Study on Impacts on Resource Efficiency of Future EU Demand for Bioenergy

Task 4: Resource efficiency implications of the scenarios

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1. Introduction

The purpose of this report is to document methodology and results of Task 4 of the project "Study on Impacts on Resource Efficiency of Future EU Demand for Bioenergy". The aim of Task 4 is to use the outcomes of Task 2 and Task 3 to assess the impacts of the production of biomass for energy on natural resources and the global environment. The assessment covers direct and indirect impacts[1] because the applied models (GLOBIOM and G4M) cover the entire land use sector and the whole globe. Thus, by comparing different scenarios with varying assumptions any impact on environmental indicators can be assessed. Different environmental indicators have been identified based on the findings from Task 2 and tightly linked to model output variables. In a first step the impacts on resources in the different policy scenarios are assessed against those foreseen under the baseline scenario by looking at the performance of selected indicators. In a second step constraints on specific model variables are introduced that aim to reduce impacts, shift production patterns and biomass origin. By this means we will assess not only implications of biomass use for the global environment but also implications of potential policy interventions for biomass resource efficiency in EU28.

2. Methodology

For the analysis of impacts a two-stage approach is followed:

In Stage 1, a screening of **environmental indicators** is carried out. A first necessary step is the definition of these indicators for the analysis of impacts. This is done by aggregating, converting and interpreting direct model output variables in a way that allows for linking them to environmental concerns, such as GHG emissions, land conversion, loss of biodiversity, water and soil issues. In this analysis we focus on environmental indicators only, as economic aspects are covered by Task 3 and social aspects are outside the scope of this study.

Selected indicators related to GHG emissions and potential environmental impacts on soil, water and biodiversity are screened in each of the selected policy scenarios (see Report on Task 3 for the description of these scenarios). The changes in scenario assumptions are expected to affect indicators differently. As an example, the increased EU Biomass Import Scenario can be expected to increase the pressure on the forest and agricultural sectors in the Rest of the World (RoW) to produce bioenergy feedstocks which in turn may affect the environmental indicators in these countries. The monitoring of indicators across all scenarios will allow the identification of those indicators that are most variable and show most extreme responses.

In Stage 2, **environmental constraints** are introduced to the model. The analysis focuses on those Stage-1 environmental indicators that are most variable across scenarios. These indicators are converted into environmental constraints. This means that if a significant change in an indicator was observed in Stage 1 (e.g. conversion of highly biodiverse grazing land); in Stage 2 the respective model variable is constrained to not exceed a certain threshold (e.g. no conversion of highly biodiverse grazing land beyond Baseline levels).

[1] Indirect impacts or displacement effects (e.g. an indirect land use change) are occurring when increased demand for one product pushes production of the same or other products to other areas or increases demand of other products to substitute the displaced one.

The implemented constraints are grouped by topic (land use, biodiversity, GHG emissions, soil and water) to be able to present them in a more aggregated manner. Within Stage 2, we will differentiate between model runs with **a combination of individual constraints** for a **single scenario** (Dimension 1) and one model set up where **all constraints combined** are implemented in **all prospective policy scenarios** (Dimension 2, see Figure 1).

2.1. Definition of indicators and assessment of impacts (Stage 1)

2.1.1. Definition of indicators

The main indicators for assessing resource efficiency of biomass use in EU28 in different policy scenarios are derived from the following model output variable:

- Production of biomass for EU by biomass type (i.e. round wood, forest and agricultural harvest residues, energy crops, industrial-by products)
- Land use of the various classes of land being accounted for (forest, energy plantations, cropland, grazing land, other natural land)
- Change in production patterns (forest and agricultural intensification)
- Use of biomass in relevant sectors (i.e. energy, material)
- Import and export of biomass to (and from) EU with breakdown by type and export/import region.
- Trends of price indices and ranges for different biomass types (for EU and other regions of importance)
- Change in costs and profits for alternative biomass uses and biomass producing sectors

All the points above are described in more detail in the Annex to this report. Furthermore, all of the above mentioned indicators can directly be extracted from the model results for each scenario.

In addition to the Task 3 indicators above, specific indicators for the assessment of environmental impacts are proposed. An overview of environmental indicators is provided in Table 1 below. The list is mostly constrained by the capability and level of detail of the modeling framework. The indicators listed can either be directly or indirectly derived from model output and are expected to be sensitive to changes in scenario assumptions.

In the following some important variables of the models GLOBIOM/G4M that serve as the basis for establishing environmental indicators, are defined. The FAO FRA definition is used when classifying land as **forest**, not including land that has trees on it but is predominantly under agricultural or urban land use (FAO 2012). **Protected forests** (as defined by WDPA Consortium 2004) are excluded from the analysis and no conversion or use is allowed. Forest that is not protected is considered as potential production forest. The model allocates harvests to this area so that the projected demand for wood for material and energy purposes will be satisfied. These forests include natural and semi-natural forests, as well as forest plantations. Forests that are used in a certain period to meet the wood demand (so–called **used forests**) are modelled to be managed for woody biomass production. This implies a certain rotation time, thinning events and final harvest. **Unused forest** does currently not contribute to wood supply (due to economic reasons). However, they may still be a source for collection of firewood for subsistence use. The model allows for conversion from used forests to unused, and unused to used forests. Area classified as **afforestation** includes land that has been converted to forest after the year 2000 (start of the model run). All new forests established through afforestation are considered to be used for wood supply.

Agricultural land includes cropland, grazing land, short rotation coppice and other natural land. **Cropland** is land used for crop production. This also includes set-aside areas declared as cropland, but not currently used for crop harvesting (e.g. fallow land). This land category also includes annual and perennial lignocellulosic plants (e.g. miscanthus and switchgrass) that are increasingly used for biofuel production as well as Short Rotation Coppice. **Short rotation coppices** are formed by tree plantations established and managed under an intensive, short-rotation regime on cropland. They can be established with quickly growing species such as poplar and willow, and managed under a coppice system in a two-to-four-year rotation. **Grazing land** contains of pasture lands used for ruminant grazing. It does not include natural grasslands. Other natural vegetation or **other natural land** is a category that includes a mixture of land that cannot be properly classified such as unused cropland (if not fallow) or unused grassland, including natural grasslands. In addition to these classes, GLOBIOM also identifies other agricultural land (e.g. vegetable production, vineyards, orchards etc.), settlements and wetlands. This land is ignored by the model and kept fixed in the scenarios.

Besides the above mentioned categories of land use we differentiate areas of **high biodiversity value** (HBV). The delineation of HBV areas is based on the Carbon and Biodiversity Atlas by UNEP-WCMC[2]. This atlas presents a set of maps of different biodiversity hot spots. In this study, we assume that where at least three maps of biodiversity hot spots of species groups (e.g. birds, mammals) overlap land is considered to be of high biodiversity value. These areas are then overlaid with the land use information in GLOBIOM. HBV areas can be found on cropland, grazing land, used and unused forests and other natural land. Similarly a map of **intact forest landscapes** is integrated in the analysis of impacts[3]. Intact forest landscapes are coherent areas of natural ecosystems within the zone of current forest extent, showing no signs of significant human activity, and large enough that all native biodiversity, including viable populations of wide-ranging species, could be maintained. Further we consider areas with **steep slopes** identified using a digital elevation map. Slopes with an inclination of more than 30% are mapped and the share of steep terrain per world region and land use class is calculated. These areas are considered too steep for certain land management practices and can potentially be excluded.

