Global Feedstock Scenarios for Bioenergy - Land-Use Change and Trade-Offs

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Abstract: This paper presents scenarios of global feedstock supply for the production of bioenergy under specified social and environmental safeguard provisions. In particular, concerns for the preservation of biodiversity and the reduction of deforestation are considered in different combinations of scenarios. The objectives of this study were 3-fold: a) to achieve a global perspective using an integrated modeling approach; b) to frame the boundaries for lower scale assessments; and c) to identify potential trade-offs to be considered in future research. The aggregate results, achieved through the application of an integrated global modeling cluster, are in line with other studies predicting a doubling of global biomass supplies by mid-century. These supplies will to the largest extent be sourced from the conversion of unmanaged forest into managed forest, from new fast growing short rotation plantations and from intensification as well as optimization of land-use. Depending on the underlying scenario, it can be shown that zero net deforestation by 2020 can be reached and uphold while implying only a minor expansion into managed forests. Results further indicate that especially regions of the southern hemisphere i.e. the tropical belt will face controlled forest conversion from unmanaged to sustainably managed as well as increased protection of area for ecosystems services such as biodiversity. The study concludes with the recommendation of increased focus on targeted regional policy design and implementation following integrated global assessments.

Keywords: *bioenergy, integrated global modelling, scenario analysis, deforestation, forestry;*

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1. Introduction and Motivation

We are facing a future where a sustainable use of the planet's resources calls for renewable and carbon-neutral energy sources to meet increasing demands for energy. According to the International Energy Agency (IEA), a major opportunity to reduce fossil CO_2 emissions is the transition to alternative sources for energy production, including biomass from forests or agricultural crops (IEA 2010). Biomass can be used for heating, cooling, producing electricity and biofuels. Use of biomass may significantly reduce greenhouse gas (GHG) emissions, since the emissions from biomass are generally accounted as carbon-neutral, e.g., the EU Renewable Energy Directive (2009/28/EC).

In 2011, more than 60 countries had some type of national renewable energy target or support policy, according to the Global Renewable Policies and Measures Database. Climate change mitigation, energy security and protection of national industries are the major rationales for supporting renewable energy. However, the extent of social and environmental regulations for production of bioenergy feedstock varies very much between countries. Many developed and developing countries have ambitious bioenergy targets, but lack sound supporting legislation. Where legislation exists, it is often confused, fails to address socioeconomic and environmental aspects properly, and may create perverse incentives (Jull et al. 2007). Also country-level requirements for GHG emissions reduction are highly variable, as well as the assessment of compliance. Moreover, in most countries forestry legislation does not contain specific regulations concerning harvesting and use of forest biomass for bioenergy (Stupak et al. 2007).

Deficiencies in policies and legislation as well as in management guidelines in both developed and developing countries indicate that especially on global level, basic social and environmental values are at serious risk from increasing bioenergy production. Agricultural land, forest biodiversity, soil and water resources will all be under additional pressure from a substantially increased use of biomass from agriculture, forestry and waste for producing energy (FAO 2008 – Forests and energy). This development may also counteract other environmental policies and objectives, such as waste minimization or ecological farming. Lack of proper planning and management of feedstock production could also have severe socioeconomic effects such as conversion of farmland and forest at the expense of small farmers and forest living people, concentration of land ownership, increasing food prices and additional pressure on food supply in already vulnerable regions (FAO 2008 – Forests and energy).

Based on these insights, we conclude that it is of utmost importance to define and analyze scenarios of global feedstock supply for the production of bioenergy to identify boundaries for future development and guide both further research and policy-making. In doing this, economic development and population growth as well as social and environmental safeguard provisions should be taken into account. However, few studies have so far addressed this issue on a global scale. The reason is that this kind of analysis calls for integrated modelling; i.e., an interdisciplinary approach that combines economic models and geographic land use models. For large/scale and global analysis of land based sectors, the economic models used are general and partial equilibrium models. These models comprise demand for and supply of commodities, trade flows between different regions and land use competition. In a general equilibrium model all economic activities and sectors are considered, while a partial equilibrium model is specialized on one or a few specific sectors like forestry or agriculture. In integrated modelling, a geographic land use model is usually linked to the equilibrium model to provide information on constraints on supply and the actual, spatially explicit effects of land-use change processes. A limited number of equilibrium models of truly global scope have been used for modelling land use and land-use change (Heistermann et al. 2006). Most of these are focused on agriculture and only a few of these comprise the forest sector, e.g., GTAP, CGTM and GFPM (Heistermann et al. 2006). As far as we know, there has been no attempt to use integrated modelling for a global and spatially explicit assessment of bioenergy feedstock from both the agricultural and the forestry sector.

The objective of this paper is to provide an outlook on the potential feedstock for bioenergy as a contribution to the decarbonization of the energy sector

- with a global perspective using an integrated modeling approach
- to frame the boundaries for lower scale assessments and to justify research on bioenergy on various scales
- to identify potential trade-offs to be considered in future research

The remainder of the paper is organized as follows: the following section will give an overview of the biophysical agriculture model EPIC, the biophysical Global Forest Model (G4M), the energy models POLES and PRIMES, and the economic Global Biosphere Management Model (GLOBIOM) which will be used to assess the different scenarios that are described in section 3. This section starts with the baseline and then continues to explain how the different scenarios have been built. In Section 4, the results from analyzing combinations of these scenarios will be presented. A discussion of the results, policy implications and further research is provided in Section 4.

2. Method

2.1. *Modelling Biomass Supply at Global Scale – An Integrated Modeling Approach*

GLOBIOM, EPIC, G4M and POLES have been used for a long time in an integrated modeling framework (see figure 1). GLOBIOM (Havlík et al., 2011) bases its crop and forest sector details on biophysical parameters supplied by the more specialized models EPIC and G4M.

