant influence on both paper topics.

3.2.4. Reducing Emissions from Deforestation and Forest Degradation (REDD)

There is a common understanding of an urgent need to reduce emissions caused by deforestation but also degradation worldwide. Warren et al., 2009 [40] suggests that it will be impossible to reduce climate change without reducing tropical deforestation and degradation activities.

The main idea behind the mechanism of REDD plus conservation, sustainable management of forests and enhancement of forest carbon stocks (REDD+) is to provide an opportunity in generating mechanisms to protect forests while combating climate change and at the same time also improving biodiversity, welfare and social aspects in affected countries (co-benefits). Similar to other flexible mechanisms like the CDM or JI projects carbon credits or other kinds of finance are “produced” in terms of emissions saving while protecting existing forests that would in a so called reference case be deforested. The REDD-credits generated by these projects could then be used by Annex 1 countries or can also be traded within the existing carbon markets.

The magnitude of the entire mechanism is very high. Myers Madeira et al., 2008 [41] point out that annually, land-use changes account for approximately 20 % of total GHG emissions, whereas most of these emissions come from deforestation in developing countries.

Agreements on REDD have been discussed in SBSTA and COP Meetings over the last years. In the Cancun agreement (UNFCCC, 2010 [42]) - as an output of COP-16 - REDD is mentioned in paragraph 70 of the AWG-LCA text saying that “Encourages developing country parties to contribute to mitigation actions in the forest sector by undertaking the following activities, as deemed appropriate by each party and in accordance with their respective capabilities and national circumstances:

(a) Reducing emissions from deforestation, (b) Reducing emissions from forest degradation, (c) Conservation of forest carbon stocks, (d) Sustainable management of forest and (e) Enhancement of forest carbon stocks.

Even when decisions on REDD are still intensely discussed, the inclusion of albedo in the carbon balance calculations may also play an important role.

Nationally Appropriate Mitigation Actions (NAMAs) as being strategic initiatives undertaken voluntarily by developing countries to avoid or reduce the production of GHG emissions are also instruments of developing countries to reduce their national emissions, but are not further mentioned here.

3.2.5. Linking Directive

To increase the flexibility of the EU-ETS the European Commission adopted in 2003 an amending directive, the so called "Linking directive" [43]. MS may allow also operators under the EU-ETS to use CERs from 2005 and ERUs from 2008 (not derived from the AFOLU sector and therefore not expiring) for compliance in the Community scheme. The quantity of JI/CDM credits which can be used is set in the National allocation plans (NAPs). JI/CDM projects are good business opportunities for European companies who have gained already experiences with bioenergy and can export know how and technologies.

4. Intended scientific contributions of the papers

To look not only on GHG emissions and mitigation options via increasing carbon stocks of land use systems has been recommended in one of the so called board meetings of the EU-FP6 funded CarboEurop-IP ("Integrated project CarboEurope-Assessment of the European Terrestrial Carbon Balance", contract no. GOCE-CT2003-505572 [44]).

The overarching aim of CarboEurope-IP was to understand and quantify the present terrestrial carbon balance of Europe and the associated uncertainty at a local, regional and continental scale. The topic of non-GHG effects on climate change has also been discussed several times in the IA4 meetings of the NoE-Bioenergy [45] (see also chapter 5.2.1).

The main reason to focus on that topic was the importance of the environmental repercussions in the AFOLU sector due to this non-GHG effect of albedo. The topic is also highly related to the Article 3.3 of the KP, to JI and CDM projects, questions regarding dLUC and iLUC in the biofuels sector and finally in the field of REDD+.
The intended contribution of the scientific work in the first paper [1] was to further clarify a possible inclusion of non-GHG effects such as albedo into the GHG accounting of land management, but also land use change regimes. This should provide an entire picture of the GHG balance and climate impacts of biomass based products and fuels (in addition to the assessment of the carbon footprint via LCA), but also on different human induced management changes for different landscapes. Other scientists share this view and suggest that considering only carbon accounting approaches neglecting the albedo effect do not show the right, entire results (e.g. Schaeffer et al., 2006 [46] and Betts et al., 2007 [47].

With respect to climate policy instruments and regulative policy roles the work in the second paper [2] should help to understand the obstacles and barriers of increasing the current level of biomass use for heat, power but also in the transportation sector.
Up to now, the CO_2 price has, on average, not been high enough to motivate companies to invest in low carbon technologies on a large scale. Surveys done within the NoE-Bioenergy, however, have shown that the EU-ETS has motivated companies to investigate internal reduction measures, and that modest emission reductions have occurred in spite of a very volatile CO_2 price (see Figure 6). This is also influenced on general allocation methods, the design of existing NAPs and options for the use of revenues from auctioning.

The transportation sector, accounting for 21 % of the EU's total GHG emissions, is currently excluded from the EU-ETS and it is unlikely to be included in the scheme until 2020.

However, to stimulate greater use of liquid biofuels, the EU-ETS may not be the most effective system due to the relatively high costs of most biofuel options in relation to other measures both in the transportation and power sector. However, there is an ongoing discussion on appropriate policy measures to reduce transport emissions and whether to include the road transport sector in the EU-ETS or not.
There are several options of implementation: the whole transport sector (road transport, aviation and maritime shipping) could be integrated in the EU-ETS. Alternatively a subset of transportation sectors (e.g. only aviation and maritime shipping) could be integrated in the EU-ETS while other transportation sectors, particularly road transport would either have their own, separate ETS or rely on other instruments. Finally, transportation fuels could be subject to a trading system separate from other transportation options.

The intended scientific contribution of the second paper [2] was to figure out the competitiveness of country specific biomass use including a variation of EU-ETS allocation methods, CO_2 price, electricity/biomass costs, plant efficiencies and national support instruments. This should give a clear picture under which conditions and options biomass could become as competitive as fossil fuels. It also showed different options to include the transportation sector and impacts when including it into the existing trading system, but also to initiate a separate trading system for the sector only. The results may support policy makers in their future decisions in enlarging the EU-ETS among further sectors.

5. Summary of the scientific papers

5.1. Schwaiger Hannes, David Neil Bird, 2010 [1] (see Annex)

“Integration of albedo effects caused by land use change into the climate balance: should we account in greenhouse gas units?”

5.1.1. Introduction and personal contribution

The scientific work for this publication is based on the contribution of the JOANNEUM RESEARCH Forschungsgesellschaft mbH (JR) to the CarboEurope-IP project. [‡]
The purpose of this paper was to describe a new methodology developed at JR, where it combined radiative forcing effects due to albedo changes with those due to carbon stock changes over time. The methodology has been applied to changes in land-use e.g. from grasslands to forest for a case study area in Spain. An albedo accounting model was first used to calculate top of the atmosphere albedo effects caused by an assumed land use change. In a second step, the carbon stock change balance was incorporated. Different equations were used to convert GHG-balance results into radiative forcing units to depict the entire effect on the climate. Finally the influence of short- and long term cumulative climate change effects was considered.
Below, a short summary of the paper in terms of methods, results and conclusion is given.

5.1.2. Methods

A carbon accounting tool has been combined with a model that calculates top of the atmosphere (TOA) net short wave radiation under different land use options for a case study area in central Spain.

[‡] As JR internal project leader (two departments were involved) I was mainly responsible for the research contents, the project management and the deliverables of the JR relevant work for CarboEuropeIP. JR contributed to WP 4.2 on “Land Carbon Inventories” led by Dr. G.-J. Nabuurs, ALTERRA, Netherlands.

Out of all JR contributions to this project and coordinated by Dr. Nabuurs as guest editor my colleague D.N. Bird and I decided to submit this scientific paper for a special issue of the ELSEVIER journal “Forest Ecology and Management”. As first author of the paper I was responsible for the technical and editorial work. Furthermore, all data required for both, the carbon accounting related and the atmospheric/albedo related part were collected by me. Several model runs (GORCAM [55] and Fu Liou [65]) and the sensitivity analysis are also parts that I was responsible for. D. N. Bird contributed by converting CO_2 balances into changes of radiative forcing by using equations based on the work of Betts, 2000 [24].

Case study area

Changes of albedo and accompanying positive or negative effects on radiative forcing are usually seen in cases of pronounced changes in surface colour.

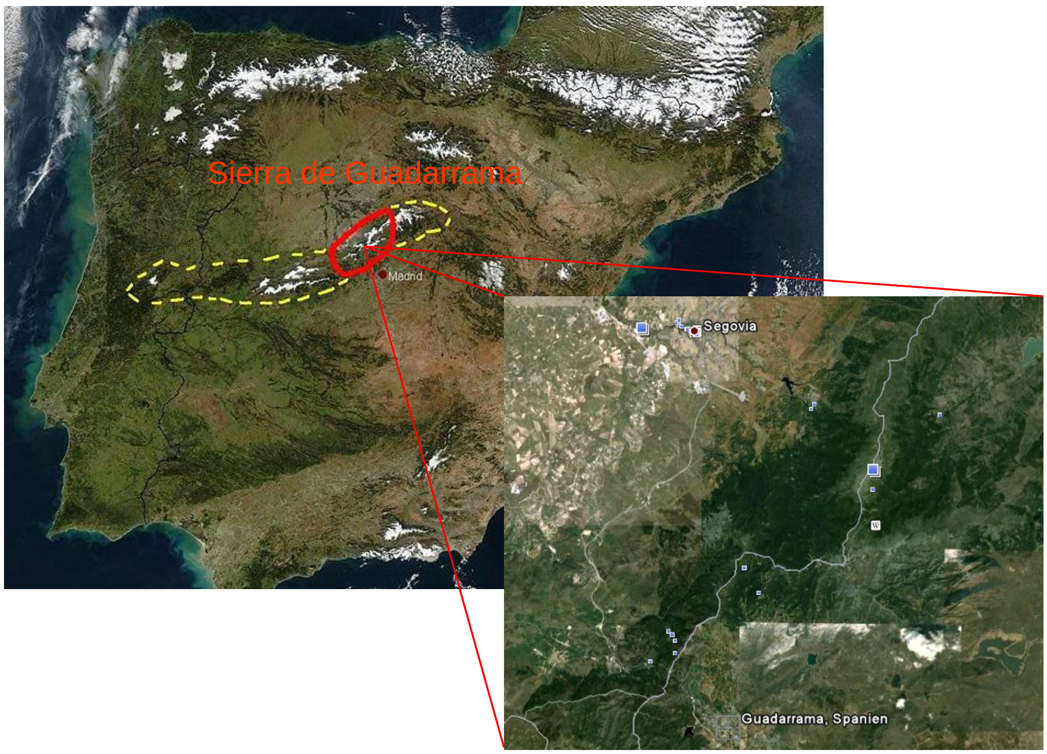

Figure 7: The case study area "Sierra Guadarrama [48]" in central Spain from space (source Google earth, 40.48 N, 4.05 W) covered by alternating grasslands and coniferous forests. Red area: Sierra de Guadaramma, yellow area: Sistema Central.

In general, the major trends observed with surface albedo are that i) albedo increases with snow cover, which is more reflective than foliage or soil, and that ii) forests, especially coniferous ones, have lower albedo than grass or croplands, due to denser, darker canopies that absorb more of the incident radiation (Robinson et al., 1985 [49], Sharratt, 1998 [50]). Therefore seasonal albedo changes occur in areas with snow cover in winter and dark surfaces in summer, such as in northern or alpine countries. Schuster, 2007 [51] also underlined the major influence and effects of snow cover on the net radiation balance of different land use categories and Bernier et al., 2012 [52] showed that albedo radiative forcing is driven by the changes in snow cover exposure, especially in early spring when the sun is high and the snow cover is still complete.

As a corollary to this observation, the aim of this work was to model the net cumulative warming/cooling profile (including both sequestration and forcing due to albedo change) of land surface changes in areas having infrequent, sparse cloud cover in Europe. The model was applied to areas of grasslands and dark forests such as Scots pine.
We applied the model in a mountainous region characterized by clear skies and snow cover in winter. As shown in Figure 7, the “Sierra de Guadarrama” region in central Spain was chosen for the calculations fulfilling the criteria mentioned above. The vegetation of the mountain range is characterized by an abundance of pine forests and copses of oak and Holm oak (*Quercus ilex*) on its lower slopes, while the mountain grasslands and pastures around the summits are fringed by juniper and Spanish Broom shrubs (*Spartium junceum* [53]). Precipitation data in the form of average values per month over a year where taken from the IWMI Online Climate Summary Service Portal 2009 [54].

<u>Carbon stock change balance</u>

To model the changes in carbon stocks over time we used the stand-level carbon model GORCAM (Schlamadinger and Marland., 1996 [55]). GORCAM tracks the flow of carbon from living above and below ground biomass to the dead wood, litter and soil pools. The model uses data from local growth curves and yield tables to drive living, above-ground biomass while below-ground, living biomass is a function of above ground biomass and annual litter is a fraction of the living biomass.

Model input data required are taken from the Intergovernmental Panel on Climate Change Good Practice Guidance for Land Use, Land-Use Change and Forestry (IPCC, 2003 [56]) and local yield tables for average site quality (Rojo and Montero, 1996 [57]). Yield tables were converted to carbon assuming biomass expansion factors from the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006 [58]). Decomposition rates of litter are calculated using a separate tool that uses material quality, average temperature, and precipitation data (International Water Management Institute, 2009 [54], Moore et al., 1999 [60]). Litter biomass decays exponentially, with decay rates based on temperature, rainfall and material (Moore et al., 1999 [59], [60]). Some of the decaying material enters the soil pool, which also decays exponentially as heterotrophic respiration over time.

For the paper the IPCC default values for the carbon fraction of woody biomass and litter have been assumed.

Albedo effects

Albedo is a very complex function of surface and radiation characteristics. Surface characteristics include land cover type and colour, specifics of the vegetation, snow condition and soil moisture (Gao et al., 2005 [61]). Radiation characteristics include incident angle and wavelength (Henderson-Sellers et al., 1983 [62], Ni and Woodcock, 1999 [63]). Average values used in the model are taken from measurements published in a number of journals summarized by Pielke et al., 1990 [64] (see Table 1).

An albedo of 1.0 means full reflection of the incoming sunlight, an albedo of 0.0 indicates full absorption. The climate forcing effect of surface albedo is modified by clouds, dust, and ice particles which reflect and scatter both incoming solar radiation and energy reflected by the earth's surface. As a result, changes in surface albedo is somewhat muted by atmospheric conditions. Using surface albedo as a base, the top of the atmosphere (TOA) difference in up- and downwelling short wave radiation was calculated using the Fu-Liou Radiative Transfer Model (Fu-Liou., 2005 [65], see Figure 8). Snow cover in winter is incorporated into the model using the assumption that there is 100% snow cover between December and February and 33% snow cover in March and November. A linear increase of crown cover up to an assumed maximum of 80% at the final felling age is used for new plantings with grassland assumed to cover areas not under crown cover. Snow cover on tree crowns, and therefore the increased albedo effects of forests in winter, is not taken into account.

Table 1: Albedo data of shortwave radiation for relevant types of ground cover.

Land use type	***Pielke 1990***	***Used in the combined model***
Grassland (long – short)	0.16 – 0.30	0.20
Forest (pine, fir, oak)	0.10 – 0.15	0.10
Snow (dirty - fresh)	0.25 – 0.95	0.50

In the combined model we selected a lower value 0.1 for forest because the area is dominated by pine trees.

Climatic information on cloud cover fractions and cloud properties are provided by the ISCCP [66]. Table 2 depicts an overview of cloud data over a year used as input parameters in the Fu-Liou Model. Two layers of cloud cover with different fractions, optical depth, top and bottom pressures and different phases (ice/water) are considered. We have assumed that in winter clouds are ice dominated and in summer that the lower cloud layer is water.

Table 2: Annual cloud fraction and specific cloud properties of the case study area (in 2008) used as input parameters in the Fu-Liou Model (see Figure 8).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Cloud Fraction [%]												
1st cloud layer (high)	15.00	19.00	20.50	37.00	21.00	7.00	9.00	9.00	10.50	21.50	25.50	34.50
2nd cloud layer (low)	13.00	12.00	20.00	21.50	22.50	20.50	23.50	21.50	18.00	17.50	15.00	8.50
Cloud Optical Depth [gm^{-2}]												
1st cloud layer (high)	7.73	8.44	9.54	10.78	9.38	8.44	8.3	7.46	7.87	9.22	9.71	9.06
2nd cloud layer (low)	8.59	6.94	6.69	7.87	6.82	5.99	5.99	6.11	5.99	7.59	7.87	9.06
Cloud Top Pressure [hPa]												
1st cloud layer (high)	610	600	605	590	585	595	605	595	610	585	585	565
2nd cloud layer (low)	755	750	780	760	770	790	790	795	775	760	745	725
Cloud Bottom Pressure [hPa]												
1st cloud layer (high)	660	650	655	640	635	645	655	645	660	635	635	615
2nd cloud layer (low)	805	800	830	810	820	840	840	845	825	810	795	775
Cloud Phase												
1st cloud layer (high)		ice					ice				ice	
2nd cloud layer (low)		ice					water				ice	

TOA results are generated by the model for each month using the study area's longitude and latitude. To obtain result for each month, each month's average cloud fraction, pressure, height, phase for both layers, its Julian day as of the 15th, and surface albedo data appropriate to the month's ground-cover condition are inserted into the Fu-Liou calculator.