[2] http://www.unep.org/pdf/carbon_biodiversity.pdf
[3] Potapov P., et al. 2008. Mapping the World's Intact Forest Landscapes by Remote Sensing. Ecology and Society, 13 (2); http://www.intactforests.org

Table 1: Suggested environmental indicators, model datasets and interpretation. Indicators in *italic* are indicators that can only be estimated from model statistics and are not explicitly modelled (e.g. indicators that relate to land with high biodiversity).[4]

Indicators	Dataset	Model variables with units for interpretation
Land use		
Basic land use categories	Model output, projection based on GLC 2000	• Forest area [ha], including the categories Afforestation, Used Forest, Unused Forest • Area of Deforestation [ha] • Area of Cropland [ha], including the category Short Rotation Coppice • Area of Grazing land [ha] • Area of other natural land [ha]
Biodiversity		
Unused and intact forests	Intact forest landscape, Greenpeace	• Unused forest area [ha] • Intact forest area [ha] • Unused forest converted to other land use [ha] • Intact forest converted to used forest [ha]
Land with high biodiversity value (HBV)	*UNEP-UCMC biodiversity atlas*	• *Area of land with HBV (forests, wetland, grazing land) [ha]* • *Area of land with HBV (forests, wetland, grazing land) converted to other land use [ha]* • *Biomass extracted from land with HBV (forests, wetland, grazing land) [t]*
Forest rotation period	Forest rotation period from national inventory	• Rotation period currently being applied [years]
Greenhouse Gases		
Emissions from agriculture and livestock	Model output, RUMINANT model integrated in GLOBIOM	• Total net emissions [t CO_2 eq.] • N_2O emissions from fertilizer application [t CO_2 eq.] • N_2O and CH_4 emissions from cropland [t CO_2 eq.] • N_2O and CH_4 emissions from livestock management [t CO_2 eq.] • Soil CO_2 emissions from cropland [t CO_2 eq.]
Emissions from forest activities and Harvested Wood Products	Model output based on GLC 2000, global forest carbon map	• CO_2 emissions from Afforestation [t CO_2 eq.] • CO_2 emissions from Deforestation [t CO_2 eq.] • CO_2 emissions from Forest management [t CO_2 eq.] • Total net forest emissions [t CO_2 eq.] • CO_2 emissions from forest biomass [t CO_2 eq.] • CO_2 emissions from forest soil [t CO_2 eq.] • CO_2 emissions from pool of Harvested Wood Products [t CO_2 eq.]
Emissions from bioenergy	Model output	• CO_2 emissions from the production and use of bioenergy [t CO_2 eq.]
Total net emissions	Sum	• Total net GHG emissions [t CO_2 eq.]
Water and soil		
Plantation of SRC on Cropland	Water stress maps; maps on water scarcity/ stress	• SRC on land with water stress [ha]
Water used for agriculture	Model output	• Irrigation area [ha] • Water used for irrigation [km^3]
Steep slopes / sensitive soil classes	Elevation model; Harmonized World Soil Database	• Area of land with restrictions to avoid soil erosion [ha] • Biomass extraction from forest on steep terrain and sensitive characteristics [t]
Residue/branch extraction in forests	*Species specific biomass expansion factor*	• *Forest area where biomass is left [ha]* • *Amount of dead wood left in forest [m^3]*
Conversion from grazing land to cropland	Model output based on GLC 2000	• Grazing land area [ha] • Grazing land area converted to Cropland [ha]

[4] For a more detailed specification of model assumptions and data sources used within the modeling structure, we refer to the Task 3 report on detailed model assumptions.

2.1.2. Assessment of impacts

Within Stage 1 indicators will be looked at individually across all scenarios. This includes an analysis of trends of indicators in the Baseline. This analysis reveals basic drivers of indicators and their development over time; an information that is also relevant to interpret differences between scenarios. It also helps to check whether any changes regarding the choice of indicators and the interpretation of the underlying model output are necessary and how indicators compare with independent estimates from the literature.

More relevant for the purpose of the project are differences between scenarios. Indicators that show a significant sensitivity to changes in scenario assumptions are analyzed in detail. Impacts in EU28 and RoW are compared and the results also looked at the level of selected world regions where useful.

As shown in Table 1, there are direct indicators that the model calculates as absolute numbers (indicators related to land use conversion, e.g. unused forest converted to cropland) and indirect indicators that can only be estimated from model statistics and are not explicitly modelled (indicators related to specific land conversion, e.g. land with high biodiversity). The differentiation is relevant for Stage 2. Direct indicators can be used directly as constraints (e.g. as an absolute amount of unused forest area not to be converted). Using indirect indicators as constraints, instead, will be based on the original map information, e.g. by clipping out areas of high biodiversity value without knowing whether exactly those lands are actually affected in the policy scenario.

2.2. Exploring implications of environmental constraints for biomass resource efficiency (Stage 2)

After the analysis of impacts of scenario assumptions on environmental indicators in Stage 1, the implications of setting environmental constraints for EU biomass resource efficiency to avoid these impacts will be assessed. Within this second stage, environmental indicators that showed significant changes across scenarios in Stage 1 are reformulated into constraints. With a second set of model runs we then evaluate the impact of those constraints across policy scenarios on resource efficiency of biomass production, trade and use in EU28.
Indicators for assessing resource efficiency of biomass use in the constrained scenarios are the following:

- Production of biomass in the EU by biomass type (i.e. round wood, forest and agricultural harvest residues, energy crops, industrial-by products)
- Import and export of biomass to (and from) EU with breakdown by type and export/import region.
- Use of biomass in relevant sectors (i.e. energy, material)
- Land use of the various classes of land being accounted for (forest, energy plantations, cropland, grazing land, other natural land)
- Total GHG emissions from the land use sector

The analysis of constrained scenarios is done along two dimensions: an assessment of the implications of each constraint individually for one scenario (Dimension 1) and an assessment of the implications of all constraints combined on all scenarios (Dimension 2, see Figure 1). This approach provides us with a good overview of implications of constraints across scenarios but avoids an enormous amount of scenarios to be analyzed, if all possible combinations of constraints and scenarios would be considered.

2.2.1. Exploring implications of single constraints in the EU Emission reduction scenario (Dimension 1)

Based on the findings from the analysis of impacts a set of the most important environmental constraints is formulated. Constraints correspond to individual indicators: for example, if for the indicator "Area of land with high biodiversity value" a significant reduction in a scenario has been observed in Stage 1, in Stage 2 the model includes a constraint on the conversion of land with high biodiversity value. The constraint can be implemented very stringently, e.g. allowing no conversion at all, allow no additional conversion beyond the baseline scenario or allow for a fraction of the land up to a certain threshold. As in this study differences between baseline and policy scenarios are in the focus of the analysis, thresholds will be set mostly at the level of the baseline. For the conversion of land with high biodiversity value this would mean that not more than the area converted in the baseline scenario can be converted. Similarly, as an example, if in a region a significant higher level of conversion from grazing land to cropland is observed in a policy scenario as compared to the baseline in Stage 1, in Stage 2 the conversion will not be allowed in the model unless it remains below the level of baseline conversion.

Each constraint will be assessed individually for the **EU emission reduction scenario** (**dimension 1**). This analysis will provide information concerning how different constraints impact scenario results. Compared to model simulations without constraints, these runs are expected to come to different outcomes, e.g. shifts in production, trade, allocation of biomass to different uses etc. The EU emission reduction scenario depicts a development where more stringent GHG emission abatement targets for EU come into play, enhancing the development of the bioenergy sector. It assumes higher targets for EU in terms of GHG emission reduction in non-land use sectors in comparison to the baseline scenario. Therefore it is a scenario where constraints on domestic and global biomass supply are expected to have strong effects on resource efficiency.

2.2.2. Exploring implications of combined constraints across scenarios (Dimension 2)

After each constraint has been evaluated in terms of its implications on model outcomes, the impact of all constraints combined will be assessed for all prospective policy scenarios. The evaluation along Dimensions 1 and 2 will be done with respect to impacts on major output variables identified in Task 3, such as production level per biomass type (e.g. solid wood, residues, energy crops, industrial by-products, etc.), land use, production patterns, biomass use and trade as well as price indices for biomass goods.