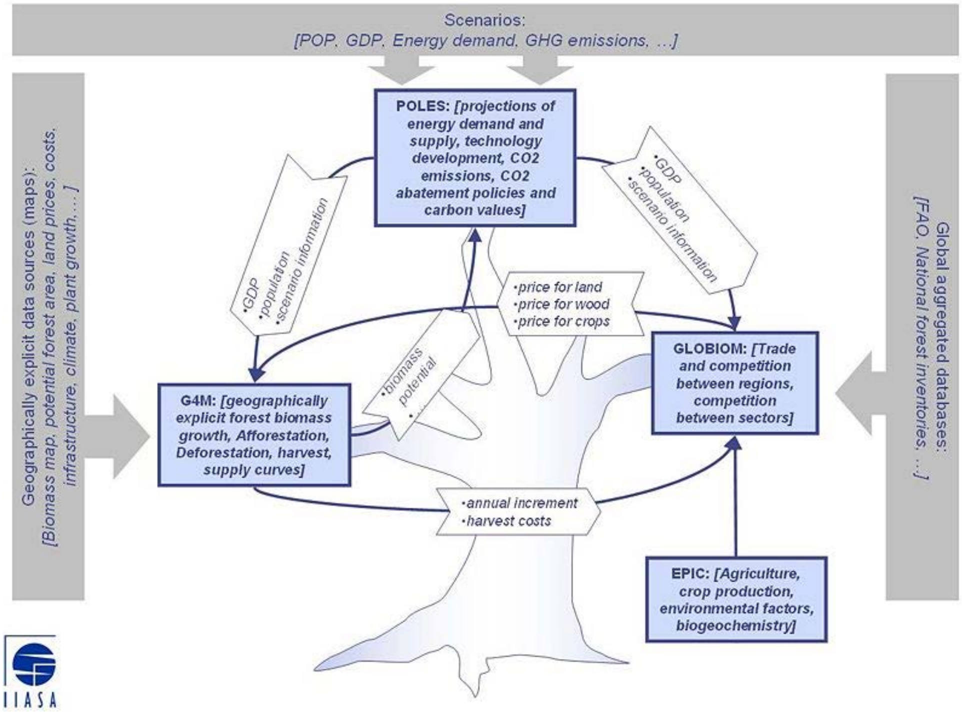

Figure 1: Integrated modeling cluster of GLOBIOM, EPIC, G4M and POLES

EPIC (Izaurralde et al., 2006) supplies to GLOBIOM detailed information on management related yields according to fertilizer and irrigation rates. EPIC is set up globally for 20 crops (barley, dry beans, cassava, chickpea, corn, cotton, cowpea, ground nuts, millet, oats, potatoes, rapeseed, rice, rye, soybeans, sorghum, sugarcane, sunflower, sweet potatoes and wheat). Four management systems are simulated by EPIC and implemented in GLOBIOM (irrigated, high input – rainfed, low input – rainfed and subsistence management systems). For each management system, EPIC provides to GLOBIOM information about yield, fertilizer and water requirements, as well as various environmental parameters including carbon and nutrient balance, and the connected greenhouse gas emissions, nitrogen leaching, soil erosion and other biophysical indicators (Table 1).

On the forestry sector side, G4M (Kindermann, 2008) provides to GLOBIOM information on mean annual increment, maximum share biomass usable as saw logs in the mean annual increment, and harvesting costs. G4M also supplies to GLOBIOM consistent accounts of carbon stocks in forests which are then used to assess GHG emissions related to deforestation. In an iterative procedure, G4M uses in return GLOBIOM projections on wood, land and agricultural commodity prices, as well as wood demand quantities, to estimate consistently with GLOBIOM future forest dynamics on high spatial resolution.

Additionally, GLOBIOM is linked to the JRC global energy model POLES (Prospective Outlook for the Long-term Energy System, Russ et al., 2007; EC, 2011) through information on macroeconomic indicators and bioenergy demand. Bioenergy demand is split in first generation biofuels, second generation biofuels, bioenergy plants and direct biomass use for energy. Population and GDP projections from the POLES model are also used as exogenous drivers for the G4M baseline.

Table 1: Parameter exchanged between the different models of the modeling framework

Model linkage	**Parameters exchanged**
EPIC → GLOBIOM	For 20 crops (>75% of harvested area) and 4 management systems (high input, low input, irrigated, subsistence) - crop yields - water balance (including irrigation water) - carbon, nitrogen and phosphorus balance
G4M → GLOBIOM	- Mean annual increment - Share of biomass suitable for sawnwood - Harvesting cost - Carbon stock in forests
POLES → GLOBIOM + G4M	- Population projections - GDP projections
POLES → GLOBIOM	- Bioenergy demand (fuel wood, biomass for energy industry, biofuels)
GLOBIOM → G4M	- Wood price projections - Land price projections - Agricultural commodity price projections - Demand for forest biomass by type

2.1.1. EPIC - Model

The EPIC (Environmental Policy Integrated Climate) model integrates a large number of terrestrial biophysical processes allowing for global environmental impact assessments of alternative land use management systems (Williams, 1995; Izaurralde et al., 2006). The major components in EPIC are weather simulation, hydrology, erosion-sedimentation, nutrient and carbon cycling, pesticide fate, plant growth and competition, soil temperature and moisture, tillage, cost accounting, and plant environment control. EPIC, as currently developed and run at BOKU University (Vienna), operates on a daily time step and is capable of simulating hundreds of years if necessary. Both, microbial nitrification and denitrification are modelled on an hourly basis in EPIC. The processes of methanogenesis and methanotrophy will be implemented as well to trace terrestrial CH4.

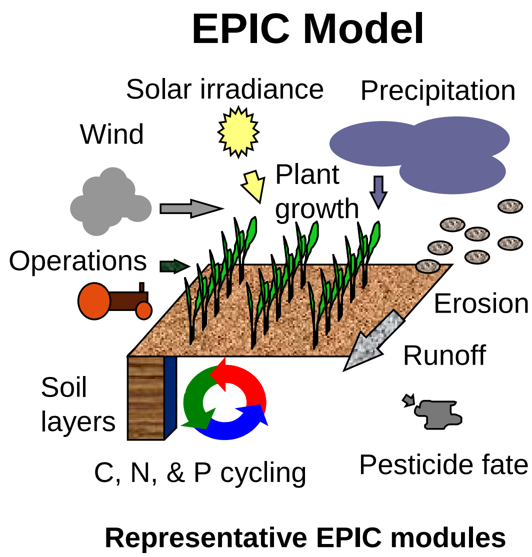

Figure 2: The EPIC Model

EPIC is used to compare land use management systems and their biophysical impacts on crop yields and biomass growth, hydrology, nitrogen emissions, soil organic carbon sequestration, sediment transport and on greenhouse gas emissions. The management components (e.g. latest Crop maps from IFPRI) that are currently analyzed include crop rotations, legume/grass mixes, agro-forestry, tillage operations, fertilization and irrigation scheduling.

The EPIC model is already operational on global and European scales and is continuously improved. It uses spatially and temporally explicit bio-physical impact vectors and allows the simulation of a large set of alternative crop management options. The model itself is very flexible and robust and is well grounded on a long modeling experience. The linkage to EU-FASOM Model and GLOBIOM Model is operational.

2.1.2. G4M

The Global Forest Model (G4M) is applied and developed by IIASA and estimates the impact of forestry activities on biomass and carbon stocks. By comparing the income of managed forest with income by alternative land use on the same place, a decision of afforestation or deforestation is made.

As G4M is spatially explicit (currently on a 0.5° x 0.5°resolution) the different deforestation pressure at the forest frontier can also be handled. The model can use external information from other models or data bases, which guarantee food security and land for urban development or account for disturbances. As outputs, G4M produces estimates forest area change, carbon sequestration and emissions in forests, impacts of carbon incentives (e.g. avoided deforestation) and supply of biomass for bio-energy and timber. For Europe the initial forest growing stock (aboveground biomass) per grid cell was taken from the European forest biomass map from Gallaun et al. (2010) and scaled to total biomass using the biomass map of Kindermann et al.

(2008). For countries outside Europe the original forest biomass map compiled by Kindermann et al. (2008) was used. The model handles age classes with one year width. Afforestation and disasters cause an uneven age-class distribution over a forest landscape. The model performs final cuts in a manner, that all age classes have the same area after one rotation period. During this age class harmonization time the standing biomass, increment and amount of harvest is fluctuating due to changes in age-class distribution and afterwards stabilizing.

The main forest management options considered by G4M are species selection, variation of thinning and choice of rotation length. G4M does not model species explicitly but a change of species can be emulated by adapting NPP, wood price and harvesting costs. The rotation length can be individually chosen but the model can estimate optimal rotation lengths to maximize increment maximize stocking biomass or maximize harvestable biomass.