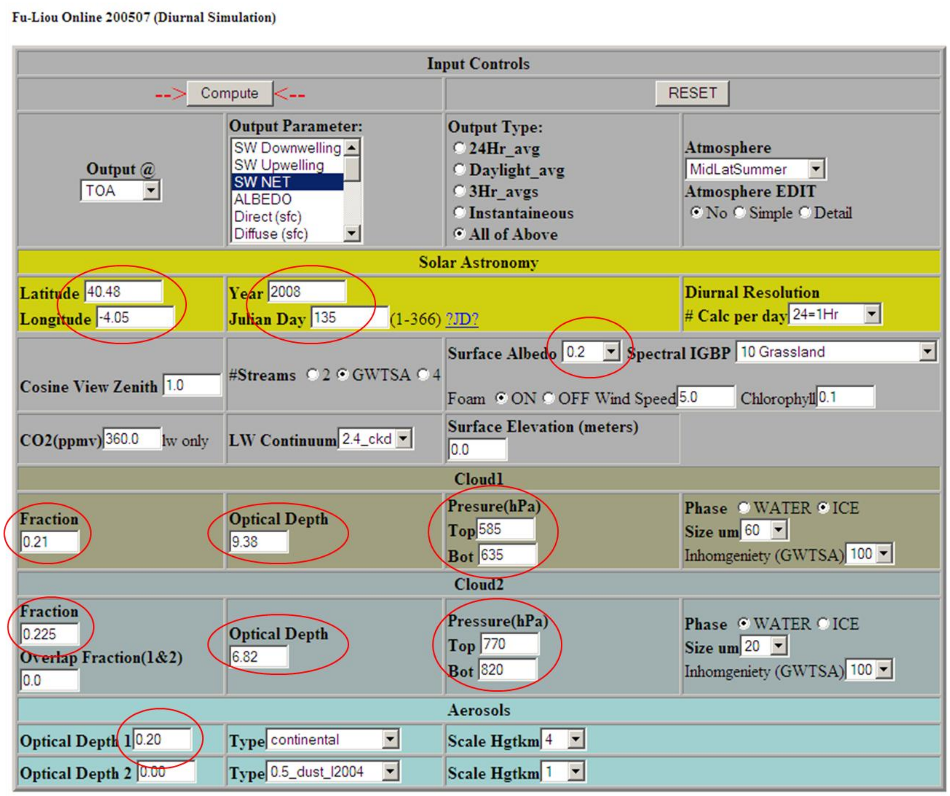

Figure 8: Screenshot of the Fu-Liou model converting surface to top of the atmosphere net short wave (ΔSW) data (here for the example of grassland in May 2008).

As a first approach to consider the influence of an increased cloud droplet number concentration (CDNC) in forest areas accompanied by increasing cloud albedo, the optical depth of the second cloud layer (low) has been raised by 5% in months May to September and discussed in the sensitivity analysis. All other input parameters used by the model are left unchanged.

Conversion of carbon/biomass stocks change to radiative forcing impact and further into CO_2 equivalences

The paper provides an explanation of how carbon and biomass stock changes were converted into radiative forcing units.
The annual change in forcing due to a change in albedo at TOA is estimated from the difference in the upwelling and downgoing shortwave radiation, where the Fu-Liou model estimates the average $\textit{Short wave}_{net}$ over a 24-hour period for a given day. However, reduced radiative forcing is not the unit in which commitments are denominated under the UNFCCC and climate agreements. The climate change mitigation community uses CO_2 equivalence as its indicator and functional unit. Therefore radiative forcing results are also depicted in these units.

5.1.3. Results and discussion

Carbon stock balance

Figure 9 shows the net increase of biomass due to an afforestation/reforestation regime where Scots pine is planted on grassland and harvested on a 90-year rotation cycle with 5 thinning operations per cycle.

The figure illustrates the annual carbon sequestration in aboveground and below-ground biomass that could be achieved by such a project. Biomass in the reference (baseline) case remains constant at 22 t ha^{-1}, whereas additional biomass due to the project ranges between 340 t ha^{-1} and 60 t ha^{-1} over the course of the harvesting and replanting cycle. To simplify modelling, the average carbon stock over the life of the project – shown by the dashed line in Figure 9 – is used (Schlamadinger et al., 2004 [67]). Planting Scots pine results in an average increase of biomass of 170 t ha^{-1} (46.4 t C). This increased biomass is accompanied by a net removal of CO_2 from the atmosphere and therefore has a cooling effect (negative radiative forcing).

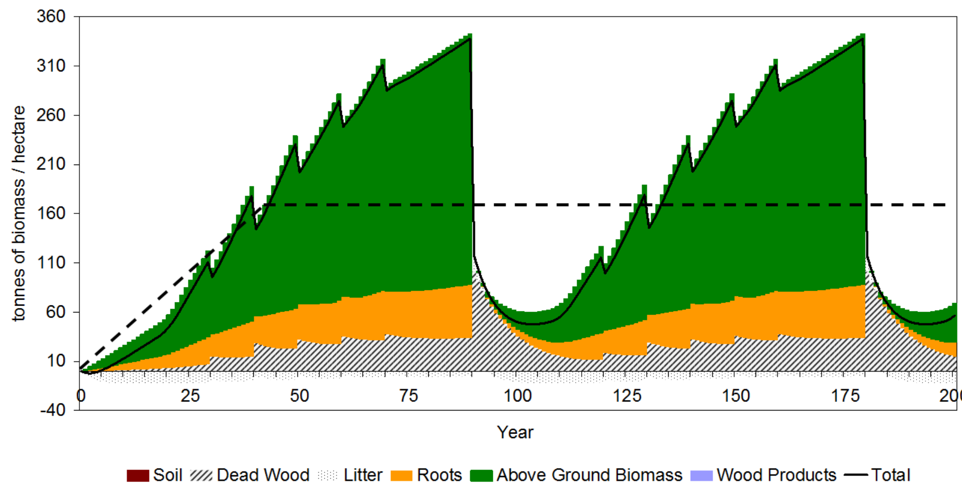

Figure 9: Net balance of biomass increase due to a land use change from grassland to a pine forest in the case study area similar to afforestation/reforestation project (soil pool not considered here).

Most of the increase is in the living biomass pool, followed by root and dead wood biomass with small losses of C in the litter pool. Changes in soil organic matter and wood product pools have not been considered here. Exclusion of these pools results in underestimation of the net biomass accumulated by the project (afforestation).

Albedo effects

By using geographic position, average cloud cover per month and other input parameters the Fu-Liou model calculates the difference in upwelling and downgoing short wave radiation (ΔSW) at TOA (radiative absorption). Figure 10 shows that the grassland ΔSW varies between 78 Wm^{-2} (Dec.) and 366 Wm^{-2} (Jun.), while the ΔSW for the mature forest has a minimum of 101 Wm^{-2} (Dec.) and maximum of 390 Wm^{-2} (Jun.). In our model, the ΔSW for under-mature forests were calculated as a mixture of grassland and mature forest, based on an estimate of the crown cover from the volume of standing stock.

Figure 11 depicts the importance of including the atmosphere when calculating ΔSW at the top of atmosphere instead of calculating it based on surface albedo and incident solar energy.

The atmosphere mutes the difference in short wave radiation absorbed. This is particularly apparent during the winter months where the ratio of grassland to forest ΔSW in January is 0.56 using the surface albedo alone, but 0.73 when atmospheric effects are included. The influence of the atmosphere is less during summer months.

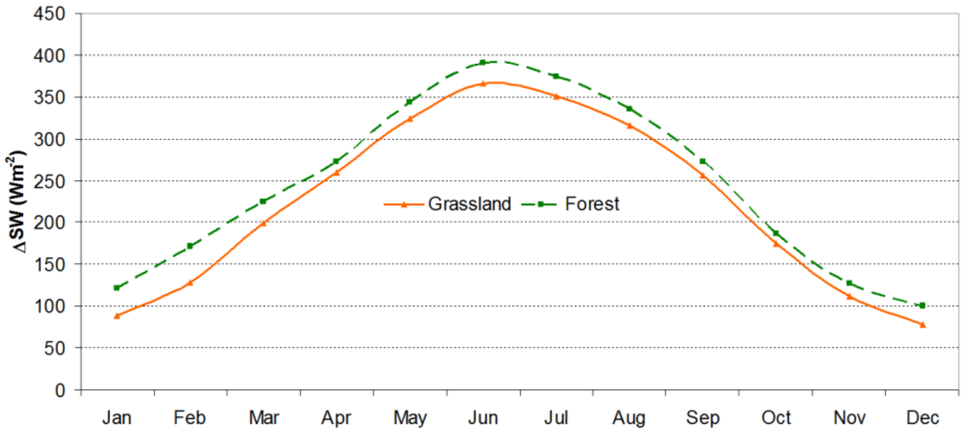

Figure 10: Variation of top of the atmosphere (TOA) ΔSW as an output of the Fu-Liou model in the case study region.

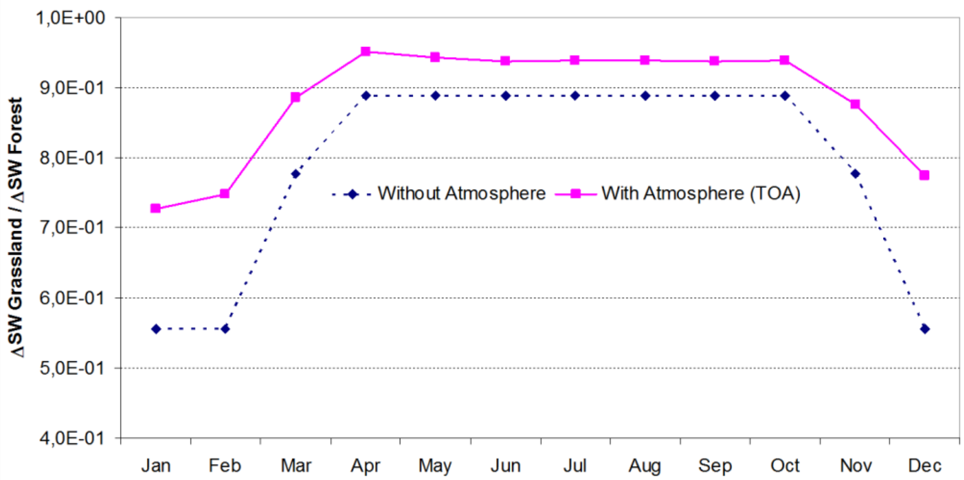

Figure 11: Ratio of grassland to forest ΔSW with and without the atmosphere.

<u>Combining carbon sequestration due to biomass growth and albedo effects</u>

The impacts are estimated in terms of energy increase per hectare of land use change.

Figure *12* (left) shows that the energy change due to biomass growth (negative values = cooling) is counterbalanced by albedo changes (positive values = warming). For the first 25 years after planting there is a net positive forcing. After that, the cooling effect of increased biomass stocks exceeds the warming impact of albedo effects, leading to a net cooling until the first harvest.

Figure *12* (right) shows that the cumulative net impact is one of cooling from year 25 until approximately year 190. The biomass component reaches a cooling maximum of -2.77×10^5 W ha^{-1} just before harvest (year 90) at which time the albedo reaches 1.80

x 10^5 W ha^{-1} with a net cooling of -9.69 x 10^4 W ha^{-1} at that point. During the first rotation period, the total balance remains on the cooling side but after two or more rotation periods, the cooling effects of forest growth are overtaken by the warming effects of the lower albedo. This long-term warming is also driven by the fact that, due to removal of atmospheric CO_2, the forest reduces CO_2 concentrations, thus reducing the rate of atmospheric CO_2 decay.

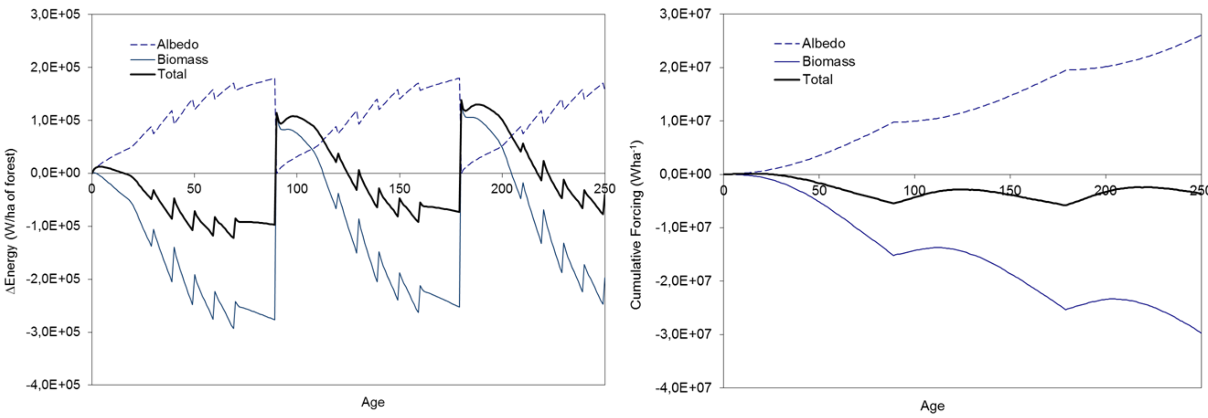

Figure 12: Biomass, albedo and total radiative forcing effects due to Scot pine forest.
Left: Annual impacts over three rotations.
Right: Cumulative impacts over three rotations.

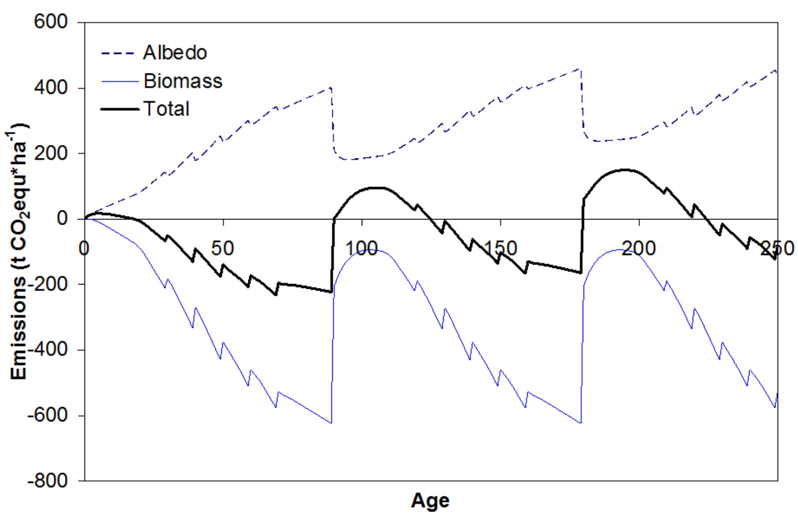

Figure 13: Cumulative net emissions including CO_2 equivalences from albedo change.

In Figure 13 model results have been converted into this commonly used accounting unit of CO_2 equiv. ha^{-1}. Therefore, afforestation in the case study area accumulates up to 624 t CO_2 equiv. ha^{-1}, while the change in albedo due to crown cover is equivalent to emissions of roughly 400 t CO_2 equiv. ha^{-1} by the end of the first rotation period. The net effect varies around a neutral level with a slight cooling in the long term.

Sensitivity analysis

In the basic model run we used a value of surface albedo of 0.2 for grassland and 0.1 for a Scots pine forest, snow cover in winter month November to March, average yield class, crown cover of 80% at maturity level and a rotation length of 90 years for our calculations. We investigated the sensitivity of the radiative forcing impact on climatic by considering winters with and without snow cover and altering growth and canopy closure parameters in the model.

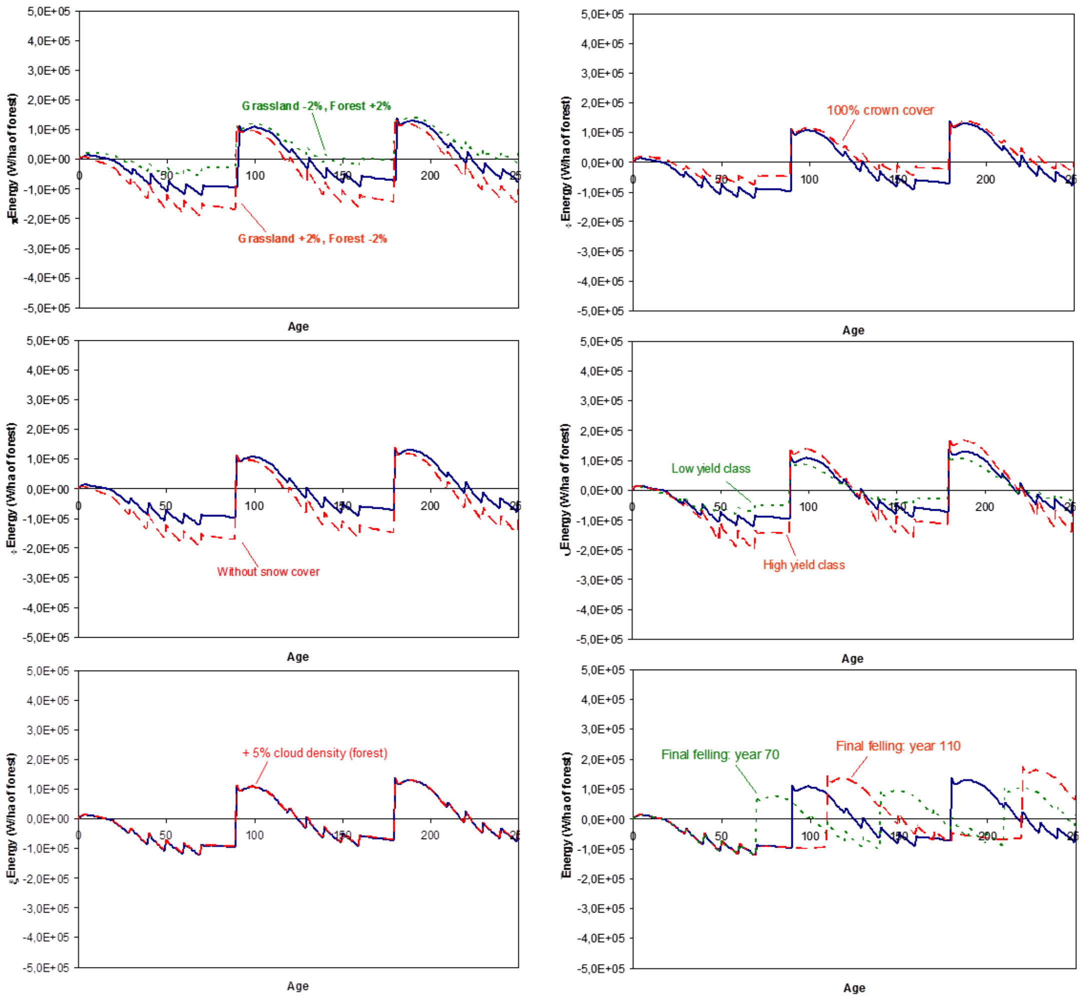

Figure 14a-f: Sensitivity to the variation of surface albedo, forest crown cover, influence of snow cover in winter and forest site qualities.