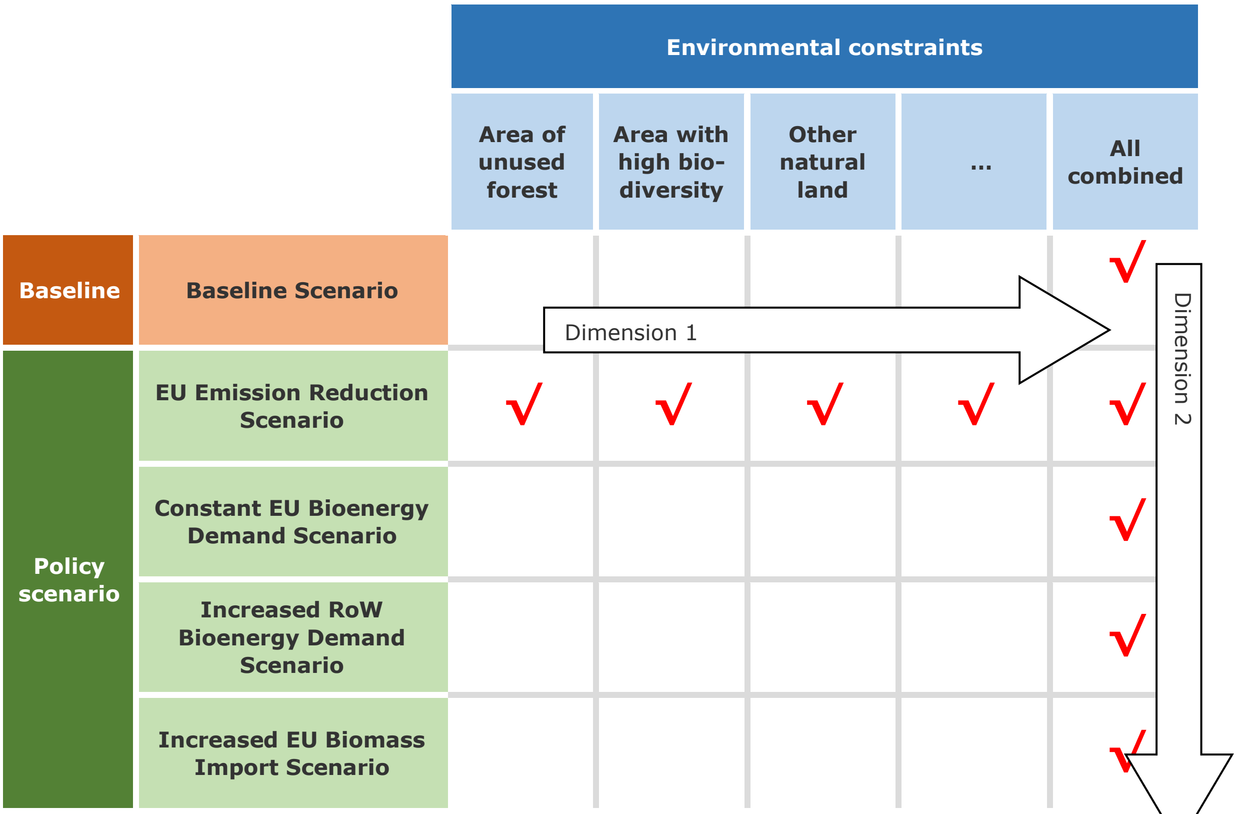

Figure 1: Overview of how the environmental constraints will be applied and their implications evaluated across the policy scenarios in two dimensions.

3. Results of Stage 1: Assessment of environmental impacts in Baseline and policy scenarios

3.1. Development of impacts observed in the Baseline scenario

In this section the impact of the Baseline scenario on land use, HBV areas, GHG emissions etc. is analyzed. A good understanding of the development of indicators under the policy scenarios compared to the Baseline is needed because the results of this analysis are used to identify the need for environmental constraints to mitigate impacts during Stage 2 of the analysis. In most cases the constraints will be applied to policy scenarios in a way that the Baseline impacts shall not be exceeded (e.g. exclusion of certain land use change beyond Baseline level is not allowed). It is still useful to understand the trends of certain indicators in the Baseline scenario and relate them to impacts of policy scenarios.

3.1.1. Development of land use

The overall development of land categories in the **EU28** is illustrated in Figure 2. The cropland area is increasing by 14 Mio ha from about 106 Mio ha in 2010 to 120 Mio ha in 2050. Also total forest area is increasing by 14 Mio ha from 154 Mio ha to 168 Mio ha. Both expansions take place at the expense of the category other natural land (abandoned cropland, unused grassland, etc.) which is declining from 60 Mio ha in 2010 to 32 Mio ha in 2050. The grazing land area (56 Mio ha), however, stays, with a slight increase of 0.4 Mio ha, almost constant. **Unused forests remain rather stable over this time period** (declining slightly from 48 Mha in 2010 to around 42 Mio ha in 2050. Since deforestation is low in EU28 (compared to the RoW), most of the increase of used forest is due to an expansion of the forest area by afforestation of 22 Mio ha new forests until 2050. The exact allocation of new forest to used or unused forest cannot be done. Therefore the figure does not show explicitly afforestation areas. However, it can be assumed that a large share of the newly established forest is also contributing to wood supply.

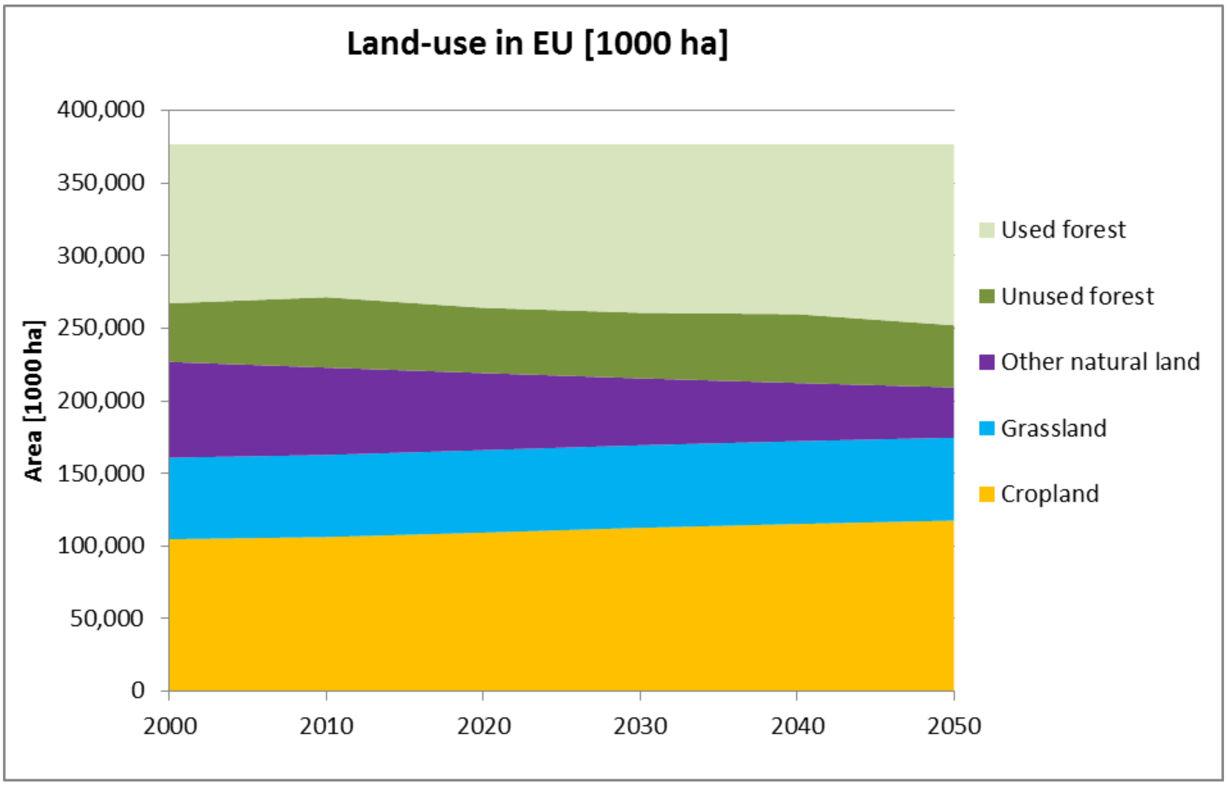

Figure 2: Development of different land use categories in EU28 for the Baseline scenario.

Also for the land use pattern in the **Rest of the World (RoW)** (Figure 3), a clear increase of cropland (878 Mio ha in 2010 and 1097 Mio ha in 2050) and a decrease of other natural land (from 3,120 Mio ha to 2,588 Mio ha) can be observed. In the RoW, grazing land area increases by more than 250 Mio ha from 1,603 Mio ha to 1,871 Mio ha. Used forest area increases over the time period (from 712 Mio ha to 1,010 Mio ha) in addition to 354 Mio ha of new forest established until 2050 (not shown explicitly). The area of unused forest decreases by 10% from 2,454 Mio ha to 2,200 Mio ha.