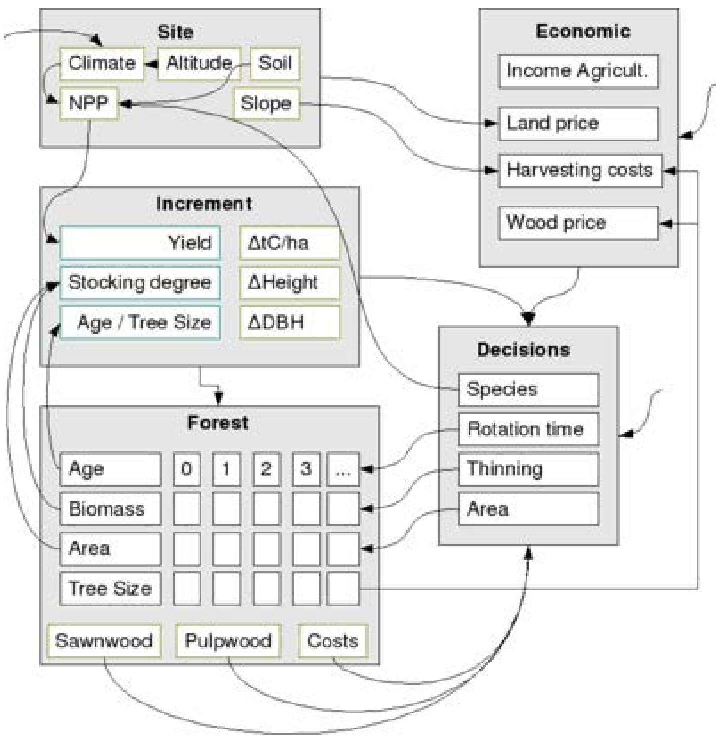

Figure 3: G4M Flow chard

2.1.3. GLOBIOM

The Global Biosphere Management Model (GLOBIOM) has been developed and is used at the International Institute for Applied Systems Analysis (IIASA). GLOBIOM is a global recursive dynamic partial equilibrium model integrating the agricultural, bioenergy and forestry sectors with the aim to provide policy analysis on global issues concerning land use competition between the major land-based production sectors. It is global in the sense that it encompasses all countries of the world, aggregated to 28 world regions. Partial denotes that the model does not include the whole range of economic sectors in a country or region but specializes on agricultural and forestry production as well as bioenergy production. These sectors are, however, modeled in a detailed way accounting for about 20 globally most important crops, a range of livestock production activities, forestry commodities as well as different energy transformation pathways.

GLOBIOM disaggregates available land into several land cover/use classes that deliver raw materials for wood processing, bioenergy processing and livestock feeding. Figure 4 illustrates this structure of different land uses and commodities.

Forest land is made up of two categories (unmanaged forest and managed forest); the other categories include cropland, short rotation tree plantations, grassland (managed grassland) and 'other natural vegetation' (includes unused grassland).

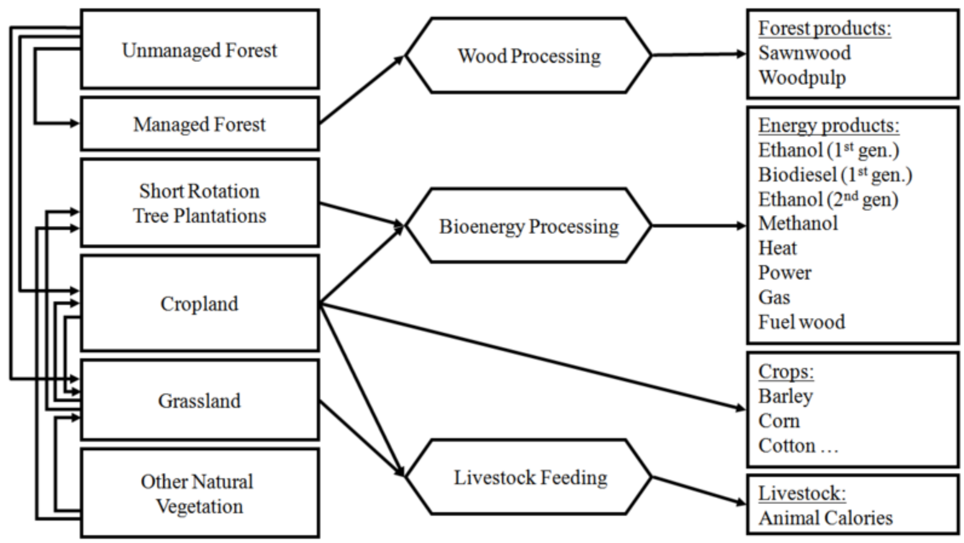

Figure 4: Supply sectors as represented in GLOBIOM

The detailed modeling of land based activities means that the GLOBIOM model relies on a detailed database containing geo-spatial information. For the bulk of global crop production four management systems are available in GLOBIOM; these are irrigated, high input – rainfed, low input – rainfed and subsistence management.

The global agricultural and forest market equilibrium is computed by choosing land use and processing activities to maximize welfare subject to resource, technological, and policy constraints. These constraints ensure that demand and supply for inter alia irrigation water and land meet but also impose exogenous demand constraints so as to reach, for instance, a certain biofuel target. Prices and international trade flows are endogenously determined for respective aggregated world regions (i.e. in this context for the 28 regions mentioned above). Imported and domestic goods are assumed to be identical (homogenous), but the modeling of trade does take into account transportation costs and tariffs. GLOBIOM includes accounting for greenhouse gas emissions and sinks from agricultural and forestry activities. This includes among others accounting for N2O emissions from fertilizer use whose intensity in turn depends on the management system.

It is possible within the model to convert one land cover/use to another; the total land area spanning all the categories included remains fixed, however (this forms part of the constraints mentioned earlier). The arrows on the left-hand side of Figure 4 indicate the initial land category and therefore show the way in which land cover/use can change (i.e. unmanaged forest can be converted into managed forest or cropland). The greenhouse gas consequences from land use change are derived from the carbon content of above- and below-ground living biomass of the respective land cover classes.

Five primary forest products are defined: sawlogs, pulplogs, other industrial logs, firewood, and energy biomass. Sawlogs, pulplogs and energy biomass are further processed. Sawnwood and woodpulp production, and demand parameters rely on the 4DSM model described in Rametsteiner et al. (2007). FAO data and other secondary sources have been used for quantities and prices of sawnwood and woodpulp. For production cost estimates of these products, for example, mill costs, an internal IIASA database and purchased data were used. The energy biomass can be converted into methanol and heat or electricity and heat, where processing costs and conversion coefficients are obtained from Leduc et al. (2008), Hamelinck and Faaij (2001), Sørensen (2005), and Biomass Technology Group (2005). Demand for woody bioenergy production is implemented through minimum quantity restrictions, similarly as demand for other industrial logs and for firewood.