In addition we investigated variations of TOA, cloud density due to aerosol emissions as well as the rotation length. Figure 14a-f shows the results of sensitivity analysis in six diagrams.

Surface albedo data for different land use options (Sharratt, 1998 [68]) is subject to wide ranges of uncertainties (e.g. albedo of short wave radiation for grassland 0.16 to

0.30 and 0.10 – 0.15 for pine, fir and oak trees (Pielke et al., 1990 [64]). Figure 14a shows the result of using (1) 2% lower surface albedo for grassland and a 2% higher surface albedo for Scot pine and (2) a 2% higher albedo for grasslands and a 2% lower albedo for Scot pine. Use of these values results in significant differences especially in the long run. Case (1) results in considerably more warming whereas case (2) results in considerably more cooling than the base case.

Figure 14b depicts the sensitivity to forest stand canopy closure. The difference between assumptions of 80% (reference) and 100% crown cover at the time of final felling are illustrated. For example low quality sites may have open canopies. We discuss sensitivity to site quality below. Figure 14c displays the sensitivity of model results to snow cover in winter. For the reference case we assumed full snow cover (albedo of 0.5) in December through February and 33% snow cover in November and March, for the sensitivity analysis a "no snow cover" scenario was used.

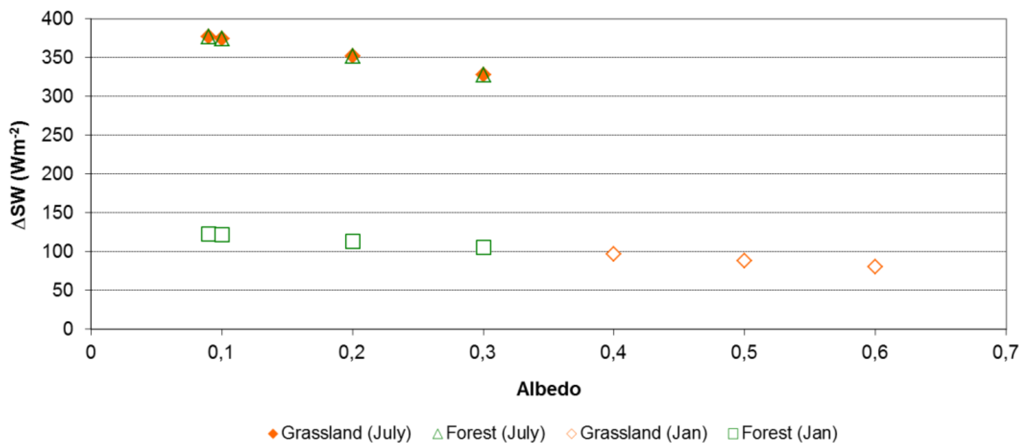

Figure 15: Sensitivity of ΔSW to changes in surface albedo.

Figure 14d shows the impact of use of different growth and yield data. In effect, this sensitivity analysis can be thought of as illustrating differences in site quality. Average yield class data were used in the base calculation, whereas best and worst site class data provided by Rojo et al., 1996 [57] were used for two alternative runs. Here the sensitivity effects on net are similar to altering surface albedo input parameters. Lower site qualities lead to greater warming roughly at the same scale as use of a higher albedo for grasslands and lower albedo for forests. Influences of cloud density increase (+5% optical depth of the second, lower cloud layer) are shown in Figure 14e, with only very small influences on the entire forcing results.

Figure 14f shows the sensitivity of changing the rotation length to 70 and 110 years. In the long run, shorter rotation periods tend to a higher cooling effect.

The sensitivity of the net short wave radiation (ΔSW) to changes in surface albedo for January and July are shown in Figure 15. It shows that a change in surface albedo of +0.1 creates a negative change in ΔSW between 7 and 10%.

5.2. Schwaiger Hannes, Andreas Tuerk, Naomi Pena, Jos Sijm, Antti Arrasto, Claudia Kettner, 2011 [2] (see Annex)

"The future European Emission Trading Scheme and its impacts on biomass use, Biomass and Bioenergy, 2011, Elsevier, Volume 38, pp. 102-107, doi:10.1016/j.biombioe.2011.07.005

5.2.1. Introduction and personal contribution

Contents and networking results for this publication are based on the involvements of JR in the European Commission's DG Research funded project "Overcoming barriers to Bioenergy – NoE-Bioenergy" (No: SES6-CT-2003-502788), where a group of eight leading bioenergy institutes in Europe integrated their R&D activities to improve bioenergy research activities and contribute to a competitive bioenergy market in Europe.[‡ ‡]

The European Energy and Climate Package sets three targets for 2020: a 20% reduction of greenhouse gas (GHG) emissions, a 20% improvement in energy efficiency and a 20% share of renewable energy for gross final energy usage (sub-target of 10% renewable energy in the transportation sector). It also aims to redesign EU-ETS leading to a new EU-ETS directive [71]. The main target of the paper was to show the possible influences of the existing EU-ETS on solid biomass use for power generation in Europe with detailed assessments of possible options to enhance and strengthen biomass use in Europe. It focused also on the question of whether the EU-ETS is an appropriate vehicle for increasing use of solid and liquid biomass.
Again, in the following a short summary of the paper in terms of methods, results and conclusion is given.

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‡ ‡ Within this Network of Excellence I was team leader of two Integrated Actions (IA 4 and 12) on "Environmental bookkeeping" and "Needs and challenges in implementing key Directives – EU Emissions Trading Directive (2003/87/EC)" and also two "Jointly Executed Research (JER) projects" on "The EU-Emissions Trading Scheme and biomass" [69] and "Effects of the RED on the Implementation of Bioenergy in the Partner Countries" [70]. Out of this scientific collaboration the JR team on climate issues decided to take the lead in publishing a paper in the special issue of the journal "Biomass and Bioenergy" edited by Prof. Dr. A.V. Bridgewater (Aston University, UK). In addition another paper has been published in the proceedings of the 16th European Biomass Conference and Exhibition, Valencia, Spain [75].

Again, as first author of the paper I was responsible for most of the technical and editorial input that represents the work of the JER "The EU-Emissions Trading Scheme and biomass" with data contribution from all other partners represented by the co-authors of the paper. Ms. Claudia Kettner contributed with some model runs on short and long run marginal costs of power generation.

5.2.2. Methods

Competitiveness of solid biomass use in substituting fossil fuels in the EU-ETS

A model to analyse the competitiveness of biomass in power generation under the EU-ETS has been developed based on previous studies by the IEA [72], designed to assess the influence of the CO_2 price on the Short Run Marginal Costs (SRMC) and Long Run Marginal Costs (LRMC) of power generation. The SRMC are calculated by taking in account fuel costs and other variable costs (appropriate to assess a fuel switch only), LRMC (appropriate to assess new installations) include SRMC plus variable costs and fixed costs. The model shows at what CO_2 price the use of biomass to replace coal becomes competitive in existing and new plants. For this paper 100 % auctioning of allowances, different thermal efficiencies and costs for medium-sized CHP biomass plants were used. Biomass prices are quite inhomogeneous starting at 2.1 € GJ^{-1} in Finland go up to 10 € GJ^{-1} in central Europe (Schwaiger et al., 2009 [73]).

Inclusion of liquid biofuel use in the EU-ETS versus other options to support biofuels for transportation

Europe's Energy and Climate Package provides that power sector allowances will generally be auctioned starting in 2013, setting in principle a major incentive to invest in low carbon technologies. However, the level of future CO_2 prices cannot be predicted with any confidence. Prices will depend on factors such as economic and emission growth. In the first phase of the EU-ETS the CO_2 price was very volatile (Ellerman and Joskow, 2008 [74]). It was over 30 € t^{-1} for a short time, before collapsing to almost zero due to the over-allocation of emission allowances during this phase.

While volatility of the CO_2 price has been lower in the second phase, volatility and intermittent low prices remain a major hurdle for the effective functioning of the EU-ETS. In the second phase the CO_2 price reached about 25 € t^{-1}, but in 2010 it fell again to 13 € t^{-1} [44]. In the third phase prices went down below 7 € t^{-1}. If, however, the current economic crisis continues to impact industrial and electricity demand, low carbon prices may prevail through 2020.

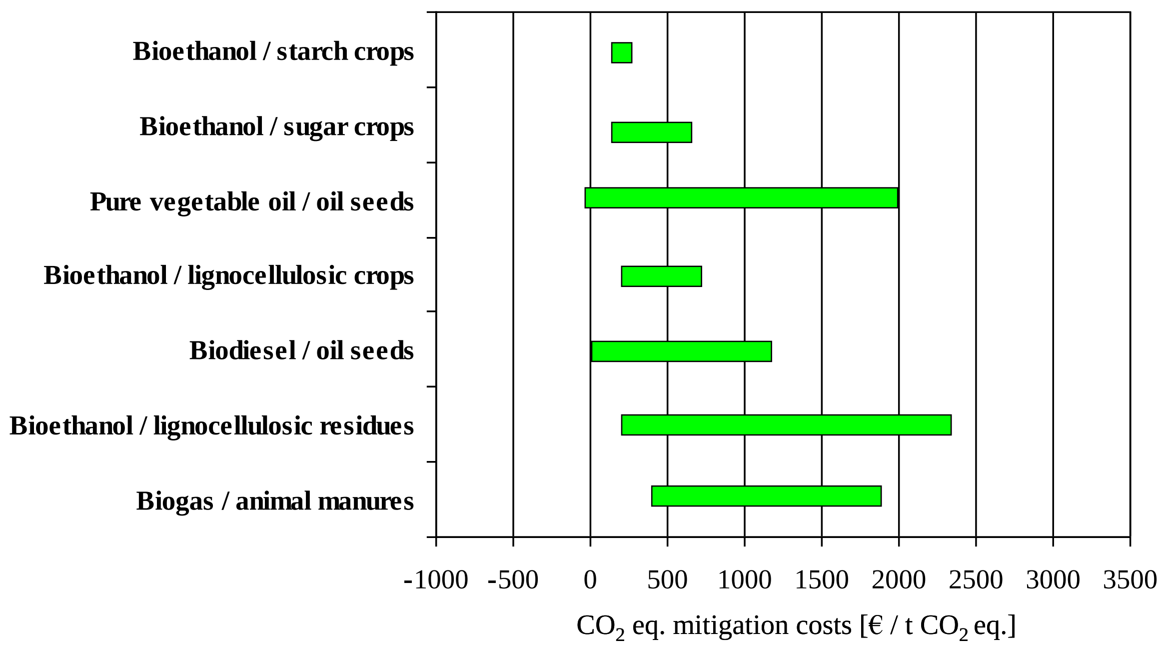

Figure 16: CO_2 eq. mitigation costs (€$_{2002}$ t CO_2 eq.$^{-1}$) – Future Technology (Tuerk et al, 2008 [75]).

The second part of the paper focuses on the issue of the consequences of including transportation fuels under the EU-ETS versus other options to support biofuels through trading schemes. The transportation sector is yet (actually) not included in the EU-ETS. While there is a wide range of options to reduce emissions in the transport sector all of these options have highly varying abatement costs. Some reduction measures have negative or small abatement costs, e.g., increasing the deployment of fuel efficient vehicles (Blom et al., 2007 [76]). However, most biofuel options have costs far above 100 € t^{-1} of CO_2 (see Figure 16).

5.2.3. Results and discussion

Competitiveness of biomass in substituting fossil fuels under different CO_2 prices

In Table 3 assumed fuel costs as well as conversion efficiencies and variable costs are figured out. Figure 17 shows the result of a case study model run for the SRMCs in Austria with 2 biomass prices (high, low) and a coal price of 2 € GJ^{-1}. The solid green line represents low biomass costs of 5.6 € GJ^{-1} (low), the dashed line of 8.3 € GJ^{-1}.

It shows that biomass becomes competitive with coal at a CO_2 price of 7 or 21 € t^{-1}, a price range that was quite common in the EU-ETS in the last two years.

Table 3: Assumed fuel prices, costs and efficiencies for SRMC calculations for different power plants.

		Coal	CCGT	CCGT a	Biomass	Biomass a
Fuel Price at Plant	€/GJ	2	12	6	5.6	8.33
Thermal Efficiency	%	40	55	55	80	80
Fuel Costs	€/MWh	18.0	78.5	39.3	25.0	37.5
Variable Costs	€/MWh	3.3	1.5	1.5	3.0	3.0
SRMC	**€/MWh**	**21.3**	**80.0**	**40.8**	**28.0**	**40.5**

In several European countries biomass prices are lower, therefore lower CO_2 prices will serve to render biomass competitive with coal. In Finland e.g. the biomass price is so low that no CO_2 price at all is necessary to make biomass competitive compared to coal.

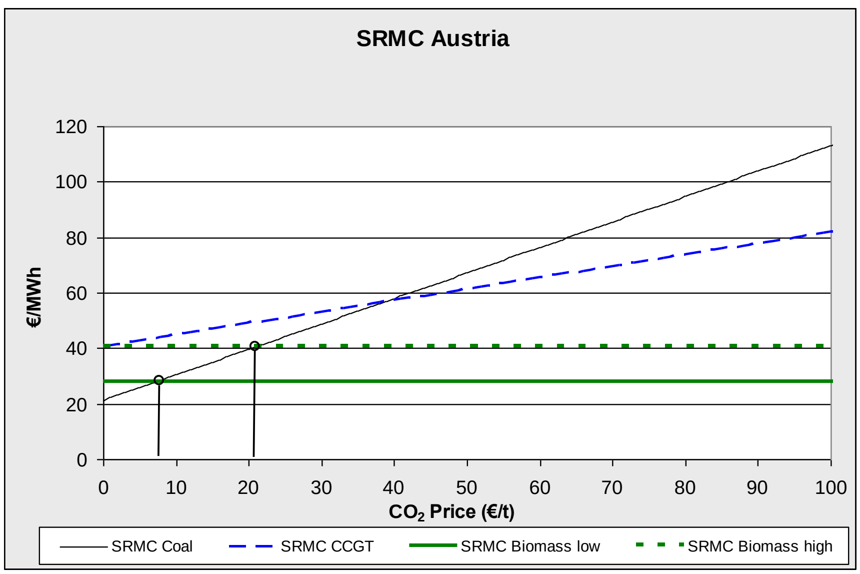

Figure 17: Influence of the CO_2 price on the SRMC of power generation by biomass and fossil fuels in Austria.

As coal has a higher emission intensity than gas, its costs rise more steeply than those of gas-based plants. SRMC for coal will exceed those of gas when CO_2 prices rise to 40 € t^{-1}. Costs for biomass do not rise as no emission allowances are required. Figure 18 illustrates the dependence of LRMC for new coal, gas and biomass plants on the CO_2 price. It shows that new gas plants become competitive to new coal plants at about 24 € t^{-1} CO_2. Biomass plants start becoming competitive with coal plants in a range of 33 to 47 € t^{-1} CO_2, significantly higher than the CO_2 prices observed so far. However, both figures only provide indicative information.

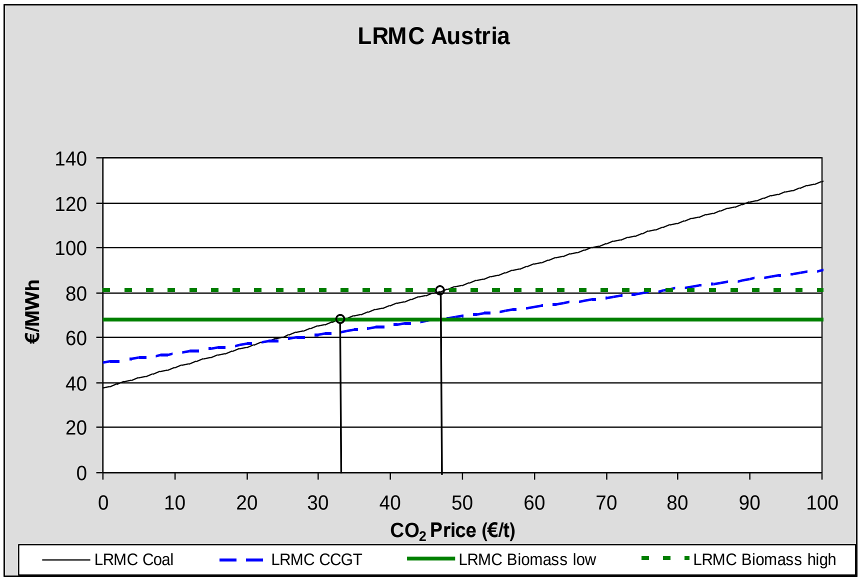

Figure 18: Influence of the CO_2 price on the LRMC of power generation by biomass and fossil fuels in Austria.

Model runs were made for biomass costs typical for other EU countries. Figure 19 depicts the range of CO_2 prices at which new medium sized CHP biomass plants become competitive.