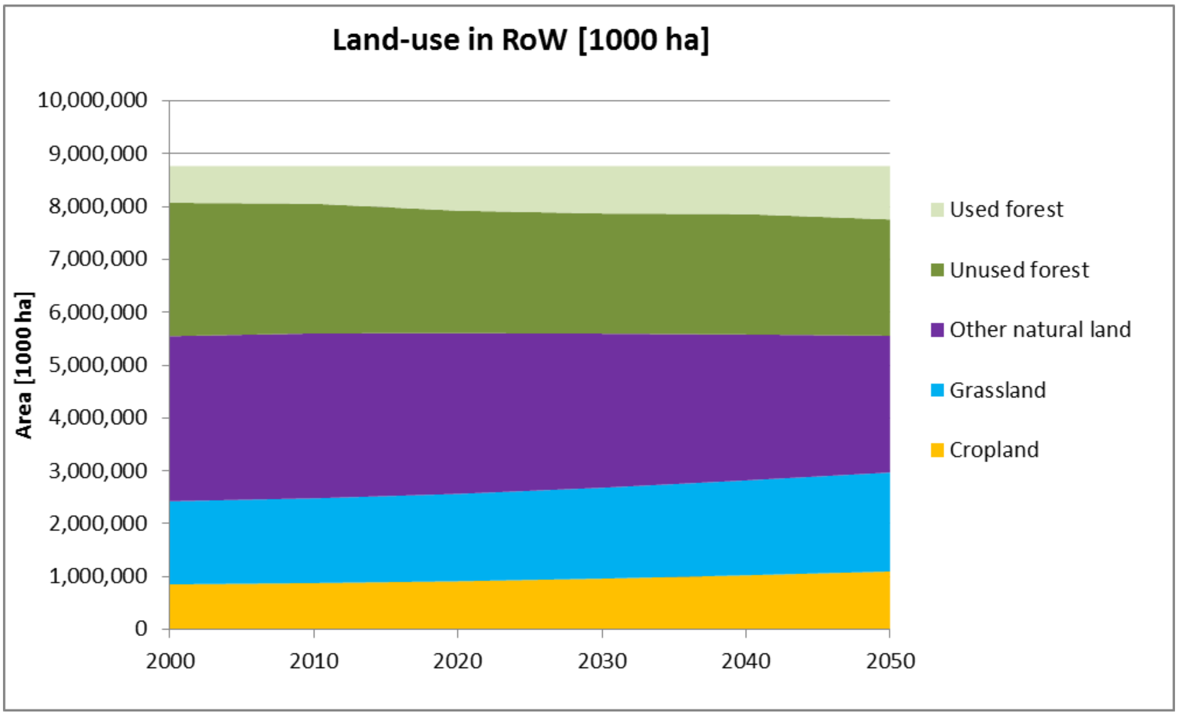

Figure 3: Development of different land use categories in the rest of the world for the Baseline scenario.

In the following, the land use pattern of Sub-Saharan Africa and Latin America are presented as these two regions showed strong change in all land use types.

Sub-Saharan Africa is characterized by a relative low amount of cropland and used forest area in 2010. Both almost double until 2050 (Figure 4). Also grazing land area, that is dominant in Sub-Saharan Africa, increases by 12% over the time period. As a result unused forest area as well as other natural land decrease by 20% and more than 30%, respectively, until 2050. The latter is likely to occur on productive areas of natural grassland.

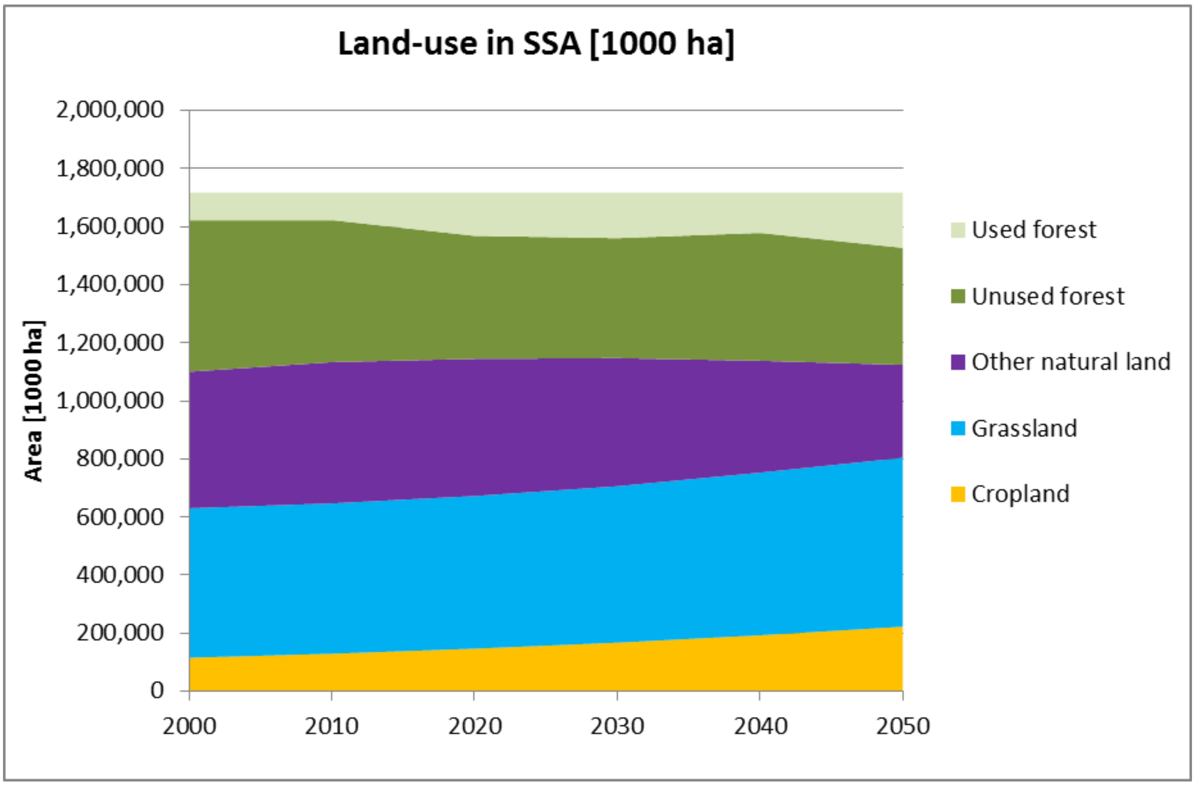

Figure 4: Development of different land use categories in Sub-Saharan Africa for the Baseline scenario.

In Latin America, used forest area covers only 5% of the land in 2010 (Figure 5). This land use category increases only slightly from 2010 to 2050. Still unused forests decrease strongly over the time period (2010: 629 Mio ha; 2050: 535 Mio ha). The main cause here is deforestation due to cropland and grazing land expansion in the first half of the simulation period. Later the expansion of cropland and grazing land occurs more into other natural land. The increase of new forest area through afforestation is also significant (55 Mio ha in 2050, not shown explicitly).