The model is recursive dynamic in the sense that changes in land use made in one period alter the land availability in the different categories in the next period. Land use change is thus transmitted from one period to the next. As GLOBIOM is a partial equilibrium model, not all economic sectors are modeled explicitly. Instead, several parameters enter the model exogenously, or are pre-determined in other words, including wood and food demand which in turn are derived from changes over time in gross domestic product (GDP), population and food (calorie) consumption per capita (projections according to FAO 2006). Assumptions on GDP, population growth and calorie consumption per capita are the underlying driver of the model dynamics. The base year for the model is the year 2000, the model horizon in this study is 2030. The exogenous drivers population and GDP growth have been updated to take recent economic downturns into account by relying on 2009 data. In relation to yield development, GLOBIOM typically assumes 0.5 % autonomous technological progress in crop improvement; in addition, the possibility to shift between management systems as well as the relocation of crops to more productive areas also provides for regional average yield changes. When it comes to ‘bioenergy dynamics’, projections from the POLES model (for regions outside Europe) and the PRIMES model (for EU 27 countries) on regional biomass demand in heat and power (BIOINEL), direct biomass use i.e. for cooking (BIOINBIOD) and liquid transport fuel use (BFP1 and BFP2 or first and second generation biofuels, respectively) over the next two decades are implemented in GLOBIOM as target demands or minimum demand constraints.

Resources for the different types of bioenergy products can be sourced from agricultural and (existing) forestry activities but also from newly planted short rotation tree plantations. First generation biofuels include ethanol made from sugarcane, corn and wheat, and biodiesel made from rapeseed, palm oil and soybeans. Biomass for second generation biofuels is either sourced from existing forests/wood processing or from short rotation tree plantations. Havlík et al (in press) define different scenarios for the sourcing of second generation biofuels. They also conducted an analysis to establish the scale of land available for short rotation tree plantations. Summarized in a few words, they arrive at available area by excluding areas unsuitable for their level of aridity, temperatures, elevation and population density from total arable land area (grassland, cropland, 'other natural vegetation').

2.2. ***Scenario Settings, Assumptions and Definitions***

Under any scenario assumption, the full potential of forests with respect to their production, protection and welfare functions will be only realized if it is possible to reduce or stop deforestation and forest degradation. As underlying settings to our scenarios we hence decided to compare a future development of feedstock under the assumption that there are, with the exception of protected areas, no restrictions with respect to deforestation (*No RED; RED = Reducing Emissions from Deforestation*) to the assumption that there is strong restriction (*100% RED*). In our study, *100% RED* is defined as "Zero Net Deforestation and Forest Degradation (ZNDD) by 2020" - in accordance with WWF's Living Forests Report (2011). ZNDD means that there is no net forest loss through deforestation and no net decline in forest quality through degradation. However, ZNDD does not mean that there is no forest clearing anywhere, but it recognizes peoples' right to clear some forests for agriculture, or the value in occasionally "trading off" degraded forests to free up other land to restore important biological corridors, provided that biodiversity values and net quantity and quality of forests are maintained. In other words, most natural forest should be retained, and the gross loss or degradation of pristine natural forests would need to be offset by an equivalent area of socially and environmentally sound forest restoration. Note that plantations are not equated with natural forests as many values are diminished when a plantation replaces a natural forest.

2.2.1. "Baseline No RED" Scenario

The *Baseline Scenario* assumes that our behavior continues in line with historical trends. Under this "business as usual " (BAU), land-use change is anticipated due to (a) demands for land to supply a growing global human population with food, fiber and fuel; and (b) continuation of historical patterns of poorly planned and governed exploitation of forest resources. Key assumptions in this scenario are:

- By 2050, world population reaches 9.1 billion and per-capita GDP almost triples;
- Demand for commodities is driven by changes in affluence (measured by GDP) and human population growth;
- Aggregate historical trends in agricultural productivity gains continue;

- the average human diet in a country changes according to historically observed relationships with per-capita GDP;
- Forestry and agricultural production does not expand into protected areas, but unprotected natural habitats can be converted to timber plantations, cropland and pasture (*No RED*);
- Total primary energy use from land-based biomass feedstock doubles between 2010 and 2050 due to projected energy demand and the competitiveness of bioenergy technologies and supply chains.

2.2.2. "Bng2010 No RED" Scenario

In the *Bioenergy 2010* (*Bng2010*) *Scenario* it is assumed that the bioenergy feedstock demand is "frozen" at its 2010-level and does not change beyond 2010. The "*Bng2010 No RED*" is linked to no restriction with respect to deforestation as explained in section 3 and is used as a comparison scenario in the results section of this study.

2.2.3. "BngPlus No RED" and "BngPlus 100% RED" Scenarios

In the *Bioenergy Plus* (*BngPlus*) *Scenario*, the bioenergy feedstock demand is based on the "global 2ºC scenario" derived from the POLES model (EC, 2011) and is and approximation of the projected bioenergy demand by 2050 in the 100% renewable energy vision by the Ecofys Energy Model (Singer, 2011)[1].

This scenario projects demand for bioenergy from land-based feedstock (excluding those not competing for land, such as municipal solid waste, industrial waste and algae) of 75.6EJ final energy supply in 2050, of which 16.9EJ are liquid biofuels.

The *Bioenergy Plus Scenario* helps explore implications for global land availability and productivity of producing sufficient bioenergy feedstock to meet future demand.

Some important assumptions of the *Bioenergy Plus Scenario* include:

- A higher carbon price and more ambitious GHG emission reduction targets than the Baseline Scenario. This makes bioenergy more competitive relative to fossil fuels, provided bioenergy use delivers genuine, full life-cycle carbon savings. This competitiveness is tempered, however, by higher bioenergy feedstock prices as more bioenergy is used.
- The land-based bioenergy feedstock is produced in natural forests managed jointly for biomass and timber production, timber plantations and in croplands. Harvesting in natural forests is modeled on a sustained yield basis.
- The model assumes that tree tops, branches and stumps (harvesting residues) are not removed from forests to ensure soil protection and long-term fertility.

[1] This scenario projects demand for bionenergy from land-based feedstocks in 2050 of 71.4 EJ, of which 16 EJ are liquid biofuels

- Traditional fuelwood harvesting is done on a sustained yield basis, phasing out current uses that cause forest loss or degradation. This shift is achieved, despite population growth, by increasing fuelwood sourced from dedicated plantations and reducing per capita fuelwood demand through introduction of more efficient stoves and heating systems that are less detrimental to human health.

The *Bioenergy Plus Scenarios* - that can be combined with no restriction with respect to deforestation (*No RED*) as well as with restrictions (100% RED) as outlined in section 3 – and also the *Baseline Scenario* (*No RED*) assume four main processes of bioenergy conversion, which are summarized in Table 1 below.

Table 2: Bioenergy conversion processes

Traditional uses	**New technological uses**
Wood heat: primary energy from wood turned into heat for domestic cooking and heating.	*First generation biofuels*: mainly bioethanol and FAME (fatty acid methyl esters) produced from starchy and oily agricultural crops. The main crops are sugarcane, corn, rape seed, soya and palm oil.
Heat from other biomass: primary energy from sources such as dung and crop residues turned into heat for domestic cooking and heating.	*Polygeneration*: primary energy from mostly woody biomass turned into electricity and heat (i.e., combined heat and power - CHP) or second generation biofuels produced mainly from wood, turned into transport fuel, gas, electricity and heat.

2.2.4. "BioLevel3 100% RED" Scenario

The BioLevel3 100% RED Scenario was developed to explore the impact of stricter biodiversity protection. Here it is assumed that remaining natural ecosystems are protected (i.e., no further conversion of these ecosystems to cropland, grazing land, plantations or urban settlement) in areas identified as important for biodiversity by anyone of the conservation mapping processes listed below. This scenario assumes that current land uses (e.g., cropland or forestry) in these areas remain constant and continue to produce food or timber.