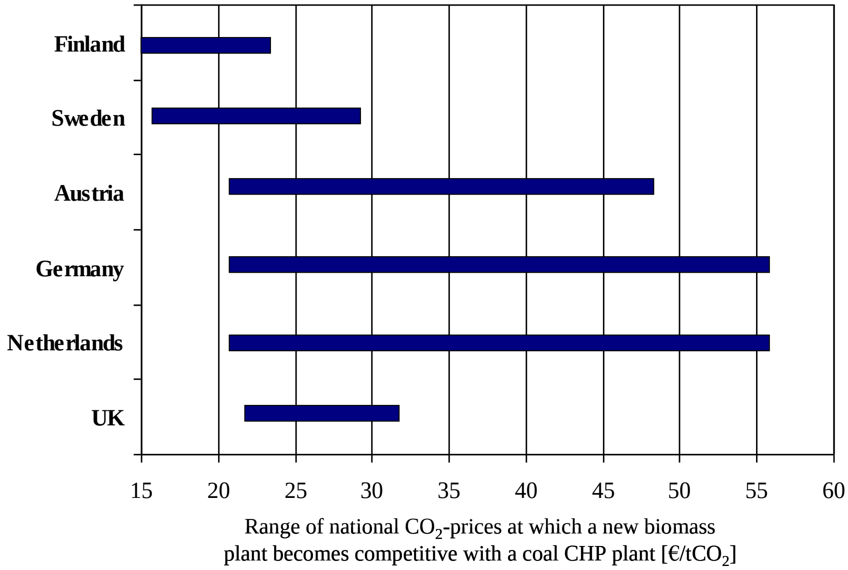

Figure 19: Competitiveness of new biomass plants under full auctioning in the power sector in selected EU countries.

It suggests that EU-ETS's third period may provide an appropriate incentive to establish biomass plants and provides a first indication of the amount of additional incentives to make biomass plants competitive.

<u>Inclusion of liquid biofuel use in the EU-ETS versus other options to support biofuels for transportation</u>

Abatement costs of 100 € t^{-1} are not only high compared to many abatement options in the transportation sector such as efficiency improvements etc., it is also higher than the 20 € t^{-1} to 60 € t^{-1} CO_2 cost range of many measures in the energy and industry sectors. Therefore a simple incorporation of the transport sector into the EU-ETS might lead to higher CO_2 prices in the energy and industry sector:

- <u>Full integration</u>

Full integration of the transport sector into the EU-ETS would increase the cost-effectiveness of the scheme (Blom et al., 2007 [76]). Under full integration, total costs of emission reductions are reduced and the price increase of fuel remains limited.

Figure 20: Most likely development of CO_2 allowance prices in a fully integration of the transport sector into the existing EU-ETS.

However, due to the purchasing power of the transportation sector, it is expected that it would purchase allowances from other ETS sectors to meet a large share of its obligation. This would lead to higher carbon prices under the EU-ETS than the guideline that "least expensive options will be taken first" would suggest. It would also result in little mitigation of transport emissions (Hohne, 2007 [77]). An increase of carbon prices under the EU-ETS would lead to a decrease of European industrial competitiveness and possibly to industry moving outside of the EU.

- <u>Partial integration</u>

Alternatively, the transport sector could be only partially integrated in the EU-ETS. Aviation and rail transport might be included, leaving road transport to another system.

Figure 21: Most likely development of CO_2 allowance prices in a partially integration of the transport sector into the existing EU-ETS.

In this case there would be only a limited impact of the transport sector on EU-ETS carbon prices. The inclusion of aviation into the EU-ETS, as planned from 2012 onwards, is already the first step towards a partial integration.

- <u>Fully separation</u>

Finally, the transportation sector could be subject to an independent cap. However, the political and societal costs of imposing significant emission reduction on the road transport sector are relatively high.

Figure 22: Most likely development of CO_2 allowance prices in a separated transportation system and the existing EU-ETS.

Further, even if the price of emission allowances under a separate transportation cap-and-trade system were higher than in the wider EU-ETS, they would probably not be high enough to support significant use of biofuels.

A separate trading system for road transport which required emission reductions at the same percentage level as in other sectors could drive fuel prices up to politically and socially unacceptable levels (Kampman et al., 2008 [78]). In particular, high fuel prices place a higher relative burden on lower income groups than on higher ones.

6. Conclusions

Economic growth, higher living standards and an increasing population worldwide caused a rising fossil fuel use over the last decades, which contributed to a human induced changing climate and requires further solutions and pioneer measurements in the future energy and land management systems. Bioenergy use – as one possible solution in fighting global change – and its impact on the climate influences thereby the world energy system, fuel markets and political discussions in terms of climate change.

This work focused on possible scientific steps to improve GHG accounting methods and tools in assessing the influences of land cover change on the climate itself and on the other hand to show the feedback and influence of political decisions in the field of energy and climate change on the bioenergy use.

Forest and land use options represent a huge reservoir of carbon und play a significant role in the global carbon cycle. Therefore the terrestrial biosphere should be integrated in climate models in addition to the hydrosphere and atmosphere to predict future developments of our climate. The results have also shown that non-GHG effects could influence the results of carbon accounting tools in assessing GHG balances of land use options significantly and should therefore not be ignored in calculations of climate impacts. The inclusion of albedo effects may neutralize the climate benefits of carbon sequestration due to forest growth. Model results are highly sensitive to both surface and TOA albedo data as well as forest growth data (site quality), whereas variations of crown and snow cover, cloud density and rotation length are of lower significance to the radiative forcing results of land use change.

Albedo impacts should, in particular, be also included in life-cycle assessments (LCA) of biofuels and bioenergy if biomass feedstocks are derived from afforestation projects or from land that has been grown biomass for energy (see also Muñoz et al., 2010 [79], Bright et al., 2012 [80]). Afforestation/reforestation measures cannot simply be viewed as a positive activity to mitigate climate change because in some cases most of the positive impact of carbon sequestered via photosynthetic CO_2 fixation of forest growth is neutralized by the warming effect of albedo changes. Scientific papers derived from Lohila et al., 2010 [81], Bernier et al., 2011 [82], Kirschbaum et al., 2011 [83], O’Halloran et al., 2011 [84] concluded similarly.

On the other hand deforestation (see again Bala et al., 2007 [26]) or regime changes within the agricultural sector should also include this effect possibly leading even to improvements of such land use change activities. Loarie et al., 2011 [85] for example found out that expanding sugar cane into existing crop and pasture land has a direct local cooling effect that reinforces the indirect climate benefits of this land use option.

The climate policy instrument of the existing EU-ETS plays an important role regarding investment decisions towards low carbon technologies such as biomass, even if the current design of the scheme shows many shortcomings regarding the incentives to invest in low emitting technologies. Model results showed that already at a moderate CO_2 price (between 0 and 21 €) biomass becomes the most competitive fuel in the short term (SRMC). Regarding the construction of new biomass plants the EU-ETS can play an important role if the EU-ETS sets the right incentives. Even when CO_2 prices are still low, the prices may increase due to stricter allocation roles of allowances in the 3rd trading period. However, due to market uncertainties policymakers should implement additional instruments to stimulate the construction of new biomass plants like the use of subsidies, feed-in tariffs or tax relieves.

For the road transport sector the key question with respect to a GHG emissions trading scheme is whether the sector should be included directly in the existing EU-ETS or whether a separate, parallel scheme should be developed. It is a fact that abatement costs for liquid biofuels are in many cases significantly higher than many options in the energy and industry sectors. Therefore liquid biofuels specifically would neither benefit from an integration of the transportation sector in the EU-ETS nor from a separate cap-and-trade scheme for the transportation sector unless the carbon price is very (prohibitively) high.

Considering a wide range of aspects and issues it becomes obvious that

i) the incorporation of effects outside the "GHG only" accounting methods and

ii) attempts to strengthen bioenergy use via negotiating additional political instruments are necessary.

7. Outlook

The use of biomass for energy with special respect to liquid biofuel production is currently worldwide discussed and questioned due to possible negative effects on the climate. These effects are caused by direct and indirect land use change and combined carbon losses. The European RED provides specific calculation methods to make sure that the production of liquid biofuels is sustainable and does improve the GHG emission balances when substitution fossil fuels in the transportation sector. The carbon footprint of biofuels is usually investigated by carrying out LCA's including all related land use activities of direct and indirect land use change via full carbon accounting. Results have shown that assessing the carbon footprint of liquid biofuels needs an additional consideration of other non-GHG effects like albedo.

Within the investigation of these non-GHG effects, one approach of further research would be the use of measured albedo data from time series of remote sensing observations rather than data drawn from literature. Satellite based estimates of surface albedo will include a range of known effects of land use change such as canopy closure, aerosols from coniferous forests, dust from crop lands, and effects of topography. Lyons et al., 2008 [86] concluded that albedo effects as seen from MODIS differ from assumed surface observations substantially. However, example data on black (directional-hemispherical reflectance) and white sky albedo (bi-hemispherical reflectance) could be derived from Moderate-Resolution Imaging Spectroradiometer (MODIS) on the National Aeronautics and Space Administration (NASA) such as the MOD43B3 (Schaaf et al., 2002 [87]). Another data source of land cover albedo could be provided by EUMETSAT [88] or beginning in 2013 by ESA's Sentinel satellite family within the GMES programme [89].

In addition, these products could then be linked to land cover data provided by e.g. CORINE (see EEA, 2006 [90]). Another improvement could take place by using different carbon accounting tools where carbon accounting data derived from forest growth data from existing inventories, simulations of patch model approaches (e.g. PICUS v.2.0, [91]), global vegetation models (e.g. ORCHIDEE [92]) or with additional remote sensing measurements. On the other hand, activities within the programme of the Coupled Model Intercomparison Project Phase 5 (CMIP5) investigate the impacts of land cover change on climate for different RCP scenarios (LUCID-CMIP5 [93], Brovkin et al., 2012 [94]). Further scientific research will provide additional significant recommendations on mitigation options in the land use sector fighting climate change.

Not only LCA results including dLUC and iLUC will improve from adding albedo change calculations, also future agreements on REDD+ should consider the implementation of such albedo effects when parties contribute to mitigation actions in the forest sector.

Future research with respect to the existing EU-ETS and policy options to make biomass more competitive would include general emission allocation methods, the design of existing NAPs and options for the use of revenues from auctioning. The designed tool was applied for the analysis of the competitiveness of country specific biomass use including a variation of EU-ETS' allocation methods, CO_2 price, electricity/biomass costs, plant efficiencies and national support instruments.

In addition, the interaction of the EU-ETS with other national and European climate policy instruments should be investigated to optimize the interplay of different climate policy instruments regarding biomass (see also Kautto, 2011 [95]).

Regarding the biofuels sector further assessment in terms of designing a combined or separate trading scheme should be addressed. Here different options for trading entities in a transport ETS (upstream, midstream or downstream) including the question who participates in the scheme (refineries, fuel importers, car manufactures or car owners) might be focused on. Further questions on how the allowances will be allocated (i.e. for free, auctioning or a mix of allocation methods) should also be included.

In future, our mankind faces the challenge of combining a worldwide increase of population to the accompanying rise of energy, food and water supply. Fighting global change is a kind of reaction to the expectations that we will see changing conditions in fulfilling those demands. In future, the integration of non-GHG effects in climate change negotiations and agreements seem to be necessary. However, we are far away from a certain answer to which extend theses additional effects influence our climate. A better way beyond the current system of assessing our influence on the climate might be a change of accounting rules and units from carbon and related CO_2 equiv. to energy balances and e.g. GJ accountings. This would automatically combine the consideration of atmosphere, hydrosphere, biosphere and geosphere in modelling our climate and maybe also help in further connecting our economy, political and scientific sectors.

At the moment and facing the increasing financial problems of the world's economy it seems to be obvious that countries not reaching their GHG reduction targets under the KP will see no financial punishments at all. There is reason for concern that for future commitment periods signatory countries will either not ratify or will make sure to have opportunities like shifting reduction requirements into next periods or simply to step out of the convention. The example of Canada, that stepped out of the KP right after COP17, showed that whenever opportunities for relieves to fulfill reduction targets like legal loopholes, timing, generalizing of targets etc. are missing, parties will show low interest in continuing the UNFCCC processes. The consequences of further negotiations with respect to the scientific work of the two papers should support the deeper incorporation of the terrestrial hemisphere into a future climate agreement and including biomass mitigation options in future project based mechanisms. The inclusion of emissions trading or non-GHG effects will make terrestrial GHG balances and methods even more complicate. However, ignoring these factors seems to be even worse and may not depict the entire impacts on our climate.

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Annex

- **Schwaiger H., D. N. Bird, 2010**

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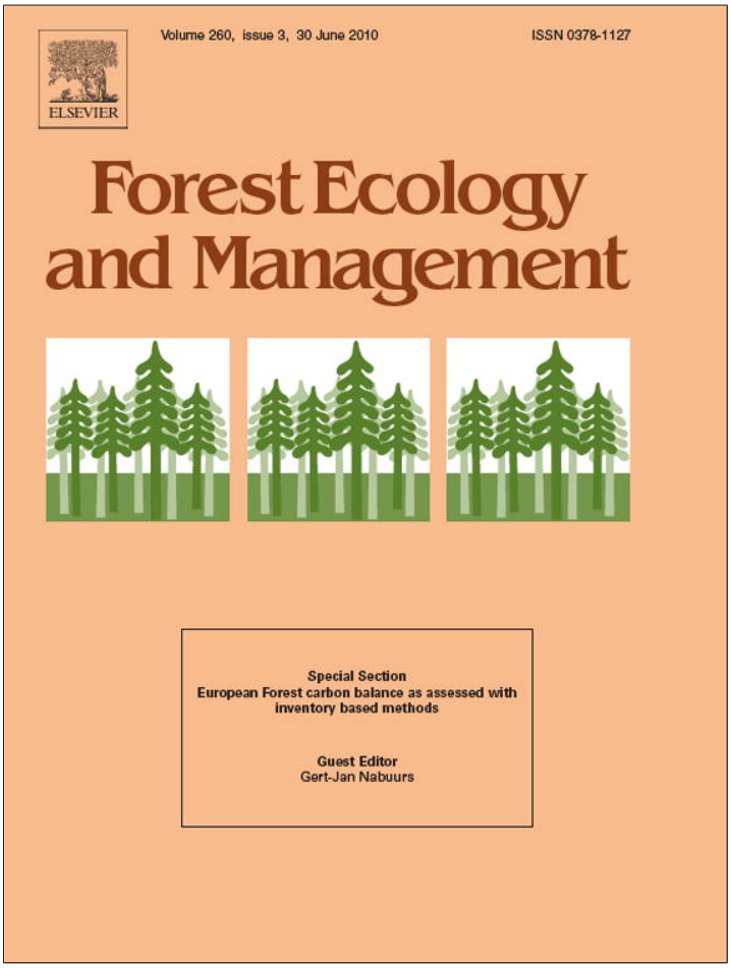
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Integration of albedo effects caused by land use change into the climate balance: Should we still account in greenhouse gas units?

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ABSTRACT

Due to impacts of albedo on climate change, benefits of afforestation/reforestation regimes are under debate. In this paper we investigate how to incorporate albedo changes in a carbon accounting tool to show the net effect of land use change on the climate. Using a study area in southern Europe, albedo and carbon sequestration modelling results are linked to determine the combined radiative forcing balance. The results show that under specific circumstances afforestation/reforestation measures may not automatically have positive impacts in a global warming context because the cooling effect of most of the carbon sequestered is neutralized by the warming effect of albedo changes. However, sensitivity analyses lead to the conclusion that improved albedo data from satellite images (MODIS) could influence and enhance outputs significantly. The paper points out that accounting based exclusively on GHG units does not, in the case of land use change, reflect the entire picture. It is highly recommended that in future global warming impacts of land use systems and biogenic products (e.g. solid biomass, liquid biofuels) should be studied using life cycle assessments (LCA) and should include these additional—non-GHG effects—on climate change.

1. Introduction

Vegetation withdraws carbon dioxide from the atmosphere through the process of photosynthetic assimilation. Over a certain period of time plant growth coupled with the production of biomass accumulates and stores carbon in living vegetation, dead organic matter, and soil. The ability to remove carbon dioxide from the atmosphere and store the carbon in biomass provides climate-mitigation benefits. For this reason, there has been interest in converting non-forest lands into both short and long rotation forests using afforestation or reforestation for bioenergy use and timber production.

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. For example, Betts (2000) found that the change in surface albedo due to planting coniferous forests in areas with snow cover can contribute significantly to radiative forcing. Brovkin et al. (1999) found that cooling due to albedo change from deforestation was of the same order of magnitude as increased radiative forcing from CO_2 and solar irradiation. Bala et al. (2007) found that a global-scale deforestation event could have a net cooling influence on the Earth's climate and Jackson et al. (2008) concluded that ignoring biophysical interactions could result in millions of dollars being invested in some mitigation projects that provide little climate benefit or, worse, are counter-productive.

Boreal forest areas are often covered by fog and clouds particularly in winter. Therefore it seems to be obvious that a "negative" albedo effect due to changing from e.g. grassland covered with snow to dark coniferous forest is substantially reduced due to the presence of clouds, thus lowering the contribution of albedo changes accompanying land use changes to overall global warming impact. However, in areas with less frequent cloud cover, land use change from grassland characterized by light color conditions (snow or bright sandy grassland) to forest causes warming effects due to albedo change might be sufficient to cancel cooling effects of carbon sequestration.