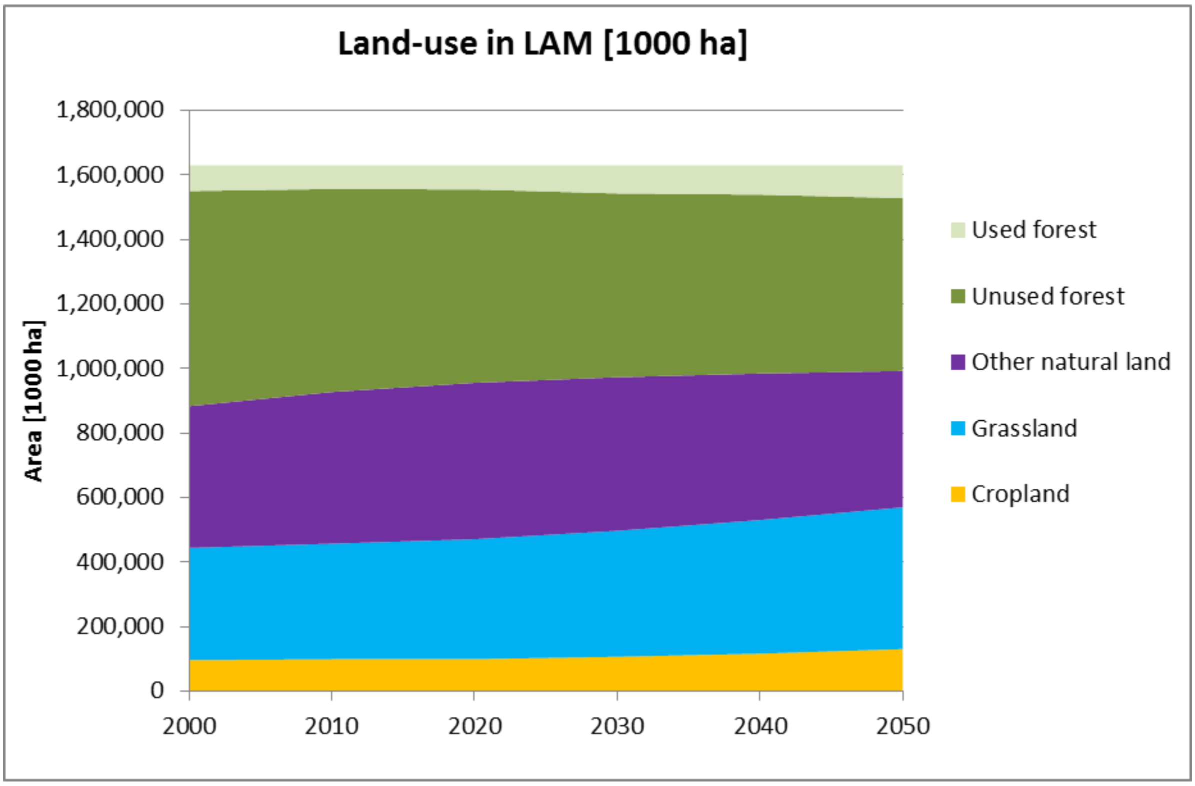

Figure 5: Development of different land use categories in Latin America for the Baseline scenario.

The RoW total forest area is expected to first further decrease from 3,166 Mio ha (2010) to 3,162 Mio ha (2020) but increase after that until 2050 to 3,211 Mio ha (Figure 6). Clear decreases of the total forest area from 2010 to 2050 are especially visible for Latin America and Sub-Saharan Africa. The latter shows a recovering trend after 2030. **In the EU28, the forest area increases during this time period steadily by 14 Mio ha from 154 to 167 Mio ha.** The total forest area includes the dynamic of used and unused forest, afforestation and deforestation. For an assessment of impacts it is important to separate these.

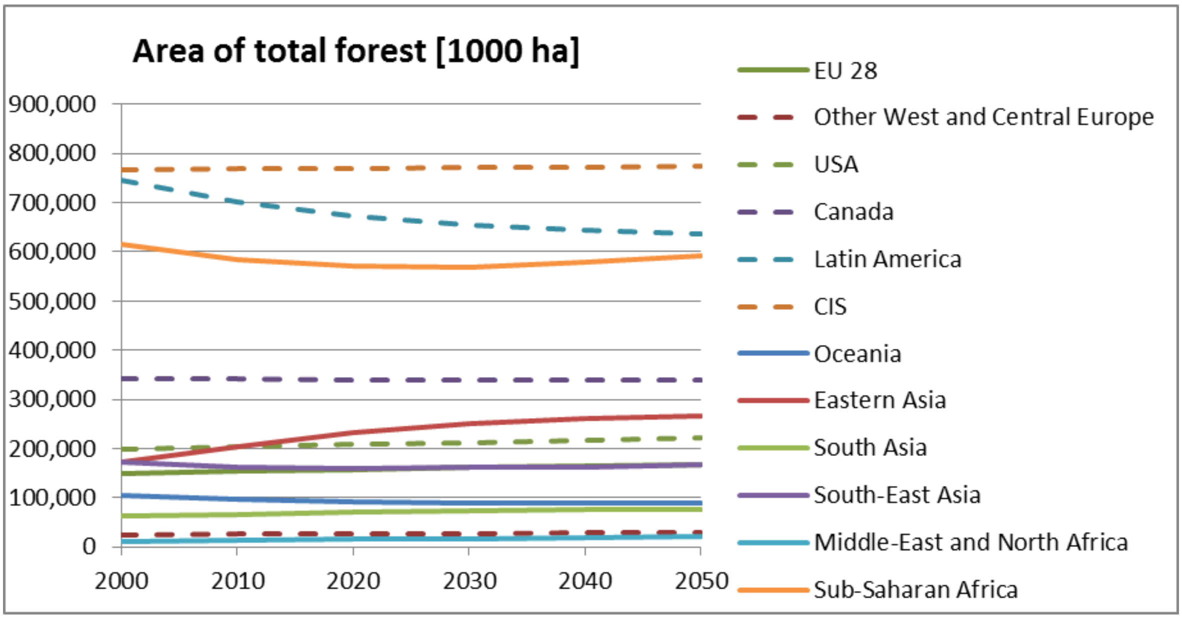

Figure 6: Development of total forest area in 12 regions of the world for the Baseline scenario.

During the Baseline scenario the area of used forests increases in several regions of the world (Figure 7). This comes either at the expense of unused forests or conversion of non-forest land to forest. In EU28 unused forest remains fairly stable over the Baseline simulation period. However, strong declines of unused forest occur during this time period in Latin America (-94 Mio ha; -15%), Sub-Saharan Africa (-86 Mio ha; -18%), USA (-19 Mio ha; -21%), South-East Asia (-17 Mio ha; -13%), and CIS (-15 Mio ha; -2%). The reasons for the loss differ and can either be due to conversion to used forests as well as conversion to cropland or grazing land.

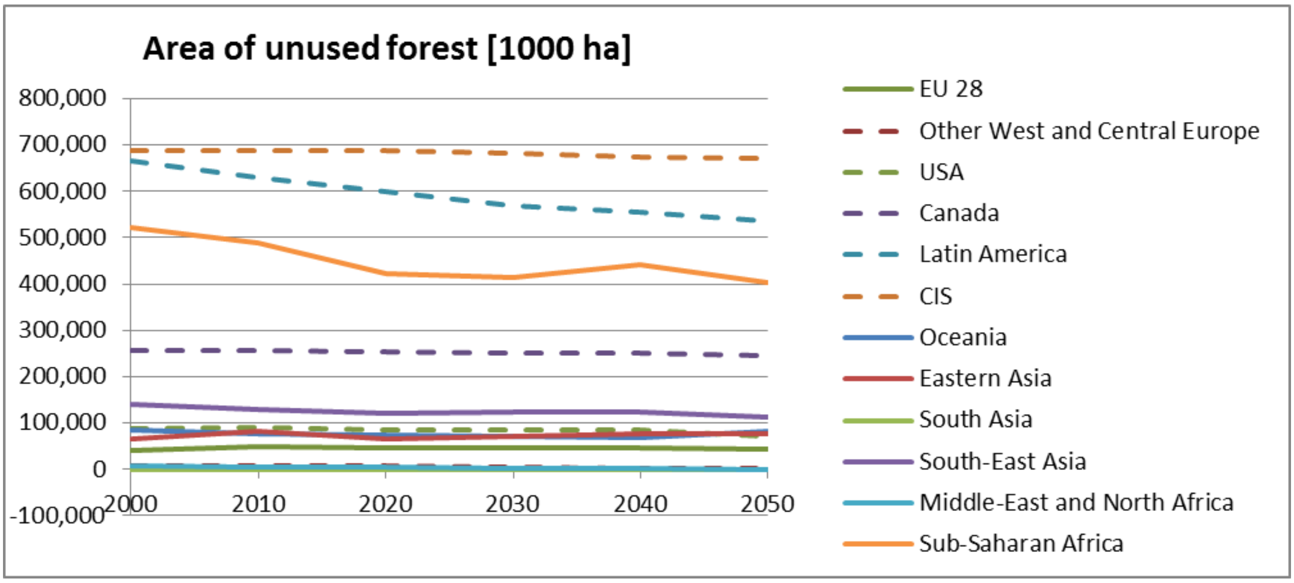

Figure 7: Development of unused forest in 12 regions of the world for the Baseline scenario.