- The UNEP-WCMC World Database on Protected Areas lists most existing protected areas; the Model uses 2009 data, with no land conversion allowed within these areas even under the Do Nothing Scenario

- WWF Global 200 Ecoregions are the most biologically distinct terrestrial, freshwater, and marine ecoregions of the planet, selected for exceptional levels of biodiversity and as representative of ecosystems
- WWF/IUCN Centres of Plant Diversity are areas of key significance for global plant biodiversity
- Amphibian Diversity Areas represent areas significant for global amphibian diversity
- Conservation International's Hotspots are areas in which there are large numbers of endemic plant and vertebrate species, and where less than 30 per cent of the natural habitat remains
- Birdlife International Endemic Bird Areas are areas where two or more bird species with ranges smaller than 50,000 km^2 co-occur
- Alliance for Zero Extinction sites are considered key sites for conservation to safeguard the last remaining refuges of endangered or critically endangered species

2.2.5. Bioenergy Definition for this study

Under the different scenarios – especially with respect to ZNDD – the (bio-) energy markets and policies will be differently affected regarding land availability for bioenergy crops, fast growing tree plantations and the supply of wood from existing natural or semi-natural forests. On the other hand, bioenergy is seen as an inevitable component of the future energy portfolios and by that carries significant environmental and social risk.

In this study we distinguish between wood-based bioenergy and crop-based bioenergy. In the first case, the bioenergy can either be produced from forests or from fast growing short-rotation plantations. Depending on this source and on the current characteristics of standing biomass (i.e. age distribution, growth rate, intensity of harvesting, disturbances, soil carbon, harvesting regime, and further management activities, etc.) the climate balance of wood-based bioenergy can vary. For example, intensive management practices like whole tree harvesting and use of fast-growing exotic species or fertilizers generally have a worse climate (e.g. regarding C-sequestration and C-emission) and ecological balance than in the case of bioenergy that is supplied from fast-growing plantations on degraded lands, using sustainable forest management practices and hence can provide climate-friendly fuel and increase carbon storage.

In the case of crop-based bioenergy which is also included in this study's assessment, we identified a clearly competitive situation for the world's productive arable land. For reasons of GHG-saving potentials, biofuels from agricultural origin ideally need to be sourced from land that does not cause forest conversion – direct or indirect. Some of the currently produced bioenergy products (i.e. some first generation biofuels) generate substantial environmental and social costs while others need to be irrigated or are displacing essential food crops causing deforestation as ultimate consequence. Thus, a careful balancing balance between all these factors and the clearly positive aspects in terms of GHG emission reduction was considered for our analysis.

2.2.6. Background on global forests

What the FAO statistics (FAO, 2010) and WWF's Living Forest Report (2011) say:

- Forests (including plantations) cover around 4 billion ha, or 31 per cent of the planet's land surface, with over half located in five countries: Russia, Brazil, Canada, the United States and China
- About 47 per cent of forests are tropical, 9 per cent subtropical, 11 per cent temperate and 33 per cent northern boreal
- Forests support 1.6 billion people, with 300 million living in forests including 60 million indigenous people. 10 million people work in forest management and conservation
- Wood removals were valued at US$100 billion/year from 2003–2007
- Gross deforestation has slowed a little since the 1990s, but is still 13 million ha per year
- Forest protected areas have increased by over 94 million ha since 1990 to around 13 per cent of the world's forests; however some forest types still have poor protection or protection is ineffective
- Deforestation is unevenly spread: natural temperate forests in much of the northern hemisphere are expanding, while tropical forests and forests in some temperate regions of the southern hemisphere are shrinking
- The 10 countries with largest annual net loss of forest area from 2000–2010 were: 1) Brazil; 2) Australia; 3) Indonesia; 4) Nigeria; 5) Tanzania; 6) Zimbabwe; 7) Democratic Republic of the Congo; 8) Myanmar; 9) Bolivia; and 10) Venezuela
- "Planted forests" make up only 7 per cent of total forest cover, yet could provide around two-thirds of global industrial wood production (Carle and Holmgren, 2008)
- 1.31 billion ha of forests (around one-third of the world's forest cover) are classified as intact forest landscapes (Stolton and Dudley, 2010)
- Forests supply ecosystem services: carbon sequestration; protection against floods, landslides, avalanches, ocean surges, and desertification; provision of clean water, medicines, crops, and fish; space for recreation and exercise; and places sacred to the world's various faiths (Potapov, et al., 2008)

3. Results

3.1. ***Outlook on forest development***

When analyzing the general development of the global biomass feedstock from a deforestation point of view, the comparison between the different scenarios indicate that under the *Baseline No RED Scenario*, 286 million hectares of forest is lost through land-use change between 2000 and

2050 (accumulated). Slightly more forest will be lost under the *BngPlus No RED Scenario*, 303 million hectares (Figure 5). This comparatively little difference between the baseline and the increased bioenergy scenario can be explained by the fact that already under the baseline, almost the same demand for bioenergy exists in 2050 than under the *BngPlus*. In other words, by 2050, most options for the energy portfolio include huge shares of bioenergy in order to meet the increasing global energy demand. In figure 5 it is clearly shown that even when keeping bioenergy demand constant between 2010 and 2050 (*Bng2010 No RED Scenario)* the accumulated deforested area is 260 million hectares in 2050, almost as high as for the *Baseline No RED* and the *BngPlus No RED Scenarios*. This phenomenon can be explained by the fact that there is no restriction on the Bng2010 No RED Scenario to source all bioenergy demand from (non protected) pristine forest. The difference in area between *BngPlus No RED* and the *Bng2010 No RED Scenarios*, 43 million hectares, represents the area deforested due to bioenergy production under the *BngPlus No RED Scenario*, which roughly corresponds to the size of Sweden. In contrast, under those scenarios combined with 100% RED (ZNDD) less than 20 million hectares of forest will be lost.

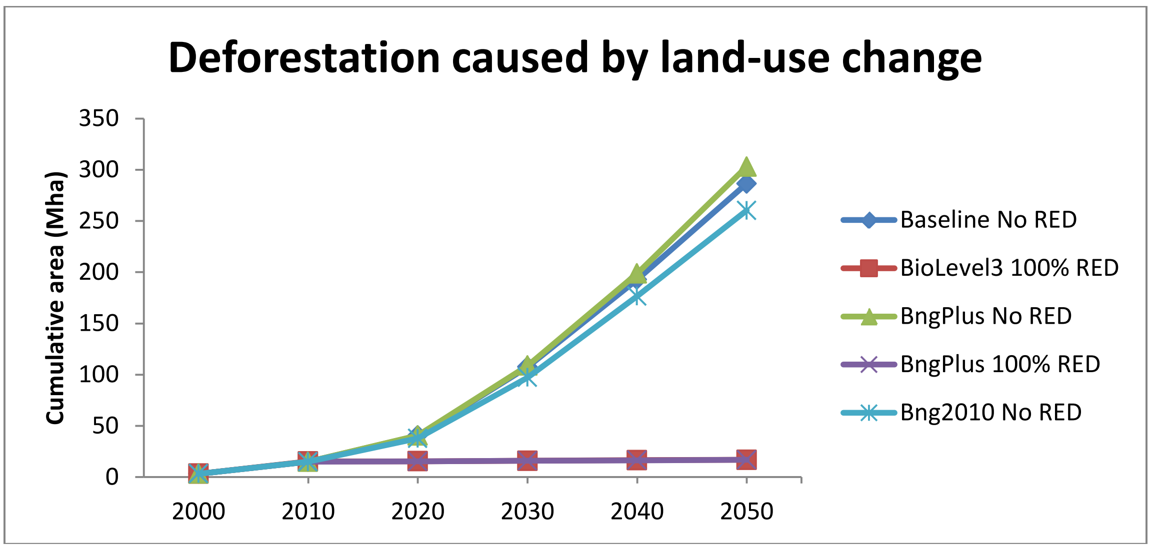

Figure 5. Cumulative deforestation 2000-2050 caused by land-use change according to the different scenarios.