Another topic that has to be discussed here is the influence of evapotranspiration and aerosols. Evapotranspiration (ET) is given as the sum of evaporation and plant transpiration from land to the atmosphere and accounts for the movement of water to the air from sources such as the soil, canopy interception, and water bodies (evaporation) plus the water within a plant and the subsequent loss of water as vapor through stomata in its leaves

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(transpiration). In comparison to land cover with low surface roughness and leaf area index like grasslands forests are seen to have a higher evapotranspiration rate over the year. It is assumed here that the latent energy included in the vapoured water releases this energy back to atmosphere on its condensing level and therefore seen as neutral. (Betts et al., 2007; Sampaio et al., 2007) figured out that evapotranspiration on the other hand promotes low-level cloud cover increasing top-of-atmosphere (TOA) albedo. Spracklen et al. (2008) found out that due to emissions of biogenic volatile organic compounds forming secondary organic aerosols (SOA) forests influence their TOA albedo itself. SOA particles act as effective cloud condensation nuclei (CCN) in summer and higher concentrations lead to an increase of cloud droplet number concentrations (CDNC) accompanied by increasing albedo and life time of clouds. For boreal forests this influence has been calculated as 3–8% increase in cloud albedo.

The purpose of this paper is to describe a new methodology developed at JOANNEUM RESEARCH Forschungsgesellschaft mbH. This methodology combines radiative forcing effects due to albedo changes with those due to carbon stock changes over time. The methodology has been applied to changes in land-use from grasslands to forest for a case study area in Spain.

An albedo accounting model was first used to calculate top of the atmosphere albedo effects caused by an assumed land use change. In a second step, the carbon stock change balance was incorporated. Different equations were used to convert GHG-balance results into radiative forcing units to depict the entire effect on the climate. Finally the influence of short- and long-term cumulative climate change effects was considered.

2. Method

A carbon accounting tool has been combined with a model that calculates top of the atmosphere (TOA) albedo (based on surface albedo data) under different land use options in a case study area. Carbon accounting results given in GHG emission units (CO_2 eq.) and albedo results, defined as the ratio of a surface's incoming to outgoing diffuse reflectivity (unitless), have been converted to radiative forcing in watts per square meter (Wm^{-2}). The model has been applied to an area in central Spain with grassland converted to a pine forest.

2.1. Case study area

Changes of albedo and accompanying positive or negative effects on radiative forcing are usually seen in cases of pronounced changes in surface colour. In general, the major trends observed with surface albedo are that (i) albedo increases with snow cover, which is more reflective than foliage or soil, and that (ii) forests, especially coniferous ones, have lower albedo than grass or croplands, due to denser, darker canopies that absorb more of the incident radiation (Robinson and Kukla, 1985; Sharratt, 1998). Therefore seasonal albedo changes occur in areas with snow cover in winter and dark surfaces in summer, such as in northern or alpine countries. As a corollary to this observation, the aim of this work is to model the net cumulative warming/cooling profile (including both sequestration and forcing due to albedo change) of land surface changes in areas having infrequent, sparse cloud cover in Europe. The model was applied to areas of grasslands and dark forests such as Scots pine.

We applied the model in a mountainous region characterized by clear skies and snow cover in winter. As shown in Fig. 1, the "Sierra de Guadarrama" region in central Spain was chosen for the calculations. The Sierra forms the eastern half of the Sistema Central (a mountain range in the centre of the Iberian Peninsula), and is located between the Sierra de Gredos in the province of Ávila, and Sierra de Ayllón in the province of Guadalajara. The range runs southwest–northeast, extending into the province of Madrid to the south, and towards the provinces of Ávila and Segovia to the north. The chain as a whole measures approximately 80 km in length, with its highest peak, Peñalara, reaching 2,428 m above sea level (7,965 ft) Wikipedia, 2009 [http://en.wikipedia.org/wiki/Sierra_de_guadarrama]. The vegetation of the mountain range is characterized by an abundance of pine forests and copses of oak and Holm oak in its lower slopes, while the montane grasslands and pastures around the summits are fringed by juniper and Spanish broom shrubs. Precipitation data in the form of average values per month over a year where taken from the IWMI Online Climate Summary Service Portal (International Water Management Institute, 2009).

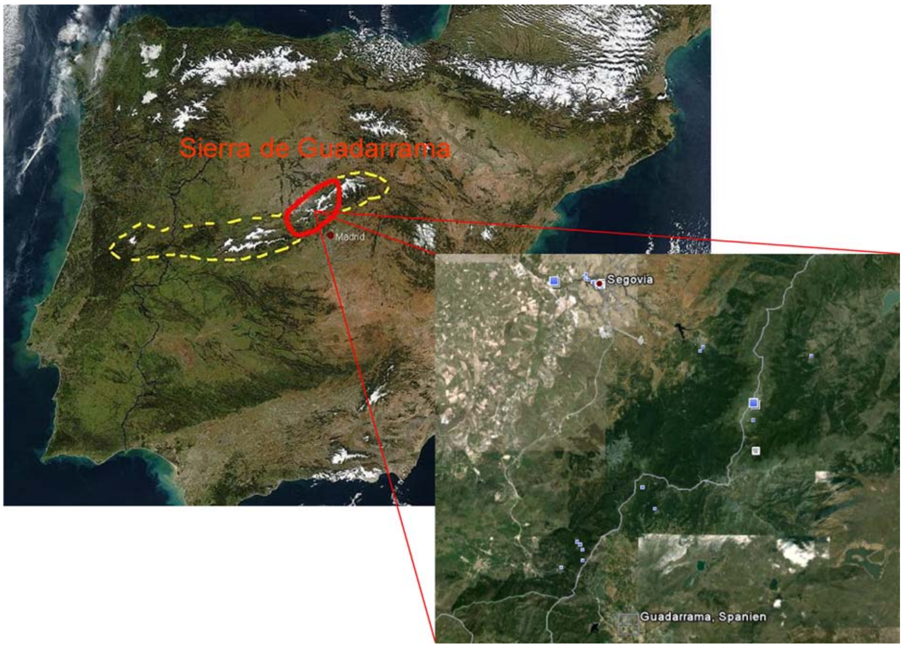


Fig. 1. The case study area "Sierra Guadarrama" in central Spain from space (source Google Earth, Wikipedia; 40.48 N, 4.05 W) covered by alternating grasslands and coniferous forests. Red area: Sierra de Guadaramma, yellow area: Sistema Central.

2.2. Carbon stock change balance

To model the changes in carbon stocks over time we used the stand-level carbon model GORCAM (Schlamadinger and Marland, 1996). GORCAM tracks the flow of carbon from living above and belowground biomass to the dead wood, litter and soil pools. The model uses data from local growth curves and yield tables to drive living, above-ground biomass while below-ground, living biomass is a function of above ground biomass and annual litter is a fraction of the living biomass. Yield tables were converted to carbon assuming biomass expansion factors from the Intergovernmental Panel of Climate Change Guidelines for National Greenhouse Gas Inventories (IPCC, 2006). Model input data required are taken from the Intergovernmental Panel of Climate Change Good Practice Guidance for Land Use, Land-Use Change and Forestry (IPCC GPG) (IPCC, 2003) and local yield tables for average site quality (Rojo and Montero, 1996). Decomposition rates of litter are calculated using a separate tool that uses material quality, average temperature, and precipitation data (International Water Management Institute, 2009; Moore et al., 1999a, 1999b). Litter biomass decays exponentially, with decay rates based on temperature, rainfall and material (Moore et al., 1999a, 1999b). Some of the decaying material enters the soil pool, which also decays exponentially as heterotrophic respiration over time.

2.3. Albedo effects

Albedo is a very complex function of surface and radiation characteristics. Surface characteristics include land cover type and colour, specifics of the vegetation, snow condition and soil moisture. Radiation characteristics include incident angle and wavelength (Henderson-Sellers and Wilson, 1983; Ni and Woodcock, 1999). Average values used in the model are taken from measurements published in a number of journals summarized by Pielke and Avissar (1990) (see Table 1).

Table 1
Albedo data of shortwave radiation for relevant types of ground cover.

Land use type	Pielke and Avissar (1990)	Used in the combined model
Grassland (long–short)	0.16–0.30	0.20
Forest (pine, fir, oak)	0.10–0.15	0.10
Snow (dirty–fresh)	0.25–0.95	0.50

In the combined model we selected a lower value 0.1 for forest because the area is dominated by pine trees.

An albedo of 1.0 means full reflection of the incoming sunlight; an albedo of 0.0 indicates full absorption. The climate forcing effect of surface albedo is modified by clouds, dust, and ice particles which reflect and scatter both incoming solar radiation and energy reflected by the earth's surface. As a result, changes in surface albedo is somewhat muted by atmospheric conditions. Using surface albedo as a base, the top of the atmosphere (TOA) difference in up- and down welling short wave radiation was calculated using the Fu-Liou Radiative Transfer Model (Fu-Liou, 2005; see Fig. 2). Snow cover in winter is incorporated into the model using the assumption that there is 100% snow cover between December and February and 33% snow cover in March and November. A linear increase of crown cover up to an assumed maximum of 80% at the final felling age is used for new plantings with grassland assumed to cover areas not under crown cover. Snow cover on tree crowns, and therefore the increased albedo effects of forests in winter, is not taken into account.

Climatic information on cloud cover fractions and cloud properties are provided by the ISCCP International Satellite Cloud Climatology Project (ISCCP, in press). Table 2 depicts an overview of cloud data over a year provided by the ISCCP und used as input

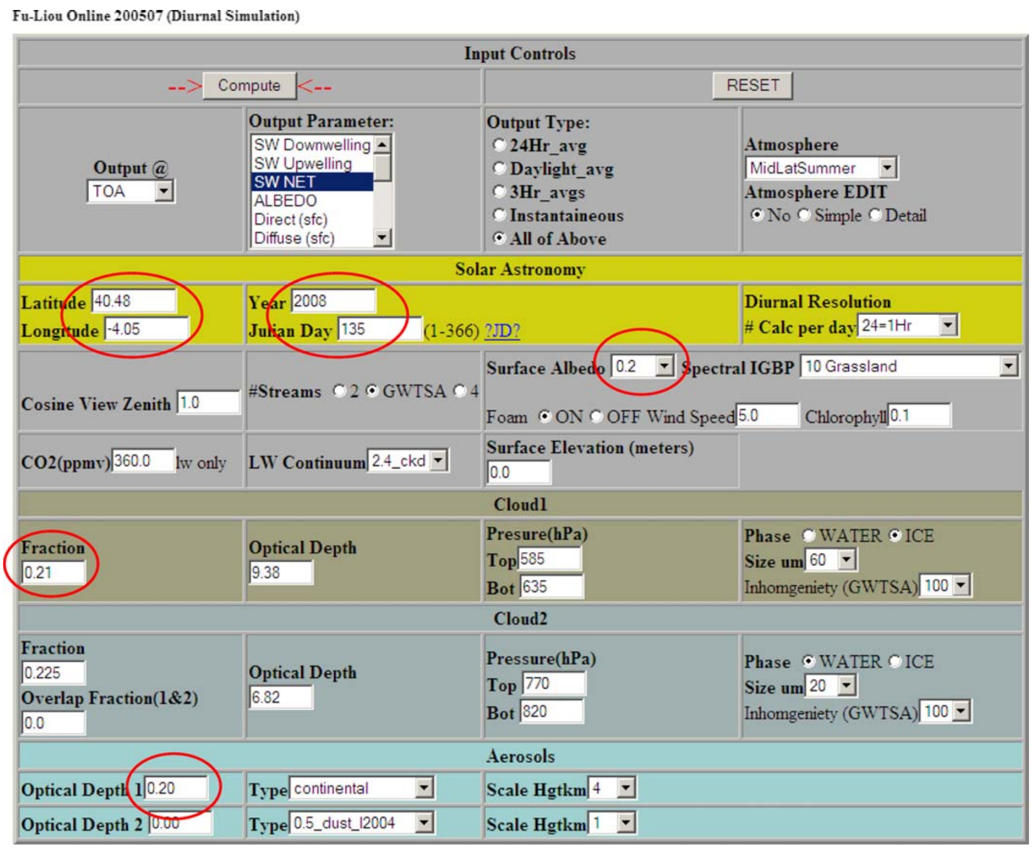


Fig. 2. Screenshot of the Fu-Liou model converting surface to top of the atmosphere net short wave (ΔSW) data (here for the example of grassland in May 2008).

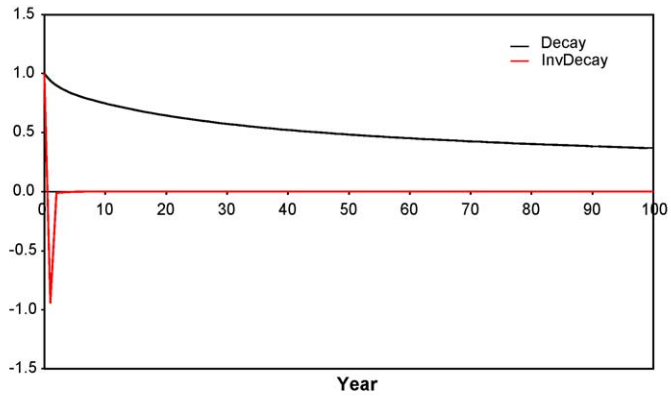


Fig. 3. The CO_2 decay and inverse operators.

parameters in the Fu-Liou Model. Two layers of cloud cover with different fractions, optical depth, top and bottom pressures and phases (ice/water) are considered. We have assumed that in winter the clouds are ice dominated and in summer that the lower cloud layer is water.

TOA results are generated by the model for each month using the study area's longitude and latitude. To obtain result for each month, each month's average cloud fraction, pressure, height, phase for both layers, its Julian day as of the 15th, and surface albedo data appropriate to the month's ground-cover condition are inserted into the Fu-Liou calculator. As a first approach to consider the influence of an increased cloud droplet number concentration (CDNC) in forest areas accompanied by increasing cloud albedo, the optical depth of the second cloud layer (low) has been raised by 5% in months May to September and discussed in the sensitivity analysis. All other input parameters used by the model are left unchanged.

2.4. Conversion of carbon/biomass stocks change to radiative forcing impact

This section provides an explanation of how carbon and biomass stock changes were converted into radiative forcing units. The Third Assessment Report has the following simplified expression for change in radiative forcing:

$$\Delta F^{\mathrm{Ann}}_{\mathrm{CO_2}}\,[\mathrm{Wm^{-2}}] = 5.35\ln\left(\frac{\mathrm{CO_2}\,[\mathrm{ppmv}]}{\mathrm{CO_{2,unperturbed}}\,[\mathrm{ppmv}]}\right) \tag{1}$$

Where, A = 5.35 and CO_2 is the atmospheric CO_2 concentration in ppm and $CO_{2,\mathrm{unperturbed}}$, the unperturbed concentration (in 2005, 379 ppmv). If we assume that CO_2 is a small perturbation to $CO_{2,\mathrm{unperturbed}}$ then

$$\Delta F^{\mathrm{Ann}}_{\mathrm{CO_2}}\,[\mathrm{Wm^{-2}}] = 5.35\ln\left(\frac{\mathrm{CO_{2,unperturbed}}\,[\mathrm{ppmv}] + \Delta\mathrm{CO_2}\,[\mathrm{ppmv}]}{\mathrm{CO_{2,unperturbed}}\,[\mathrm{ppmv}]}\right) \tag{2}$$

And, using a first order approximation to the ln (1 + x)

$$\Delta F^{\mathrm{Ann}}_{\mathrm{CO_2}}\,[\mathrm{Wm^{-2}}] \approx 5.35\left(\frac{\Delta\mathrm{CO_2}\,[\mathrm{ppmv}]}{\mathrm{CO_{2,unperturbed}}\,[\mathrm{ppmv}]}\right) \tag{3}$$

$$\Delta\mathrm{CO_2}\,[\mathrm{ppmv}] = \frac{\Delta\mathrm{CO_2}\,[\mathrm{g}]}{M_{\mathrm{CO_2}}\,[\mathrm{gmole^{-1}}]}\left(\frac{M_{\mathrm{air}}\,[\mathrm{gmole^{-1}}]}{m_{\mathrm{air}}\,[\mathrm{g}]}\right)*1.0\times10^{6}\,[\mathrm{ppmv}] \tag{4}$$

Because the volume of a mole of gas is independent of the gas constitution. M_{CO2} = molecular mass of carbon (44.0095 g/mol), M_{air} = molecular mass of dry air (28.95 g/mol), m_{air} = mass of the atmosphere (5.148×10^{15} Mg) and ΔCO_2 = the change in CO_2 (in grams) as a result of the afforestation/reforestation regime.

Combining equations:

$$F^{\mathrm{Ann}}_{\mathrm{CO_2}}\,[\mathrm{Wm^{-2}}] \approx 5.35\,\frac{1.0\times10^{6}\,[\mathrm{ppmv}]\,\Delta\mathrm{CO_2}\,[\mathrm{g}]\,M_{\mathrm{air}}\,[\mathrm{gmole^{-1}}]}{\mathrm{CO_{2,unperturbed}}\,[\mathrm{ppmv}]\,M_{\mathrm{CO_2}}\,[\mathrm{gmole^{-1}}]\,1.0\times10^{6}\,[\mathrm{g/Mg}]\,m_{\mathrm{air}}\,[\mathrm{Mg}]} \tag{5}$$

Betts (Betts, 2000) does not include the decay of CO_2 in his paper, but instead assumes that half the CO_2 remains airborne over forest growth time scales. The decay of CO_2 is given by:

$$\Delta\,p\mathrm{CO_2}(y) = \Delta\,p\mathrm{CO_{2,init}}\left(a_0 + \sum_{i=1}^{3} a_i e^{-y/\tau_i}\right) \tag{6}$$

Where $\Delta pCO_{2,\mathrm{init}}$ = the initial perturbation of atmospheric CO_2 content and a_i and τ_i are decay constants (see Forster et al., 2007, page 213).