Table 2: Distribution of intact forest landscape in 12 regions of the world in 2000

Region	Intact Forest in 2000 [1000 ha]	% of Total Forests in the region
EU28	2,230	0.9
Other West and Central Europe	178	0.4
USA	53,881	17.2
Canada	304,298	71.4
Latin America	458,763	55.8
CIS	276,891	33.7
Oceania	30,576	25.8
Eastern Asia	4,645	1.5
South Asia	4,058	3.2
South-East Asia	48,562	25.0
Middle-East and North Africa	0	0.0
Sub-Saharan Africa	99,932	14.1
World	**1,284,014**	**31.0**

Parts of the unused forests shown in Figure 7 are primary forest. However, no global data on the extent of primary forest are available that could be easily integrated into the modeling framework. The dataset on Intact Forest Landscapes (cf. Chapter 2.1) can be used as a proxy to estimate likely impacts on primary forests. Intact forests are forest landscapes that show no signs of significant human activity. Intact forest landscapes could therefore consist only of primary forests. However, there might be still areas of primary forest that are not considered an intact forest landscape because of small size and fragmented structure. In the year 2000, intact forests covered about 30 % of the global forest area, with high relative shares in Canada (71%) and Latin America (56%), and low shares in Eastern Asia, South Asia and Europe (Table 2). The conversion of unused forests will very likely also affect primary forests. However, the explicit impact in terms of area converted cannot be calculated due to lack of geographical references for the modelled land use change.

The area of used forests, including afforestation, increases in almost all regions of the world between 2000 and 2050 (Figure 8). For example, in EU28, area of used forest increases by 19 Mio ha from 105 Mio ha in 2010 to 124 Mio ha in 2050 as a result of expansion of forest area through afforestation and a reduction of the deforestation rate. In Eastern Asia the increase of used forests of 69 Mio ha from 2010 to 2050 (57%) is almost equivalent with the area of new forests in 2050 (64 Mio ha), indicating that only small parts of the former unused forest area were converted to used forest. In Sub-Saharan Africa the used forest area increases by 96 Mio ha compared to a conversion of unused forests of 86 Mio ha. So here the intensification of forestry is mainly through conversion of unused forest to used forest. In other regions, however, the increase of used forest areas is much lower than the conversion of unused forests. For example, in Latin America, the used forest area increased by 29 Mio ha but unused forest area decreased by 94 Mio ha. This indicates that forest areas have been deforested, i.e. converted to other land use types, especially cropland and grazing land. The drop of the area of used forest in Sub-

Saharan Africa that can be observed in Figure 8 in 2040 is due to an increased afforestation in that region (see also Figure 11).

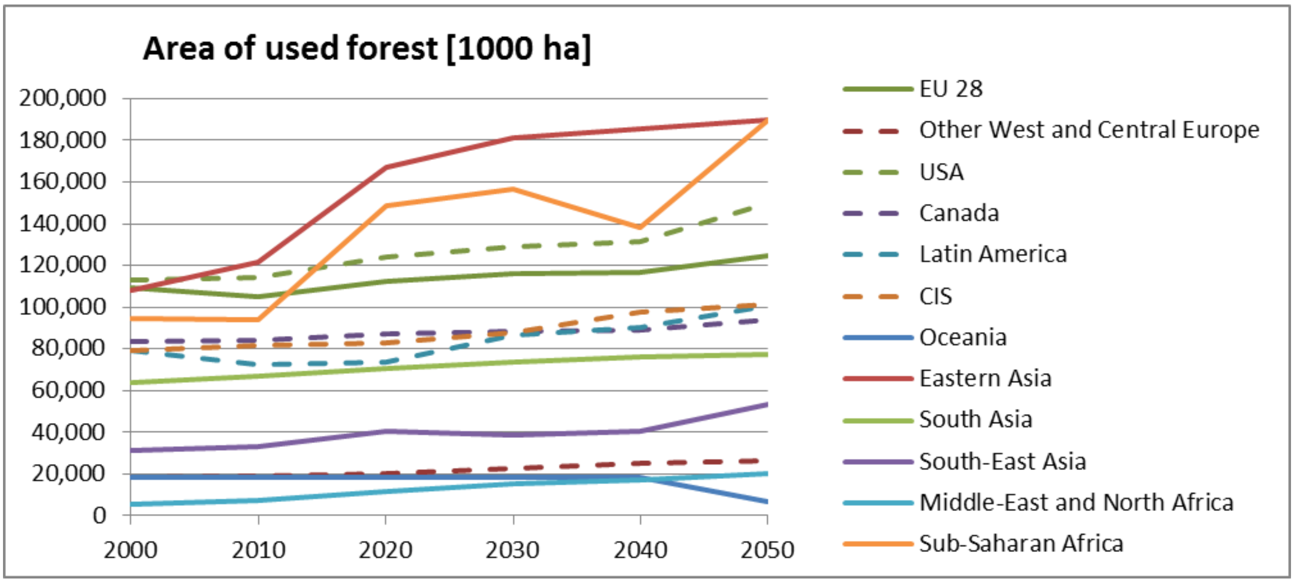

Figure 8: Development of used forest in 12 regions of the world for the Baseline scenario.

Deforestation can be more explicitly expressed as the accumulated loss of forest areas existing in 2000 (Figure 9) and as an annual deforestation rate in relation to forest area in 2000 (Figure 10). The deforestation rate represents the decline of used and unused forests already existing in 2000 without taking into account newly afforested areas. Large scale deforestation under the Baseline scenario is taking place until 2050 in Latin America (loss of 170 Mio ha) and in Sub-Saharan Africa (loss of almost 100 Mio ha). In total until 2050 360 Mio ha of forest will be lost in RoW, 4.4 Mio ha in EU28. Most deforestation rates are currently (for the period 2000-2010) below 0.5%, except for Latin America, Sub-Saharan Africa, South-East Asia and Oceania. The Baseline projects a constant decline of relative deforestation rates until 2050 with most remarkable changes for South-East Asia and Latin America (from 0.9 and 0.7 to 0.2 and 0.4, Figure 10).

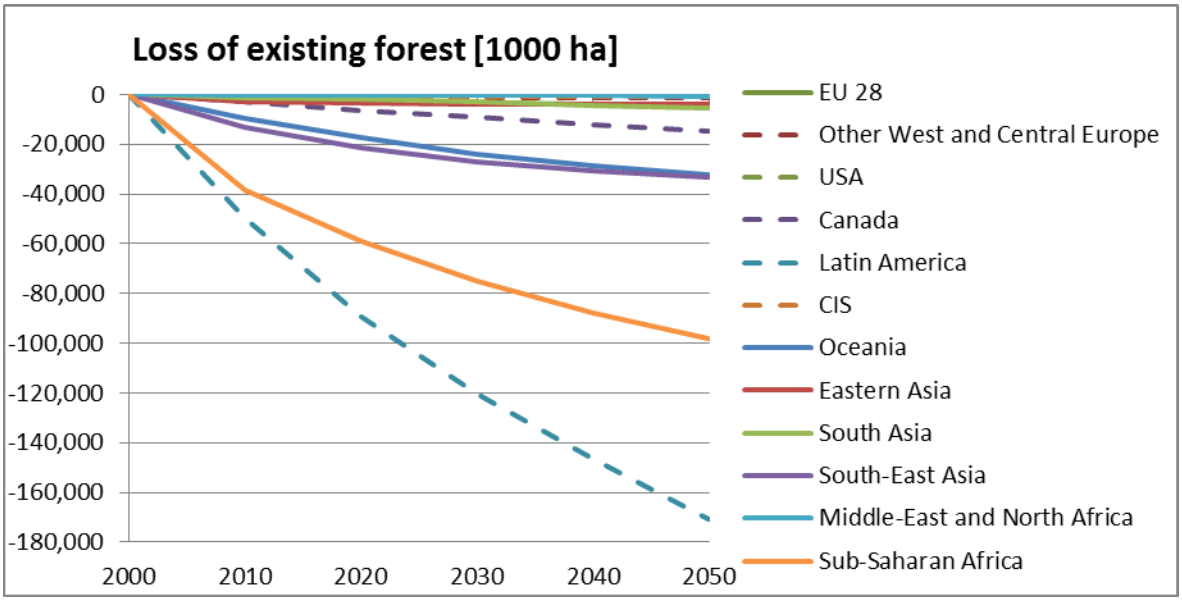

Figure 9: Loss of forest area existing in 2000 (accumulated) in 12 regions of the world for the Baseline scenario.