Since it is allowed to convert unmanaged forest into sustainably managed forest, under all scenarios, the area of managed forest will increase. The largest increase, of more than 300 million hectares, takes place under the *BngPlus No RED* and BngPlus *100% RED Scenarios*, while the increase under the *Bng2010 No RED Scenario* is less than half of this, only 124 million hectares. Again in this comparison the difference can be explained such that under those scenarios combined with ZNDD (100% RED), no net deforestation but conversion from unmanaged into managed forest is possible.

3.2. ***Bioenergy potential under different scenarios***

In figure 6 the total bioenergy production under the individual scenarios is described. The total bioenergy demand was approximately 450 Mtoe in 2010 and according to definition the bioenergy production is kept constant at this level in the *Bng2010 No RED Scenario*. From 2020 and onwards, the bioenergy production will increase more under the *BngPlus No RED* and *BngPlus 100% RED Scenarios* than under the *Baseline No RED* and *BioLevel3 100% RED Scenarios* (Figure 6). In 2050, the bioenergy production under the *BngPlus No RED Scenario* will be 1806 Mtoe and slightly less, 1776 Mtoe under the *BngPlus 100% RED*, while the *Baseline No RED Scenario* results in a bioenergy production of 1545 Mtoe. It is interesting to note that about the same total bioenergy production is generated under the BngPlus scenarios, no matter if under deforestation restriction or not. The only difference is that under No RED the largest part of the bioenergy will be sourced in unmanaged or pristine forest while under the 100% RED (ZNDD) the largest part of the bioenergy production will be sourced by intensification (short rotation plantations) and partially through conversion from unmanaged into managed forest. The latter produces consequently the same amount of bioenergy but at less environmental and social costs.

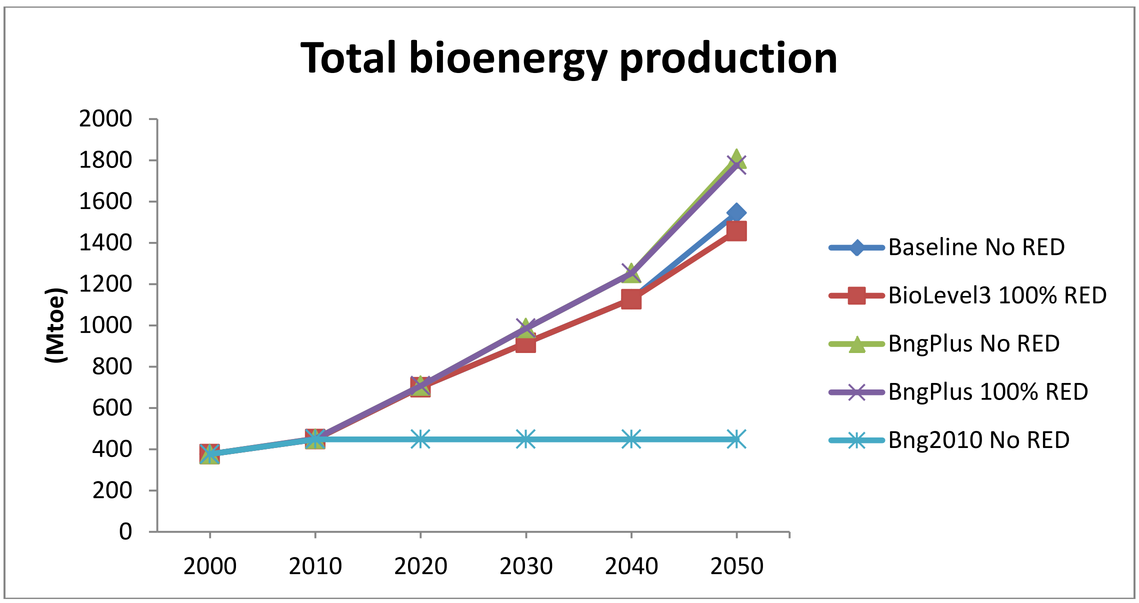

Figure 6. Total production of bioenergy 2000-2050 under the different scenarios.

If split into different categories of bioenergy, the scenarios show various patterns. All scenarios but the *Bng2010 No RED* indicate that production of bioenergy for heat and power will be increasingly important in the future and form a large part of the total bioenergy. Thus, the scenarios show the same patterns as they do for the total bioenergy production. In 2050, as much as 1031 Mtoe bioenergy will be used for heat and power under the *BngPlus No RED Scenario* while the bioenergy production under the *Baseline No RED* is 869 Mtoe.

In 2010, the production of first generation biofuels was 26 Mtoe. Under the *Baseline No RED* and *BioLevel3 100% RED Scenarios* the production will increase to 56 Mtoe in 2030 and then decrease. Under the *BngPlus No RED* and *BngPlus 100% RED Scenarios* the production will also increase, culminate in 2040 on 54 Mtoe and then decrease.

3.3. ***Land-use change under additional bioenergy demand***

By comparing the cumulative land-use change due to bioenergy production under the biodiversity protecting *Biolevel3 100% RED Scenario*, it can be shown that the target of avoiding deforestation creates a typical pattern of land-use change with respect to the different land-use types. In 2050, areas of other natural vegetation have decreased by 354 million hectares, grasslands by 272 million hectares, and croplands by 91 million hectares (Figure 7). Areas of short rotation coppice have increased by 314 million hectares, unmanaged forest by 224 million hectares and managed forest by 179 million hectares. It is clearly indicated that the protection of biodiversity within pristine and other types of forest would be at the costs of e.g. grassland and savannah (which is mostly located in the southern hemisphere).