Including this term and assuming making a small scale approximation to ln (1 + x),

$$F^{\mathrm{Ann}}_{\mathrm{CO_2}}(y)\,[\mathrm{Wm^{-2}}] \approx 5.35\left(\frac{1.0\times10^{6}\,[\mathrm{ppmv}]\,\Delta\mathrm{CO_2}\,[\mathrm{g}]\,M_{\mathrm{air}}\,[\mathrm{gmole^{-1}}]}{\mathrm{CO_{2,unpeturbed}}\,[\mathrm{ppmv}]\,M_{\mathrm{CO_2}}\,[\mathrm{gmole^{-1}}]\,1.0\times10^{6}\,m_{\mathrm{air}}\,[\mathrm{Mg}]}\right) \times \left(a_0 + \sum_{i=1}^{3} a_i e^{-y/\tau_i}\right) \tag{7}$$

Table 2
Annual cloud fraction and specific cloud properties of the case study area (2008) used as input parameters in the Fu-Liou Model (see Fig. 3).

	January	February	March	April	May	June	July	August	September	October	November	December
Cloud fraction [%]												
1st cloud layer (high)	15.00	19.00	20.50	37.00	21.00	7.00	9.00	9.00	10.50	21.50	25.50	34.50
2nd cloud layer (low)	13.00	12.00	20.00	21.50	22.50	20.50	23.50	21.50	18.00	17.50	15.00	8.50
Cloud optical depth [gm^{-2}]												
1st cloud layer (high)	7.73	8.44	9.54	10.78	9.38	8.44	8.3	7.46	7.87	9.22	9.71	9.06
2nd cloud layer (low)	8.59	6.94	6.69	7.87	6.82	5.99	5.99	6.11	5.99	7.59	7.87	9.06
Cloud top pressure [hPa]												
1st cloud layer (high)	610	600	605	590	585	595	605	595	610	585	585	565
2nd cloud layer (low)	755	750	780	760	770	790	790	795	775	760	745	725
Cloud bottom pressure [hPa]												
1st cloud layer (high)	660	650	655	640	635	645	655	645	660	635	635	615
2nd cloud layer (low)	805	800	830	810	820	840	840	845	825	810	795	775
Cloud phase												
1st cloud layer (high)	ice	ice	ice									
2nd cloud layer (low)	ice	water	ice									

And for a project that removes CO_2 annually:

$$F^{Ann}_{CO_2}(y)\,[Wm^{-2}] \approx 5.35\left(\frac{1.0\times10^6[ppmv]\,\Delta CO_2(y)[g]M_{air}[gmole^{-1}]}{CO_{2,unperturbed}[ppmv]M_{CO_2}[gmole^{-1}]1.0\times10^6 m_{air}[Mg]}\right) \otimes Decay^{Ann}_{CO_2}(y) \quad (8)$$

Where $\otimes$ represents the convolution operation and $Decay^{Ann}_{CO_2}(y)$ is given by:

$$Decay^{Ann}_{CO_2}(y) = a_0 + \sum_{i=1}^{3} a_i e^{-y/\tau_i} \quad (9)$$

The effect of the CO_2 concentration change is felt over the entire surface of the Earth so the change in energy is given by:

$$E^{Ann}_{CO_2}(y)[W] = A_{Earth}[m^2]F^{Ann}_{CO_2}(y)\,[Wm^{-2}] \quad (10)$$

2.5. Radiative forcing impact due to a change in surface albedo

The annual change in forcing due to a change in albedo at the top of the atmosphere (TOA) is estimated from the difference in the up welling and down going shortwave radiation, SW_{net}

$$F^{Ann}_{\alpha}(y)\,[Wm^{-2}] = SW^{Ann}_{net}(\Delta\alpha(y))\,[Wm^{-2}] \quad (11)$$

The Fu-Liou model estimates the average SW_{net} over a 24-hour period for a given day. As mentioned earlier, we have used the Fu-Liou model to estimate the SW_{net} on the 15th day of each month. To convert this to the annual net short wave radiation, we average the Fu-Liou monthly estimate. Therefore:

$$F^{Ann}_{\alpha}(y)\,[Wm^{-2}] = \frac{1}{12} * \sum_{m=1}^{12} SW_{net}(\alpha(m,y)\,[Wm^{-2}] \quad (12)$$

Therefore the change in energy caused by the change in albedo is given by

$$E^{Ann}_{\alpha}(y)[W] = Area_{albedo}[m^2]F^{Ann}_{\alpha}(y)\,[Wm^{-2}] \quad (13)$$

2.6. Combining the forcing effects

Our goal is to combine the two effects; the energy change is given by

$$E^{Ann}_{Total}(y)[W] = F^{Ann}_{CO_2}(y)[W] + F^{Ann}_{\alpha}(y)[W] \quad (14)$$

2.7. Conversion of radiative forcing into CO_2 equivalences

Reduced radiative forcing is not the unit in which commitments are denominated under the United Nations Framework Convention on Climate Change (UNFCCC) and Kyoto Protocol agreements. The climate change mitigation community uses CO_2-equivalence as its indicator and functional unit. Fortunately, through mathematical reorganization of Eq. (7), changes in radiative forcing can be expressed in terms of CO_2 equivalences.

$$\Delta CO_2 eq_{\alpha}(y)[g] \approx \frac{F^{Ann}_{\alpha}(y)\,[Wm^{-2}]}{5.35} \times \left(\frac{CO_{2,unperturbed}[ppmv]M_{CO_2}[gmole^{-1}]1.0\times10^6 m_{air}[Mg]}{1.0\times10^6[ppmv]M_{air}[gmole^{-1}]}\right) \otimes In^{Ann}_{CO_2}(y) \quad (15)$$

Where

$$F^{Ann}_{\alpha}(y)\,[Wm^{-2}] = \frac{E^{Ann}_{\alpha}(y)[W]}{Area_{albedo}[m^2]}$$

Where $In^{Ann}_{CO_2}(y)$ is the inverse-filter of $Decay^{Ann}_{CO_2}(y)$ so that

$$Decay^{Ann}_{CO_2}(y) \otimes In^{Ann}_{CO_2}(y) = 1 \quad (16)$$

$In^{Ann}_{CO_2}(y)$ can be calculated analytically since we are modelling only changes in albedo (i.e., no change before the start of the human activity).

The form of $Decay^{Ann}_{CO_2}(y)$ and $In^{Ann}_{CO_2}(y)$ is shown in Fig. 3.

3. Results

3.1. Carbon stock balance

Fig. 4 depicts the net increase of biomass due to an afforestation/reforestation project where Scots pine is planted on grassland and harvested on a 90-year rotation cycle with 5 thinning operations per cycle. The figure illustrates the annual carbon sequestration in aboveground and belowground biomass that could be achieved by such a project. Biomass in the without project case (baseline) remains constant at 22 t ha^{-1}, whereas additional biomass due to the project ranges between 340 t ha^{-1} and 60 t ha^{-1} 1 over the course of the harvesting and replanting cycle. To simplify modelling, the average carbon stock over the life of the project—shown by the dashed line in Fig. 4—is used (Schlamadinger et al., 2004).

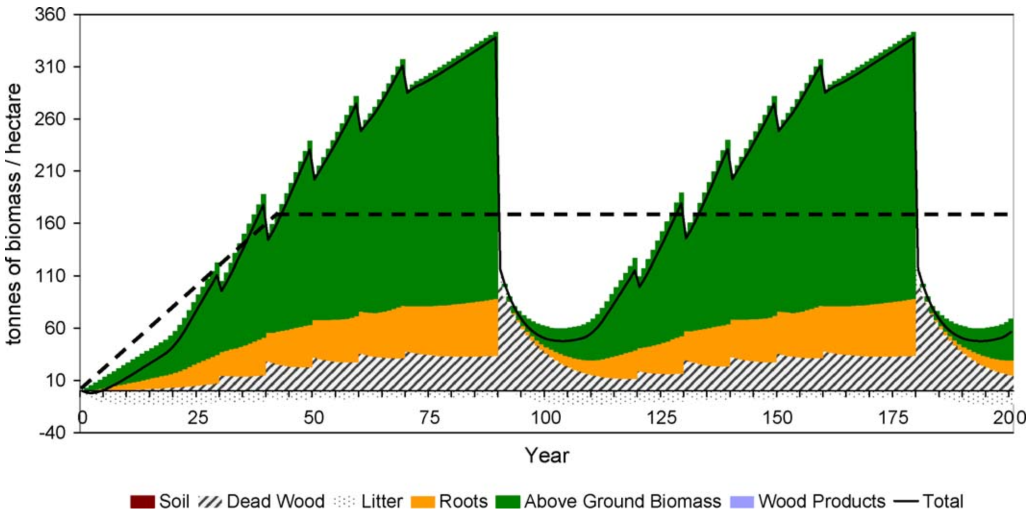


Fig. 4. Net balance of biomass increase due to a land use change from grassland to a pine forest in the case study area similar to afforestation/reforestation project.

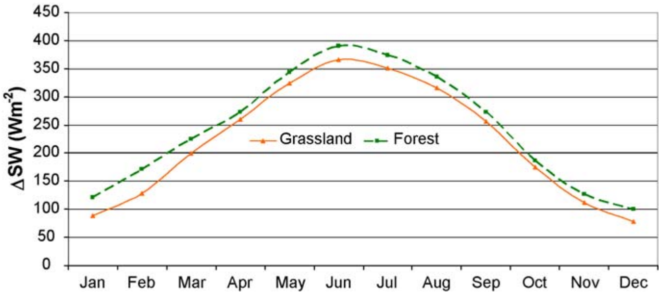


Fig. 5. Variation of top of the atmosphere (TOA) ΔSW as an output of the Fu-Liou model in the case study region.

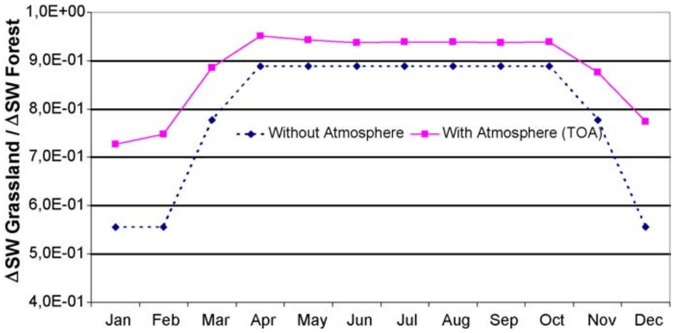


Fig. 6. Ratio of grassland to forest ΔSW with and without the atmosphere.

Planting Scots pine results in an average increase of biomass of 170 t ha^{-1} (46.4 tC). This increased biomass is accompanied by a net removal of CO_2 from the atmosphere and therefore has a cooling effect (negative radiative forcing). Most of the increase is in the living biomass pool, followed by root and dead wood biomass with small losses of C in the litter pool. Changes in soil organic matter and wood product pools have not been considered here. Exclusion of these pools results in underestimation of the net biomass accumulated by the project.

3.2. Albedo effects

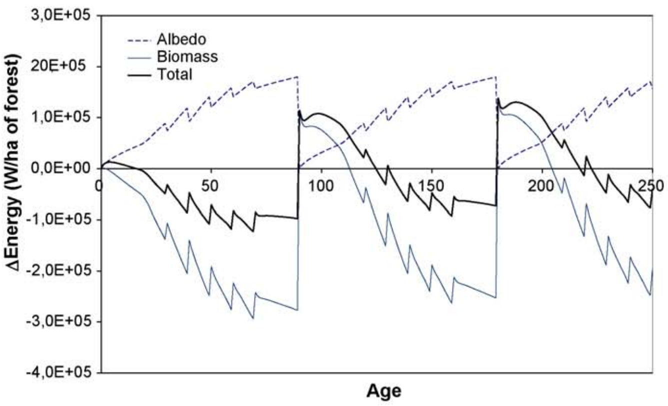
By using geographic position, average cloud cover per month and other input parameters the Fu-Liou model calculates the difference in up welling and down going short wave radiation (ΔSW) at the top of atmosphere (radiative absorption). In Fig. 5, we show that the grassland ΔSW varies between 78 Wm^{-2} (December) and 366 Wm^{-2} (June), while the ΔSW for the mature forest has a minimum of 101 Wm^{-2} (December) and maximum of 390 Wm^{-2} (June). In our model, the ΔSW for under mature forests were calculated as a mixture of grassland and mature forest, based on an estimate of the crown cover from the volume of standing stock.

Fig. 6 depicts the importance of including the atmosphere when calculating ΔSW at the top of atmosphere instead of calculating it based on surface albedo and incident solar energy. The atmosphere mutes the difference in short wave radiation absorbed. This is particularly apparent during the winter months where the ratio of grassland to forest ΔSW in January is 0.56 using the surface albedo alone, but 0.73 when atmospheric effects are included. The influence of the atmosphere is less during summer months.

3.3. Combining carbon sequestration due to biomass growth and albedo effects

Using Eqs. (1) through (14) enables an evaluation of land use impacts on climate considering influences of both carbon stocks and albedo. The impacts are estimated in terms of energy increase per hectare of land use change. Fig. 7a shows that the energy change due to biomass growth (negative values = cooling) is counterbalanced by albedo changes (positive values = warming). For the first 25 years after planting there is a net positive forcing. After that, the cooling effect of increased biomass exceeds the warming impact of albedo effects, leading to a net cooling until the first harvest. Fig. 7b shows that the cumulative net impact is one of cooling from year 25 until approximately year 190. The biomass component reaches a cooling maximum of $-2.77 \times 10^{+5}$ W ha^{-1} just before harvest (year 90) at which time the albedo reaches $1.80 \times 10^{+5}$ W $ha^{-1}$with a net cooling of $-9.69 \times 10^{+4}$ W ha^{-1} at that point. During the first rotation period, the total balance remains on the cooling side but after two or more rotation periods, the cooling effects of forest growth are overtaken by the warming effects of the lower albedo. This long-term warming is also driven by the fact that, due to removal of atmospheric CO_2, the forest reduces CO_2 concentrations, thus reducing the rate of atmospheric CO_2 decay.

Radiative forcing in Wm^{-2} is not the unit used within the UNFCCC and the Kyoto Protocol negotiations, where the climate change impacts are accounted for in carbon dioxide (CO_2) equivalences. In Fig. 8 model results have been converted into this commonly used accounting unit of CO_2 equiv. ha^{-1}. Therefore, afforestation in the case study area accumulates up to 624 t CO_2 eq. ha^{-1}, while the change in albedo due to crown cover is equivalent to emissions of roughly 401 t CO_2 eq. ha^{-1} by the end of the first rotation period. The net effect varies around a neutral level with the cumulative effect of a slight cooling in the long term (Fig. 7b).



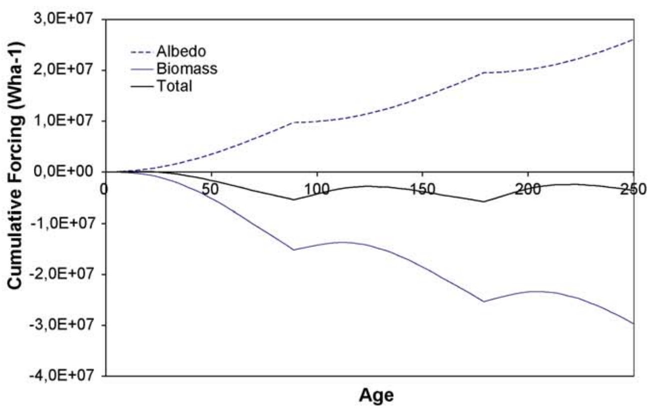


Fig. 7. Biomass, albedo and total radiative forcing effects due to Scot pine forest. 7a: Annual impacts over three rotations. 7b: Cumulative impacts over three rotations.

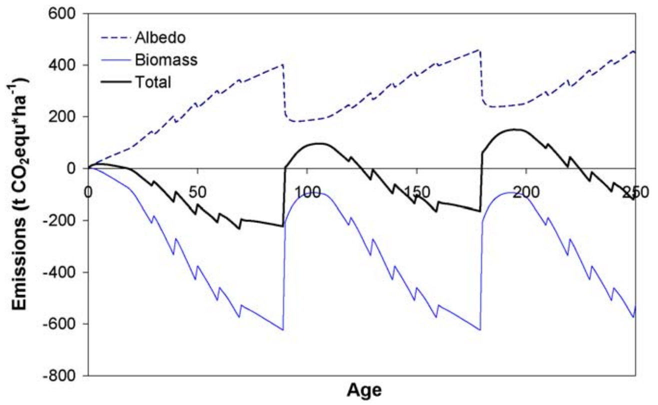


Fig. 8. Cumulative net emissions including CO_2 equivalences from albedo change.

3.4. Sensitivity analysis

In the basic model run we used a value of surface albedo of 0.2 for grassland and 0.1 for a Scots pine forest, snow cover in winter month November to March, average yield class, crown cover of 80% at maturity level and a rotation length of 90 years for our calculations. We investigated the sensitivity of the radiative forcing impact on climatic by considering winters with and without snow cover and altering growth and canopy closure parameters in the model. In addition we investigated variations of TOA, cloud density due to aerosol emissions as well as the rotation length. Fig. 9a–f shows the results of sensitivity analysis in six diagrams.