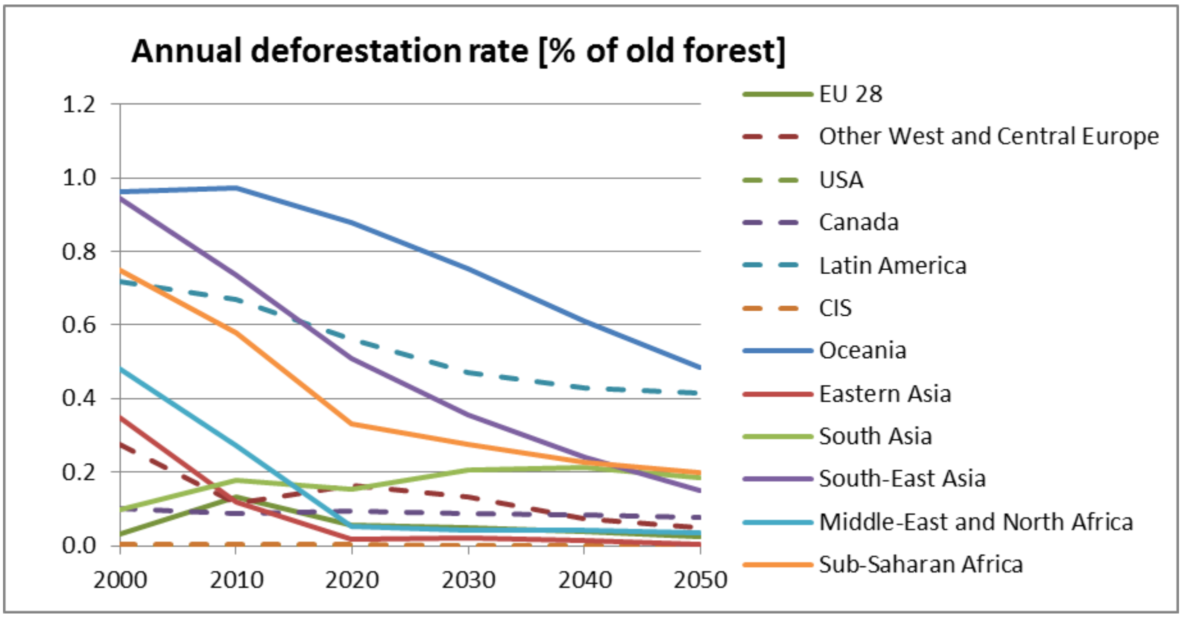

Figure 10: Annual deforestation rate in relation to forest existing in 2000 in 12 regions of the world for the Baseline scenario.

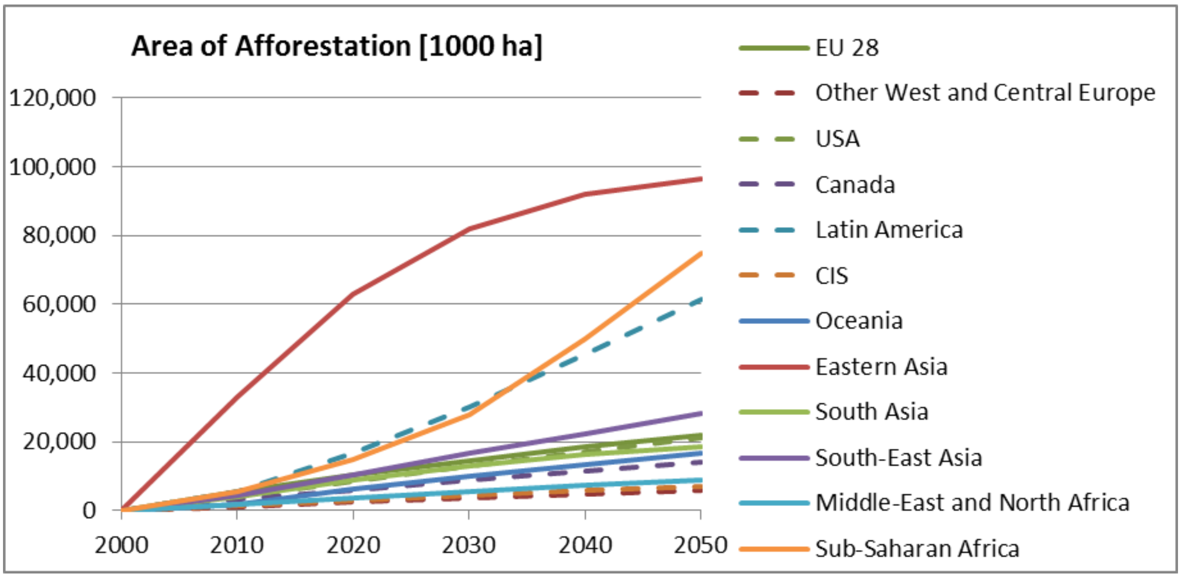

Figure 11: Development of afforestation areas in 12 regions of the world for the Baseline scenario.

The conversion of forest in certain regions of the world is contrasted by the expansion of forest area through afforestation in other parts of the world. Figure 11 shows that countries with high deforestation rates can also have high afforestation rates. According to the model, by 2025 about 50 Mio ha of new forests will be established in Latin America and Sub-Saharan Africa with an increasing rate despite still high rates of forest loss. Another extreme example is Eastern Asia. Most of the new forests established until 2050 will grow in China (almost 100 Mio ha) where recent deforestation is low due to relatively low forest cover.

3.1.2. Development of land with high biodiversity value (HBV)

The development of areas of high biodiversity value (HBV) is a key indicator for assessing effects on biodiversity. The conversion of these areas is very likely related to a loss of biodiversity. This applies to areas under forest, grazing land and other natural land, in particular. The loss of HBV area can only be approximated by assuming that HBV land is converted at the same relative rate as other non-HBV areas. This means, that the relative share of HBV areas in each land use category will not change over time. This assumption must be taken into account when interpreting the data below.

Figure 12 shows that in many regions of the world a significant conversion of areas of HBV (including forest, grazing land, cropland and other natural land) is likely to occur until 2050. However, depending on the type of conversion (e.g. to used forest, grazing land or cropland), negative effects on the biodiversity may be more or less severe. Therefore, for the conversion of unused forests, for the three regions with the highest amount of HBV area and with high conversion rates (Latin America, South-East Asia and Sub-Saharan Africa), a detailed analysis is presented below.

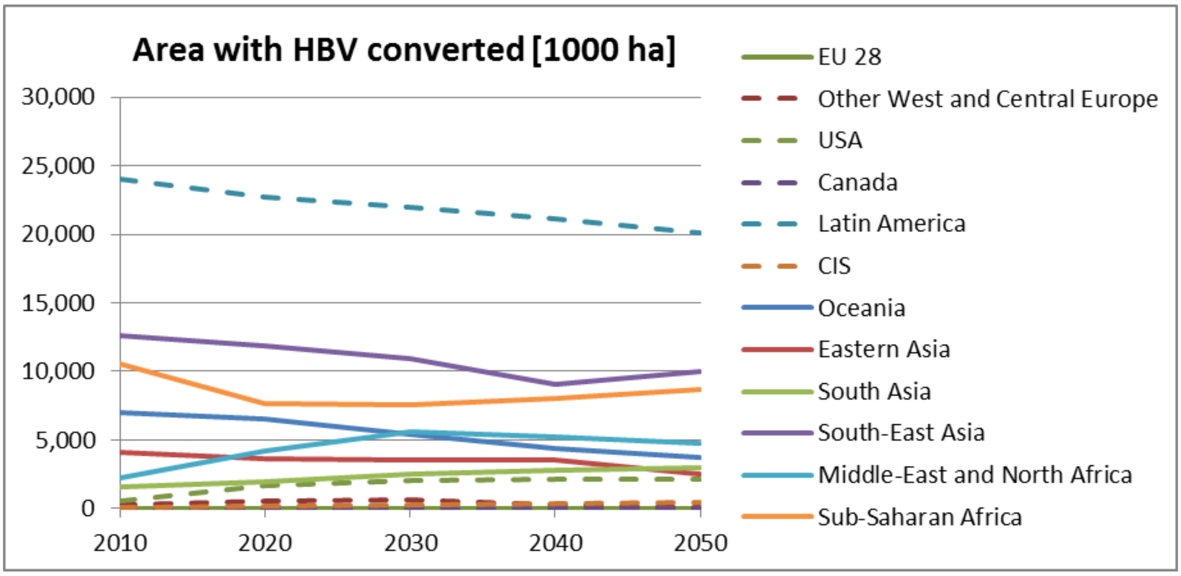

Figure 12: Development of area of HBV areas converted in the Baseline scenario in 12 regions of the world.