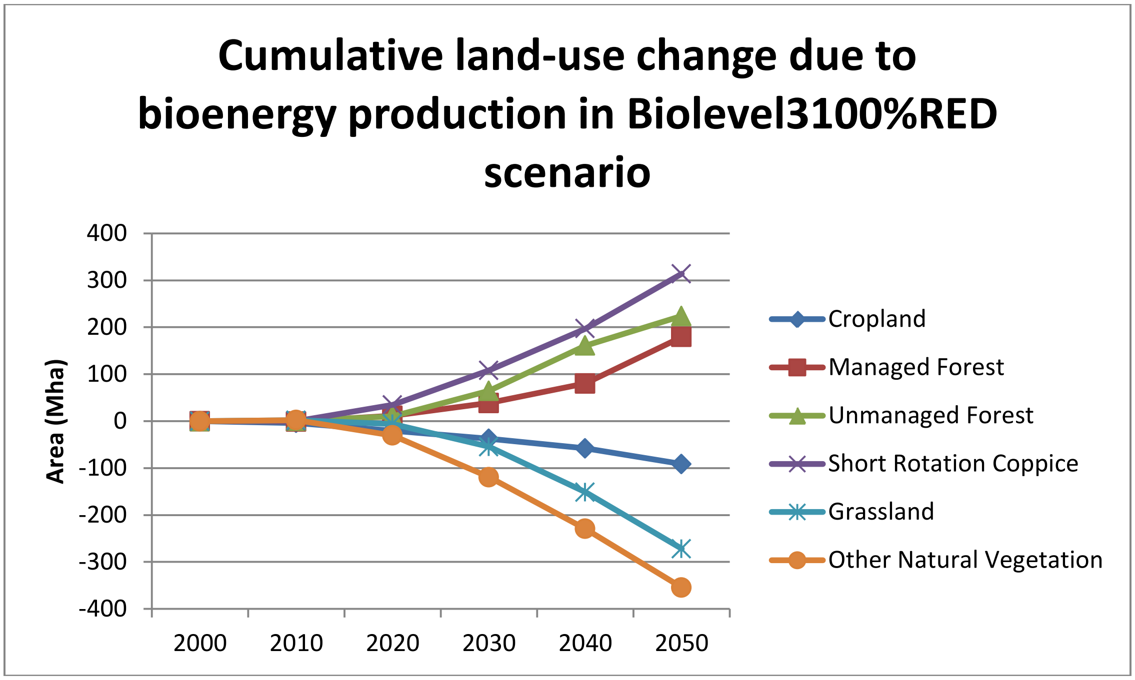

Figure 7. Cumulative land-use change caused by bioenergy production under the BioLevel3100%RED scenario.

3.4. ***Regional effects on ecosystem services from additional bioenergy demand***

Increased bioenergy feedstock production directly affects land use and land-use change and thereby various ecosystem services like biodiversity, carbon fixation and water resources.

The effects of feedstock production on biodiversity cannot be directly assessed with the model cluster used. However, here we use the area of unmanaged forest as a proxy for biodiversity of forest ecosystems. In 2000, the area of unmanaged forest was 3146 million hectares, compared to the area of managed forest, which was 719 million hectares and the area of short-rotation plantations which was 47 million hectares. Unmanaged forest will be lost under all scenarios but under the *BngPlus 100% RED* and *BioLevel3 100% RED Scenarios* the loss in 2050, 336 million hectares and 260 million hectares, respectively, is only half of the loss under the *Baseline No RED Scenario*, 529 million hectares.

Under the *Baseline No RED Scenario* (= business as usual with no deforestation restriction), most of the loss of unmanaged forest takes place in the tropical areas of South America, Africa and Asia. Compared to that, under the *BngPlus 100% RED Scenario*, the loss of unmanaged forest is not only considerably smaller but also more evenly distributed in a global perspective (Figure 8). This is the general pattern under the other *100% RED* Scenarios as well.

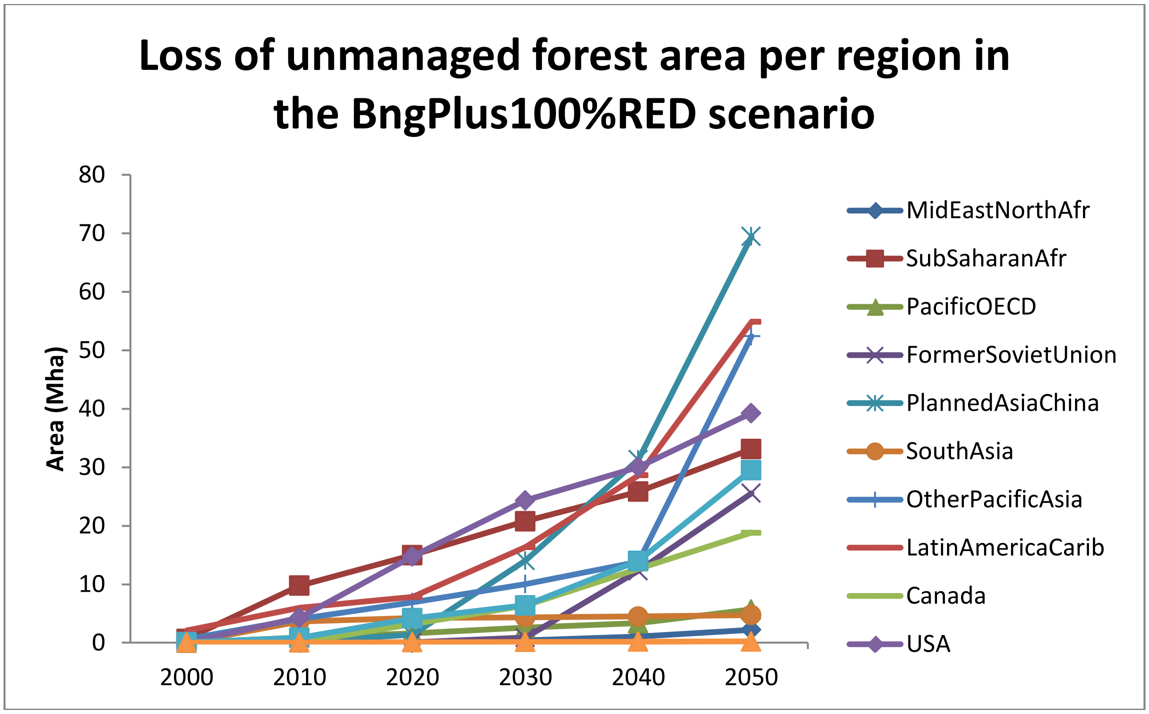

Figure 8. Cumulative loss of area of unmanaged forest 2000-2050 in different regions under the BngPlus100%RED scenario.

3.5. ***GHG effects on ecosystem services from additional bioenergy demand***

The scenarios show that although bioenergy is a better alternative than fossil fuels, bioenergy production indirectly affects GHG emissions considerably through deforestation. Under the *Bng2010 No RED Scenario*, the bioenergy use is small compared to the other scenarios, and the GHG emissions are the highest, 8091 Mt CO_2/year. The GHG emissions are lower under the *Baseline No RED* and *BngPlus No RED*, where the bioenergy use is more extensive. However, under the *BngPlus 100% RED* and *BioLevel3 100% RED Scenarios* the GHG emissions are considerably lower, around 5000 Mt CO_2/year, due to the restrictions on deforestation (Figure 9).