Surface albedo data for different land use options (Sharratt, 1998) is subject to wide ranges of uncertainties (e.g. albedo of short wave radiation for grassland 0.16–0.30 and 0.10–0.15 for pine, fir

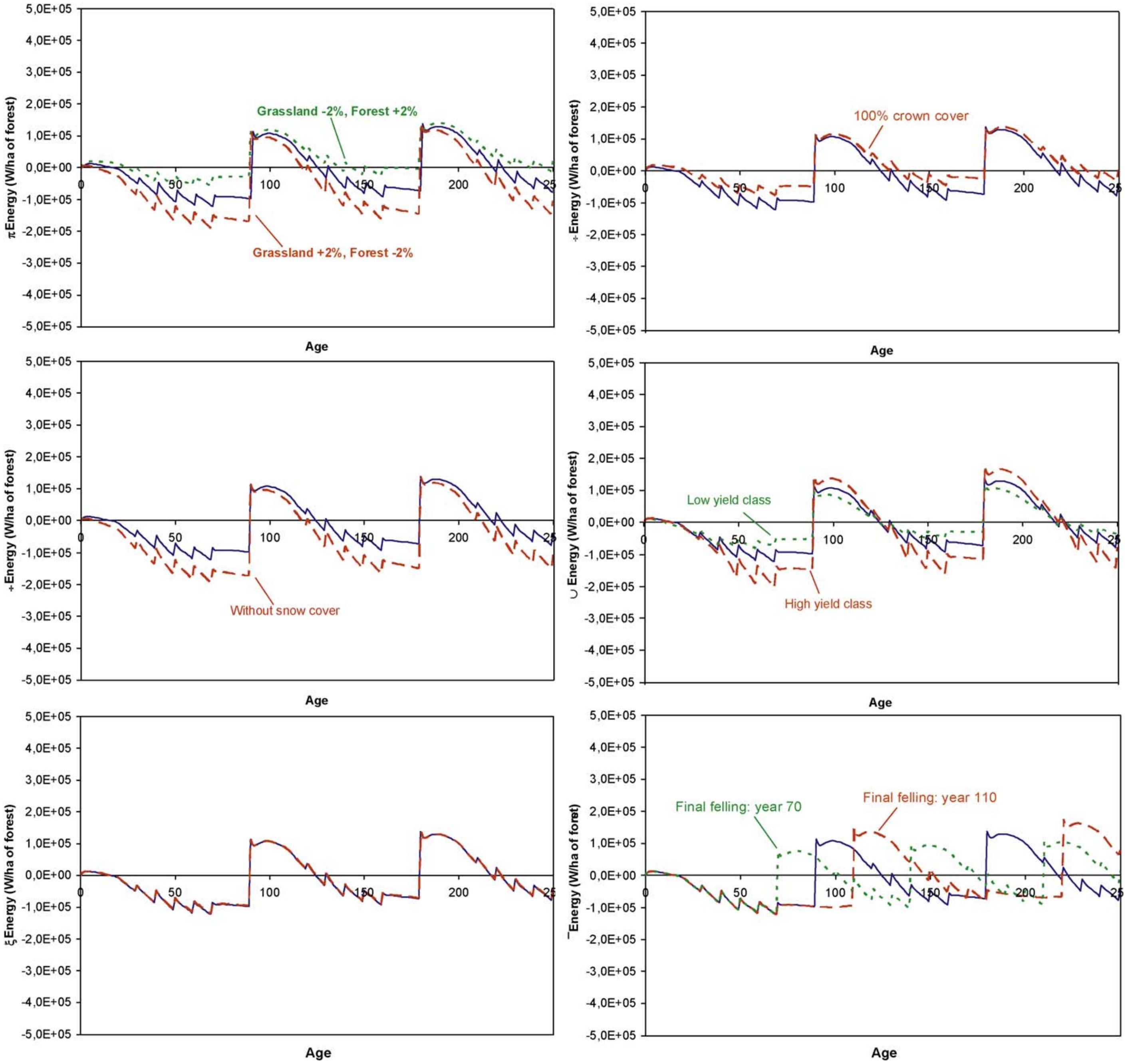


Fig. 9. (a–f) Sensitivity to the variation of surface albedo, forest crown cover, influence of snow cover in winter and forest site qualities.

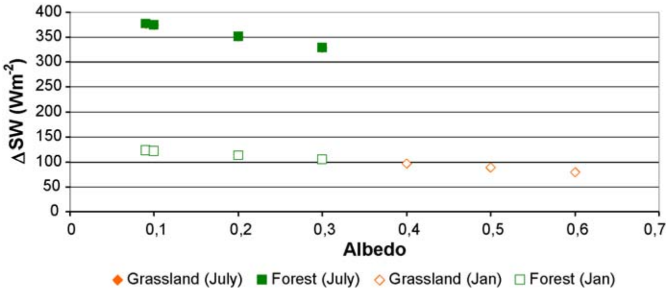


Fig. 10. Sensitivity of Δ*SW* to changes in surface albedo.

and oak trees (Pielke and Avissar, 1990; Table 1). Fig. 9a shows the result of using (1) 2% lower surface albedo for grassland and a 2% higher surface albedo for Scot pine and (2) a 2% higher albedo for grasslands and a 2% lower albedo for Scot pine. Use of these values results in significant differences especially in the long run. Case (1) results in considerably more warming whereas case (2) results in considerably more cooling than the base case.

Fig. 9b depicts the sensitivity to forest stand canopy closure. The difference between assumptions of 80% (reference) and 100% crown cover at the time of final felling are illustrated. For example low quality sites may have open canopies. We discuss sensitivity to site quality below. Fig. 9c displays the sensitivity of model results to snow cover in winter. For the reference case we assumed full snow cover (albedo of 0.50) in December through February and 33% snow cover in November and March, for the sensitivity analysis a "no snow cover" scenario was used.

Fig. 9d shows the impact of use of different growth and yield data. In effect, this sensitivity analysis can be thought of as illustrating differences in site quality. Average yield class data was used in the base calculation; best and worst site class data provided by Rojo and Montero (1996) was used for two alternative runs. Here the sensitivity effects on net are similar to altering surface albedo input parameters. Lower site qualities lead to greater warming roughly at the same scale as use of a higher albedo for grasslands and lower albedo for forests. Influences of cloud density increase (+5% optical depth of the second, lower cloud layer) are shown in Fig. 9e, with only very small influences on the entire forcing results. 9f shows the sensitivity of changing the rotation length to 70 and 110 years. In the long run, shorter rotation periods tend to a higher cooling effect.

The sensitivity of the net short wave radiation (Δ*SW*) to changes in surface albedo for January and July are shown in Fig. 10. It shows that a change in surface albedo of +0.1 creates a negative change in Δ*SW* between 7 and 10%.

4. Conclusions

In conclusion, stand-scale modelling suggests inclusion of albedo effects may neutralize the climate benefits of carbon sequestration. Sequestration due to forest growth and albedo changes may compensate for each other, tending towards a slight warming effect over the very long term (250 years).

Sensitivity analyses carried out showed that model results are highly sensitive to both surface and TOA albedo data as well as forest growth data (site quality), whereas variations of crown and snow cover, cloud density and rotation length are of lower significance to the radiative forcing results of land use change.

Therefore, the albedo effects of land use changes should not be ignored in calculations of climate impacts. Albedo impacts should, in particular, be included in life-cycle assessments of biofuels and bioenergy if biomass is derived from afforestation projects or from land that has been to grow biomass for energy. Afforestation/reforestation measures cannot simply be viewed as a positive activity to mitigate climate change because in some cases most of the positive impact of carbon sequestered via photosynthetic CO_2 fixation of forest growth is neutralized by the warming effect of albedo changes.

There are many areas where further research is needed to properly understand the affects of land use changes. One approach that would lead to better results would be use of real albedo data from satellite images (e.g. MODIS) rather than surface measurements. Satellite based estimates of TOA albedo will include a range of known effects of land use change such as canopy closure, aerosols from coniferous forests, dust from crop lands, and effects of topography. Lyons et al. (2008) concluded that albedo effects as seen from MODIS differ from assumed surface observations substantially. Another improvement to the model could be to use data from forest inventories or remote sensing instead of yield tables. Finally, the current analysis does not include energy impacts of changes in evapotranspiration that often accompany a land-use change. Forests, in general, evapotranspire more than grasslands and croplands and which may have increase cloud cover and increase the cooling.

The results described in this paper should be considered as preliminary since the surface albedo data used were drawn from literature and a simplified carbon accounting tool was used. Further studies should use improvements mentioned above. In addition, it should be clearly pointed out that existing forests and forest growth have a significant and important role in sequestrating and storing carbon over time and that the results of this study apply only to a possible change of vegetative land cover in a specific geographic location with specific cloud cover and growth characteristics.

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The future European Emission Trading Scheme and its impact on biomass use

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ABSTRACT

Based on research carried out within the NoE, this paper assesses possible impacts of changes to the European Emission Trading Scheme on solid and the possible future inclusion of liquid biomass use in the EU. Based on these assessments, recommendations are outlined for optimising support for solid and liquid biofuels. In December 2008 the European Council agreed on the European Energy and Climate Package. This agreement contains fundamental changes to the European Emission Trading Scheme (EU-ETS), which started in 2005. With some exceptions, emissions allowances in the power sector will be auctioned starting with the third trading period of the scheme in 2013. This may have significant impacts on the sector's fuel mix and investment decisions. To the extent to which the EU-ETS results in a price on CO_2 emissions, it increases the competitiveness of low carbon fuels. Under current regulations no CO_2 emissions are attributed to combustion of biomass, thus it functions as a zero-carbon fuel. The paper shows that while the use of biomass is already viable under CO_2 prices that have been reached within the EU-ETS, investments in new biomass plants need a higher price level as well as more stable prices, conditions which cannot be predicted with any confidence. The road transport sector, which has significant scope to increase its use of biofuels is currently not part of the EU-ETS, and will not be included in the third trading period which begins in 2013 but may be included later. The likely consequences of including transportation fuels under the EU-ETS are considered as well as options which involve separate trading schemes for liquid biofuels. The paper also reviews other trading mechanisms which might serve as more effective vehicles for increasing the share of liquid biofuels, taking sustainability issues into account.

1. Introduction

In December 2008, the European parliament adopted the EU Energy and Climate Package followed by its adoption by the European Council in April 2009 [1]. The package sets three targets for 2020: a 20% reduction of greenhouse gas (GHG) emissions; a 20% improvement in energy efficiency; and a 20% share of renewable energy for gross final energy usage. Within

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the latter target, there is an additional sub-target of 10% renewable energy in the transport sector [1]. The Energy and Climate Package also aims to significantly redesign and improve the European Emission Trading Scheme (EU-ETS), and in 2009 a new EU-ETS directive was adopted [2]. This paper focuses on the question of whether the EU-ETS is an appropriate vehicle for increasing use of solid and liquid biomass.

Following the Directive 2003/87/EC [3] which established a scheme of GHG emission allowance trading within the community, in January, 2005 the European Union implemented the EU-ETS as a main instrument to reach its Kyoto commitments on climate change. The EU-ETS is the largest multi-country, multi-sector greenhouse gas emissions trading scheme worldwide. The scheme establishes a cap on total emissions from covered sectors. The cap approach guarantees that its environmental goal is met but the costs that companies will face in meeting this goal cannot be fully predicted. The first phase of the EU-ETS ran from 2005 to 2007, and included about 12,000 industrial plants [4]. It covered about 46% of total EU CO_2 emissions - about 40% of total GHG emissions - and included the most energy intensive sectors: iron and steel, minerals, pulp and paper production, refineries, and the power sector [3]. The second period runs from 2008 to 2012 and coincides with the first Kyoto commitment period. The third period will run from 2013 to 2020 [2].

The EU-ETS allows companies to buy and sell the certificates, referred to as allowances, that they must hold to cover their releases of CO_2 into the atmosphere. During the first and second periods, the number of allowances allocated to companies and the method of allocating them were determined by member states in National Allocation Plans (NAPs). Most allowances have been allocated free of charge based on historical emissions (grandfathering). At least 95% of allowances were grandfathered in the first period and at least 90% in the second phase. The trading scheme provides that companies whose CO_2 emissions exceed the amount received can purchase allowances from companies in possession of excess allowances.

The objective of a cap-and-trade system is to create incentives for the affected industry sectors to reduce their CO_2 emissions. The cap imposed on total allowances allocated should create scarcity, a precondition for a market. This will occur if emissions during the trading period would exceed total allowances if no emission-reducing actions are taken. Companies that manage to keep their CO_2 emissions below their allocations through emission reduction efforts can sell any excess allowances at the price determined by the market. Under this system, in theory, emissions reductions ought to be carried out where they are least expensive. The system should encourage measures to reduce CO_2 emissions such as switching to lower emission fuel mixes and investing in "climate friendly" technologies.

Starting in 2013 allocations will be determined at the EU level and, with a few exceptions, allowances for the power sector will be auctioned. Exceptions may be made for highly efficient co-generation plants and district heating as well as for electricity producers in some new EU member states [2]. To the extent to which then EU-ETS results in a price on CO_2, it will increase the competitiveness of low carbon fuels. Under current regulations no CO_2 emissions are attributed to combustion of biomass [3]. Therefore no allowances must be purchased to cover emissions due to the combustion of biomass, and, the scheme has the potential to increase use of biomass. In fact the European Commission expects a large increase in biomass use in the energy sector by 2020 [4].

Up to now, the CO_2 price has, on average, not been high enough to motivate companies to invest in low carbon technologies on a large scale. Surveys done within the NoE, however, have shown that the EU-ETS has motivated companies to investigate internal reduction measures, and that modest emission reductions have occurred in spite of a very volatile CO_2 price [5]. The transport sector will not be included in the EU-ETS beginning in 2013 but may be included in other planned emissions trading schemes in the future, such as in California. To stimulate greater use of liquid biofuels, emissions trading however may not be the most effective system due to the relatively high cost of most biofuel options in relation to other measures both in the transportation and power sectors.

2. Solid biomass under the EU-ETS

A model to analyse the competitiveness of biomass in power generation under the EU-ETS has been developed within the NoE based on previous studies by the IEA [6]. The model is designed to assess the influence of the CO_2 price on the Short Run Marginal Costs (SRMC) and Long Run Marginal Costs (LRMC) of power generation. The NoE model shows at what CO_2 price the use of biomass to replace coal becomes competitive in existing plants (e.g., through co-firing), and at what CO_2 price the construction of new biomass plants will become competitive. Model runs shown in this paper use an assumption of 100 percent auctioning of allowances however the model can be run under other assumptions. Further, in assessing CO_2 prices which would be required for new biomass plants to be build, the runs use costs for a medium-sized CHP biomass plant. Costs for small plants would be higher, thus requiring higher CO_2 prices for competitiveness than discussed below.

SRMCs, which are based on fuel prices and other variable costs, are the basis for daily operational decisions regarding which fuel to use. Investment decisions are based on the Long Run Marginal Costs (LRMC) of a plant which include not only fuel and other variable costs but also fixed costs such as investment and capital costs. In the cases shown in this paper, different thermal efficiencies were used for LRMC and SRMC calculations. For SRMC calculations a thermal efficiency rate of 37% was used for coal plants as representing the average of currently operating plants. For LRMC of coal plants a rate of 40% was used as new plants will have higher efficiencies. For gas (CCGT) an efficiency rate of 40% was assumed for existing and 55% for new plants. For new CHP biomass plants a thermal efficiency rate of 80 percent was assumed. The model can be run with other efficiency assumptions to address specific cases of interest.

The cheapest biomass, starting at €2.1/GJ, was available in Finland and the UK in 2009. Germany, Austria and the Netherlands faced the costs up to €10/GJ in 2009 [7]. While the

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coal and gas prices are quite homogeneous in the EU, the biomass prices are very inhomogeneous and also depend on the quality of biomass. Where it is available, biomass residues can used to co-fire power plants. In other cases high quality, imported wood pellets may be the only source with adequate supply.

Fig. 1 shows the result of a case study model run for the SRMCs in Austria. Two biomass prices typical for Austria are shown. A coal price of €2/GJ was used. The solid green line represents a biomass cost of €3 per GT ("Biomass low"). It shows that at this cost, biomass becomes competitive with coal, when only SRMC is considered, at a CO_2 price of €7 per tonne. The dashed green line represents a biomass price of €5 per GT ("Biomass low"). Under these conditions biomass becomes competitive with coal at €21 per tonne CO_2. The figure shows for biomass costs typical in Austria, biomass becomes competitive compared to coal in the range of €7 to €21 per tonne for CO_2, a price range that was quite common in the EU-ETS in the last 2 years. In several NoE countries the biomass price is below the range of €3 to €5 per GT. In these countries, a lower CO_2 price will serve to render biomass competitive with coal. In Finland the biomass price is so low that no CO_2 price at all is necessary to make biomass competitive compared to coal.

With no carbon price (price 0), coal has the lowest SRMC of all options. As the CO_2 price increases, the variable costs for both gas and coal-based power plants rise because an emission allowance will be needed for each unit of CO_2 emitted. The rate at which costs for fossil fuel-based plants rise depend on the CO_2 emissions intensity of the fuel used. As coal has a higher emission intensity than gas, its costs rise more steeply than those of gas-based plants. Fig. 1 shows, for example, that SRMCs for coal will exceed those of gas when CO_2 prices rise to approximately the €40 per tonne level. Costs for biomass do not rise as no emission allowances are required when biomass is combusted.

Fig. 2 illustrates the dependence of LRMC for new coal, gas and biomass plants on the CO_2 price. As in Fig. 1, two biomass costs typical in Austria are shown. Without a carbon price coal fired plants have the lowest LRMC. As is the case for SRMC, as the CO_2 price increases, the LRMCs of fossil fuel power plants will rise due to the requirement for emission allowances for each tonne of CO_2 emitted to the atmosphere. Fig. 2 shows that new gas plants become competitive to new coal plants at about €24 per tonne CO_2. Biomass plants start becoming competitive with coal plants in a range of €33 to €47 per tonne CO_2, as biomass costs range from €3 to €5 per GJ. These CO_2 prices are significantly higher than the CO_2 prices observed so far. In addition to the ranges of biomass costs found across the EU, gas prices are also volatile. Figs. 1 and 2 only provide indicative information.

Model runs were made for biomass costs typical for other EU countries. Fig. 3 shows the range of CO_2 prices at which new medium-sized CHP biomass plants become competitive in a number of EU countries based on costs typically faced by plants in each nation. These ranges encompass different assumptions on biomass, gas and coal prices as well as plant efficiencies. Assuming that there is full auctioning and that the scheme results in CO_2 prices at or above the €35 to €40 range, Fig. 3 suggests that EU-ETS's third period may provide an appropriate incentive to establish biomass plants across most of the EU. Under these prices, biomass plants would be competitive in only a subset of EU nations. CO_2 prices however may not rise to €40 during the period up to 2020 [8]. The figure also provides a first indication as to the extent that countries would need additional incentives to make biomass plant competitive at various CO_2 price levels.

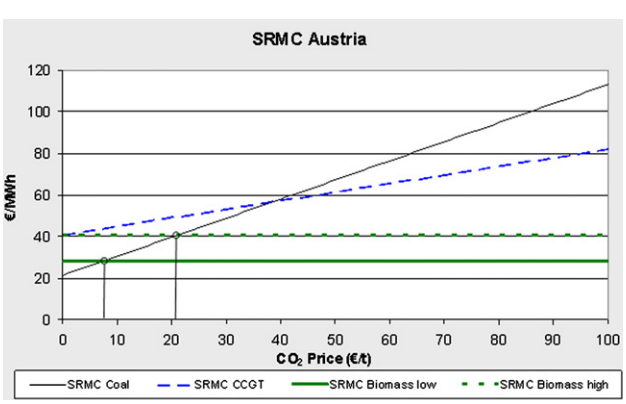

Fig. 1 – Influence of the CO_2 price on the SRMC of power generation by biomass and fossil fuels in Austria.

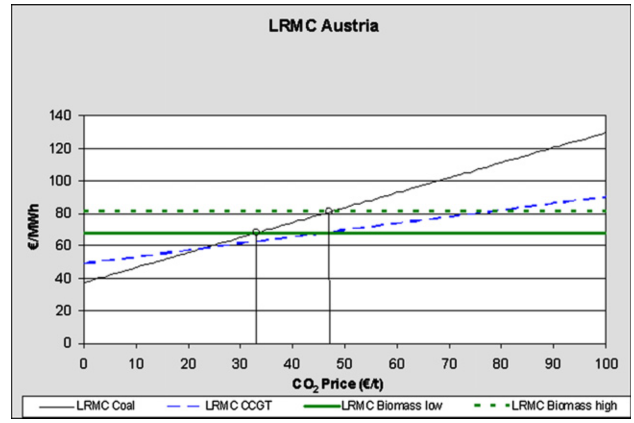

Fig. 2 – Influence of the CO_2 price on the LRMC of power generation by biomass and fossil fuels in Austria.

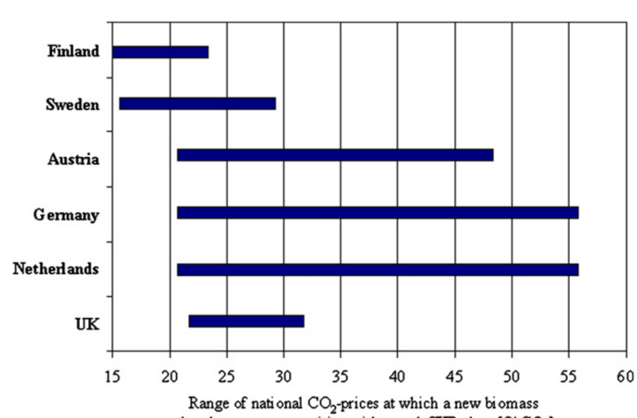

Fig. 3 – Competitiveness of new biomass plants under full auctioning in the power sector.

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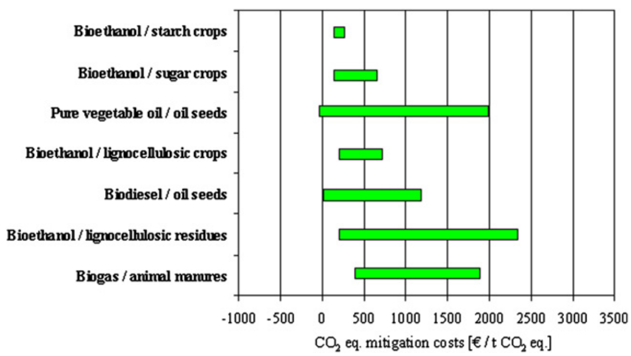

Fig. 4 – CO_2 eq. mitigation costs (€$_{2002}$/t $CO_{2\ eq.}$) – Future Technology [5].

3. Biofuel versus other abatement options

While the previous chapters assessed the impact of carbon prices under the EU-ETS on solid biomass, the following chapters turn to the issue of consequences of including transportation fuels under the EU-ETS versus other options to support biofuels through trading schemes. Currently the transportation sector is not included in the EU-ETS, but it may be included later in this or other trading schemes. While there is a wide range of options to reduce emissions in the transport sector, abatement options here have highly varying abatement costs. Some reduction measures have negative or small abatement costs, e.g. increasing the deployment of fuel efficient vehicles [9]. However, most biofuel options have costs far over €100 per tonne of CO_2 (see Fig. 4).

An abatement cost of €100 per tonne is not only high compared to many abatement options in the transportation sector, it is also higher than the €20 to €60 per tonne CO_2 cost range of many measures in the energy and industry sectors. As shown in Fig. 1, substitution of solid biomass for coal becomes competitive with electricity generation at carbon prices below €20 per tonne. At €40 per tonne new biomass generation plants become competitive across Europe. While some biofuels are available at these prices, many biofuels-for-transport options require far higher prices.

3.1. *Transport sector cap-and-trade options*

There is an ongoing discussion as to whether to include the road transport sector in the EU-ETS or not, while it will be part of several other emerging emissions trading schemes worldwide. There are several options to implement emissions trading in the transport sector: The whole transport sector – road transport, aviation and maritime shipping – could be integrated in the EU-ETS. Alternatively a subset of transport sectors (aviation, shipping) could be integrated in the EU-ETS while other transport sectors, particularly road transport would either have their own, separate ETS or rely on other instruments. Finally, transportation fuels could be subject to a trading system separate from other transportation options.

Full integration of the transport sector into the EU-ETS would increase the cost-effectiveness of the scheme [9]. Under full integration, total costs of emission reductions are reduced and the price increase of fuel remains limited. However, due to the purchasing power of the transport sector, it is expected that it would purchase allowances from other ETS sectors to meet a large share of its obligation. This would lead to higher carbon prices under the EU-ETS than the theory that "least expensive options will be taken first" would suggest. It would also have the result that little mitigation of transport emissions would occur [9,10]. An increase of carbon prices under the EU-ETS would lead to a decrease of European industrial competitiveness and possibly to industry moving outside of the EU [11].

Alternatively, the transport sector could be only partially integrated in the EU-ETS. Aviation and rail transport might be included, leaving road transport to another system. In this case there would be only a limited impact of the transport sector on EU-ETS carbon prices. The inclusion of aviation into the EU-ETS, as planned from 2012, is already the first step towards a partial integration.

Finally, the transport sector could be subject to an independent cap. However, the political and societal costs of imposing significant emission reduction on the road transport sector are relatively high. A separate trading system for road transport which required emission reductions at the same percentage level as in other sectors could drive fuel prices up to politically and socially unacceptable levels [11]. In particular, high fuel prices place a higher relative burden on lower income groups than on higher ones. Further, even if the price of emission allowances under a separate transportation cap-and-trade system were higher than in the wider EU-ETS, they would probably not be high enough to support significant use of biofuels (Table 1).

3.2. *Tradable systems for fuel refiners, importers or distributors: caps and standards*

Given the difficulties of promoting biofuels or reducing petrol and diesel use through economy-wide or transport sector-wide cap-and-trade systems, proposals have emerged to place obligations on fuel distributors, refiners or importers. Such obligations are seen as a promising avenue to achieve emission reductions in the transport sector and to offer

Table 1 – Comparison of different policy instruments.

	EU-ETS	Transport ETS	Fuel Standards	Cap on fuel emissions
Cost	Unclear, however more flexibility compared to a standard	Unclear, however more flexibility compared to a standard	Uncertain	Uncertain
Impacts on emissions	Certain	Certain	Uncertain	Certain
Impacts on biofuels	Only at high CO_2 prices	Only at high CO_2 prices	High	Moderate

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opportunities to support biofuels. Obligations can take the form of caps or standards. Standards can take the form of CO_2 emissions per unit of fuel sold or percents of, e.g. biofuels in the fuel mix. Under both standards and cap approaches, efficiency will be served through allowing trading to meet the obligation.

3.2.1. *Example of the standards approach to promoting biofuels*

An example of a trading scheme that uses a standards approach is the UK Renewable Transport Fuel Obligation (RTFO). The RTFO sets a standard for the use of biofuels with the objective of helping bring the UK into line with the European Union biofuels directive. The EU biofuels directive sets targets for all EU countries for biofuel usage of 5.75% of road fuel by the end of 2010 [12]. The RTFO requires that as of April 2008 biofuels constitute 2.5% of total road transport fuels in 2008–09, 3.75% in 2009–10, and 5% in 2010–11 and beyond. The RTFO places the obligation for meeting this standard on refiners and importers supplying at least 450,000 L of transport fuels a year ('obligated suppliers') [13]. The obligated suppliers must demonstrate that they have met their obligation by surrendering Renewable Transport Fuel Certificates (RTFCs) to the Renewable Fuels Agency (RFA) at the end of the year [12].

One RTFC is awarded for every litre (or kilogram in the case of biogas) of biofuel produced. An obligated supplier can obtain RTFCs either by producing or purchasing and supplying the biofuel itself or by buying RTFCs from other biofuel suppliers. There is also an option to 'buy-out' of the obligation by paying a fee. This 'buy-out' fee acts as a cost 'safety valve'. Money collected from buy-out fees paid will be placed in a fund, with the money reallocated to companies who submitted certificates, providing an additional incentive to supply biofuels.

The RTFO requires reporting regarding the sustainability of biomass. Certain criteria have to be fulfilled for fuels to be eligible for credits. The criteria require reporting on lifecycle emissions from direct land use change, cultivation, processing and transport of biofuels. Biofuels will have to meet the 35% savings compared to fossil fuels established in the EU Renewable Energy Directive in order to obtain a RTFC. However, savings in excess of 35% do not increase the number of certificates received.

For the 2008/09 obligation period all obligated suppliers met their RTFO obligation through submission of certificates. No obligated supplier needed to pay into the 'buy-out fund', thus for the 2008/09 obligation period the buy-out fund was zero [12]. A substantial number of certificates were traded between suppliers of road-transportation fuels, and at the end of the first year all obligated suppliers were able to meet their obligation with certificates. In the first year of the RTFO, based on the RTFO methodology, net CO_2 savings of 1.6 million tonnes were achieved by replacing 2.7% of road transport fuel with 1.3 billion litres of biofuels. This represented a reduction of 46 percent of transportation emissions, which exceeded the Government's target of 40% savings [12].

3.2.2. *Example of the cap-and-trade for transport*

DeCicco [13] has proposed a system in which biofuels would be encouraged through a cap-and-trade system. In contrast to the RTFC system, the lower the carbon footprint of the biofuel, the fewer allowances must be submitted. Consequently lower carbon footprint fuels are more advantageous to the obligated entities and the system automatically encourages a continual search to lower biofuels' GHG profile at any given cost. Under the proposed system, an emission cap would be placed on fuel distributors. Fuel distributors must submit allowances to cover the CO_2 emissions caused by use of fuels sold. In contrast to systems currently in operation, allowances would have to be submitted to cover the full carbon content of both fossil fuel-based and biomass-based fuels. There is no assumption of carbon neutrality for biofuels; the attribution of zero emissions to biofuels is replaced by calculated emissions. CO_2 emissions are assigned to biofuels based on the net emissions due to cultivation (including emissions due to land use change if any), processing and transport. Since net emissions are used, removals of carbon dioxide from the atmosphere are deducted from emissions due to land use change, cultivation, processing and transport. Due to these deductions, biofuels can have substantially lower CO_2 emission profiles than fossil fuels, giving them a positive value under the cap. In fact, after subtracting emissions due to cultivation, processing and transport biofuels can have negative emissions. Negative emissions are converted to credits per megajoule (MJ) of biofuels with the credits used to reduce allowances required for an equivalent number of MJs of other fuels.

4. Discussion

Europe's Energy and Climate Package provides that power sector allowances will generally be auctioned starting in 2013, setting in principle a major incentive to invest in low carbon technologies. However, the level of future CO_2 prices cannot be predicted with any confidence. Prices will depend on factors such as economic and emission growth. In the first phase of the EU-ETS the CO_2 price was very volatile [13]. It was over €30 per tonne for a short time, before falling to almost zero due to the over-allocation of emission allowances during this phase [13]. While volatility of the CO_2 price has been lower in the second phase than in the first phase, volatility and intermittent low prices remain a major hurdle for the effective functioning of the EU-ETS. In the second phase the price reached about €25 per tonne, but currently it is €15 per tonne [14].

During the third phase a higher CO_2 price is expected, if, however, the current economic crisis continues to impact industrial and electricity demand, low carbon prices may prevail through 2020. In contrast to trading schemes in other countries, the EU-ETS has not had, and does not envision employing, mechanisms for price control and management [14]. This lack of price management is not in line with company needs. Firms need stable, long term expectations of carbon prices to undertake major investment decisions. Under these conditions-where the CO_2 price level through 2020 is uncertain and it is unclear whether or how long the CO_2 price will be above levels that would justify, for example, investment in new biomass plants-there is a need for policy-makers to implement additional instruments to stimulate their construction. These may be very country specific and could include subsidies, feed-in tariffs, or tax relief.

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	EU-ETS	Transport ETS	Fuel Standards	Cap on fuel emissions
Cost	unclear, however more flexibility compared to a standard	unclear, however more flexibility compared to a standard	uncertain	uncertain
Impacts on emissions	certain	Certain	uncertain	certain
Impacts on biofuels	only at high CO_2 prices	only at high CO_2 prices	high	moderate

Fig. 5 – Comparing different policy instruments.

Neither the EU-ETS, as an economy-wide, nor a new transport sector-wide cap-and-trade system may set the appropriate incentives for a broader use of biofuels. Consequently fuel obligations may be more promising instruments. The choice of instrument, or combinations of instruments, depends on the policy goals that should be achieved. In the case of biomass use it is important to be clear whether the policy goal is to promote the use of biomass or to achieve a specific emissions reduction target, as is the main policy goal of the EU-ETS.

Fig. 5 compares the impact of the EU-ETS, a transport-specific ETS, fuel standards, and a cap on transportation fuel emissions on costs of achieving the policy goal, on CO_2 emissions, and on use of biofuels. In the case of cap-and-trade schemes, the environmental outcome is clear but the costs are uncertain. Only a standard set as a percent of biofuels can ensure that biofuels will be brought onto the market. A standard combined with a trading mechanism such as the RTFO in the UK provides flexibility and may therefore be a suitable instrument mix for increasing biofuels. If, however, the primary objective is reduced emissions from transport fuels, a cap-and-trade system focused on transport fuels such as suggested by DeCicco may be the more efficient instrument.

The apparent success of the RTFO suggests that it might form the basis for a mechanism to reduce road transport emissions on a European scale. However, the RTFO's weaknesses as well as its strengths need to be evaluated and weaknesses addressed before extending its use. In particular, the issues of emissions due to indirect land use change needs to be addressed. Some 25 percent of the biomass and biofuels used to meet the RTFO were imported from Argentina, Brazil, Indonesia and Malaysia [12]. Exports of biomass and biofuels may contribute to indirect land use change in all of these countries. Whether under a RTFO-type system or a cap-and-trade on transportation fuels, mechanisms need to be developed to address emissions due to land use change as well as emissions on land remaining in the same use that are currently escaping accounting systems and sustainability criteria.

5. Conclusions

The changes to the European Emission Trading Scheme in the EU Energy and Climate Package may strongly impact the investment behaviour in the power sector. In the power sector all allowances will be fully auctioned (with a few countries being granted exceptions) and the CO_2 price is likely to be higher than in the first two phases due to a stricter allocation of allowances. This may significantly improve the competitiveness of new biomass plants. Policymakers should be aware of the crucial importance of a high and stable CO_2 price in order to enable the needed long term investments, such as in new biomass plants. As the CO_2 price level up to 2020 is uncertain, and it is unclear whether and how long the CO_2 price will be over the required level there is a need for policymakers to implement additional instruments to stimulate the construction of new biomass plants. Additional instruments could be the use of subsidies, feed-in tariffs or tax relieves. Such additional instruments could give the companies more certainty on the costs.

The road transport sector, currently excluded from the EU-ETS, is unlikely to be involved into the scheme until 2013. Some member states, however, are already discussing pilot activities on a national level. One of the key questions, with respect to a GHG emissions trading scheme for the road transport sector, is whether the sector should be included directly in the existing EU-ETS or whether a separate, parallel scheme should be developed. It is a fact that abatement costs for liquid biofuels are in many cases significantly higher than many options in the energy and industry sectors (the main current EU-ETS sectors). The paper illustrates that liquid biofuels specifically would not benefit from an integration of the transportation sector in the EU-ETS nor from a separate cap-and-trade scheme for the transportation sector unless the carbon price is very (prohibitively) high.

The paper showed that the choice of the appropriate instrument depends on whether policymakers want to cap emissions in the transport sector or want to increase the use of biofuels. When the aim is to increase the use of biofuels significantly, a trading scheme based either on standards or on a cap on fuel distributors could be effective without leading to high costs of allowances in either the EU-ETS or in a transportation sector specific cap-and-trade system. Furthermore, such schemes can be designed to address issues of sustainability and to accelerate the implementation of new technologies. This approach was taken in the UK. Even if a separate scheme for biofuels may not be implemented in the EU in the short term, national pilot activities such as in the UK, could give valuable insights in the functioning of such a mechanism.

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