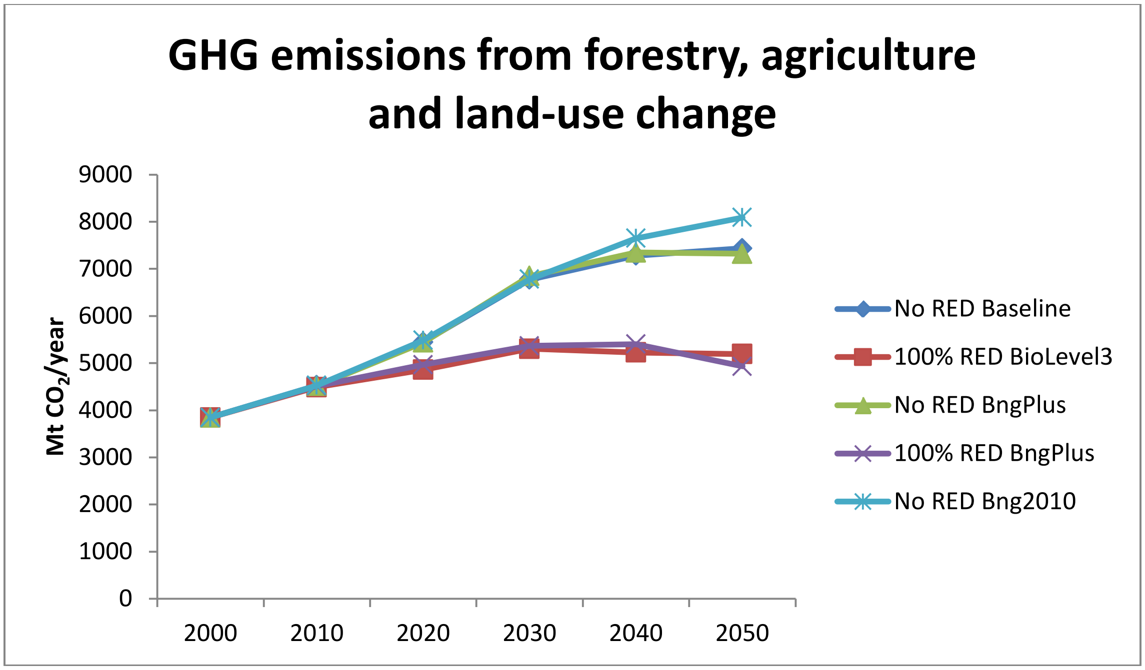

Figure 9. GHG emissions from forestry, agriculture and land-use change 2000-2050 under the different scenarios.

3.6. *Water effects on ecosystem services from additional bioenergy demand*

Water resources will be affected by increased bioenergy feedstock production directly but also indirectly through higher pressure on agricultural land. Consequently, the water consumption for agriculture is lowest under the *Bng2010 No RED Scenario*, only 0.97 Mt in 2050, because of the low level of bioenergy production. The water consumption for agriculture is 1.00 Mt in 2050 under the *Baseline No RED* and the *BngPlus No RED Scenarios*, where the bioenergy production is higher. Under the BngPlus100%RED and BioLevel3100%RED scenarios the water consumption is highest because the restriction on deforestation calls for even more intensive use of the agricultural land through, e.g., increased irrigation.

4. Discussion, Conclusions and Outlook

Without additional policies in place to halt deforestation and forest degradation, both the Baseline and Bioenergy Plus scenarios project bioenergy leading to some increased deforestation. Bioenergy is, however, not a major driver of forest loss.

In theory, deforestation due to the expansion of bioenergy feedstock production should be limited in the Bioenergy Plus Scenario, as this assumes energy and climate policy frameworks that require reduced GHG emissions. This prompts a move from the production of first generation crop-based biofuels to second generation biofuels derived from wood harvested in managed natural forests or plantations established on non-forest land. However the Model projects that these frameworks are not enough to stem deforestation completely, as some expansion of bioenergy will be driven by public policy incentives not linked to climate change –

such as energy security goals – or markets that do not require compliance with environmental safeguards.

Between 2040 and 2050, when the food and energy demands of a rising global population make land competition most acute, projected loss of non-forest ecosystems such as shrublands is 8.5 million hectares per year under the *Baseline Scenario*, with 4.3 million ha attributed to bioenergy. Under *Bioenergy Plus*, projected loss is 10 million ha per year, with 5.8 million ha attributed to bioenergy. Impacts on other ecosystems are greater if forests are more strictly protected; so if *ZNDD/100% RED* and *Bioenergy Plus Scenarios* are combined, projected loss of other natural habitats grows to 13.5 million hectares per year, with 9.4 million ha (70 per cent) due to bioenergy.

Such land use changes could have major social, cultural and economic impacts, along with impacts on biodiversity and the provision of ecosystem services. The addition of biodiversity protection (*BioLevel3*) reduces this problem of leakage and indicates that quite large areas of land could be used for bioenergy feedstock production (7.3 million ha) without major impacts on biodiversity. But experiments show that the impacts would result in higher food prices. With rising populations and projected consumption levels, our planet does not have enough land simultaneously to conserve nature completely, halt forest loss and switch to 100 per cent renewable energy. This means that many of us will need to reduce our overall resource consumption, for example with respect to the amount of animal-based calories in our diets.

Today 1.2 billion hectares, or 30 per cent of forests, have production designated as their primary function (FAO, 2010). The projected expansion of forest management based on the model results is driven primarily by demand for bioenergy. Between 2040 and 2050, a projected 14.5 million hectares per year of additional natural and semi-natural forests are dedicated to forest management under *Bioenergy Plus Scenarios*; with the total area managed for production of timber and biomass expanding by 304 million hectares between 2010 and 2050.

Aiming for instance at near zero forest loss does not have much impact on the rate of expansion of forest management (as the *Bioenergy Plus Scenario* assumes the expansion is via sustainable forest management that does not cause forest loss or degradation). Similarly adding a nature conservation element into the projections through adding a lower biodiversity conservation scenario than the *BioLevel3 Scenario* has only a small impact. Adding the BioLevel3 Scenario, however, "pushes" bioenergy feedstock production into natural forests by excluding the conversion of large areas of other natural habitat and doubles the size of the additional forest area that needs to be allocated to production each year.

An increase in the area of natural forest allocated to sustainable management is considered preferable to outright loss of forests or other natural ecosystems with high conservation value through conversion to energy plantations. This is based on an assumption that such managed forests will still support much of the original biodiversity and ecosystem services. Some forests brought under management might already be degraded or impacted by illegal use; in these cases management can bring positive environmental and social benefits. However projections suggest that relatively pristine forests will also need to be managed and great care will be needed to maintain or enhance their social and environmental values.

Forest management certificationt is seen as one of the key tools to be applied in order to ensure sustainable management combined with control of illegal logging, while still proving to encourage local forest owners to produce biomass for bioenergy (Kraxner et al., 2010). However, most of the certification activities are still only carried out on the northern hemisphere while the need for certification needs to be clearly focused on the tropical belt of the southern hemisphere (Kraxner et al., 2011). This is also proven in the regional analysis included in this study which shows that most forest losses and conversion (to the cost of other land-use type) is happening in the south.

The biodiversity and carbon implications of extracting more biomass from more forests will depend on factors such as the intensity of management, quality of environmental practices and connectivity with protected areas. From a social perspective, management not under the direct control of indigenous peoples or local communities should ensure forests remain accessible for traditional uses. Indeed, bioenergy could provide an additional revenue stream for forest communities, which could motivate them to manage rather than clear forests.

The immediate drivers of deforestation and forest degradation are complex. They include demand for food, fuel and fiber, but also pollution, human-induced disturbances (e.g., fires) and invasive species. Those clearing forests vary from individual families to some of the world's largest corporations. Illegal logging operations target valuable timber, including from protected areas (WWF, 2010).

It can be concluded that the listed facts to gether with the projections deriving from this study regading GHG emissions make urgent action with respect to policy assessment, integrated policy design, implementation as well as law enforcement and improvement of governance inevitable. Focus needs to be put on intensification and technological shift in order to achieve and uphold ZNDD. Targeted policy action has to come along with R&D in an integrated way that ensures local and regional policy targets and directives are based on global assessments.

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