The conversion of unused forest with HBV is high in most regions (Figure 13). **In regions like Latin America, South-East Asia and Sub-Saharan Africa the conversion of unused forest accounts for about half of the total conversion of HBV areas**. Focusing on Latin America, most HBV areas converted belong to other natural land. Unused forest areas of HBV as well as other natural land in Latin America are mainly converted to grazing land and with a lower proportion to cropland and new forests (Figure 14).

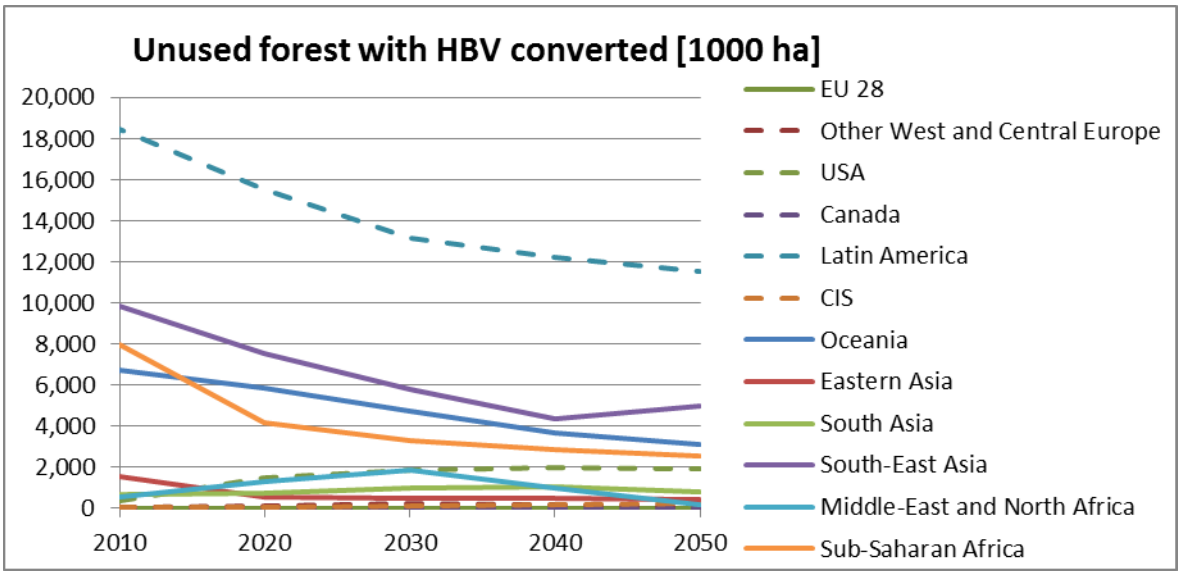

Figure 13: Development of accumulated area of unused forest area classified as HBV converted in 12 regions of the world for the Baseline scenario.

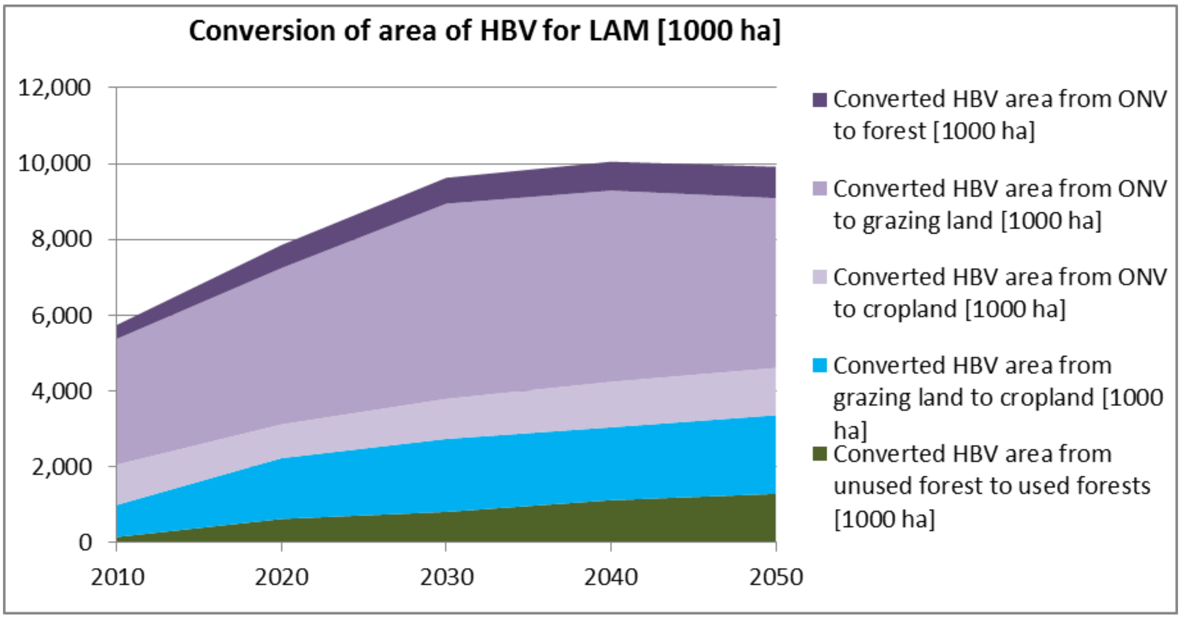

Figure 14: Development of annual area converted of unused forest, grazing land and other natural land classified as HBV in Latin America for the Baseline scenario.

Most HBV areas in Sub-Saharan Africa are on grazing land and other natural land. Other natural land with HBV is mainly converted to grazing land, and grazing land to cropland (Figure 15). The conversion of unused forest of HBV to used forest of HBV, however, also occurs.

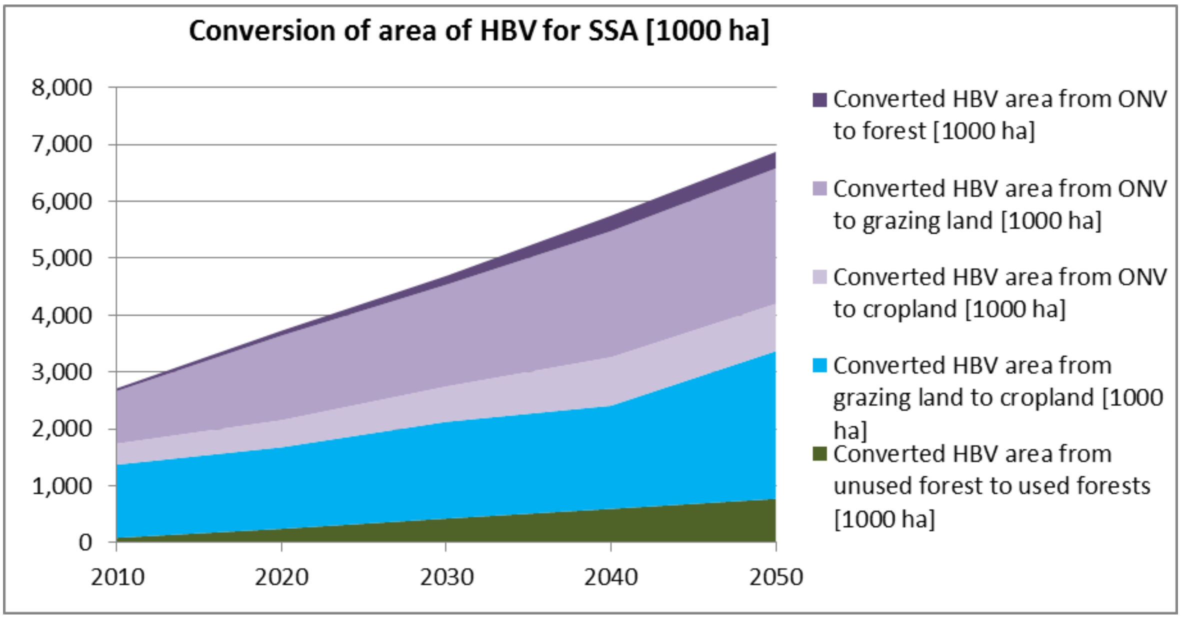

Figure 15: Development of annual area converted of unused forest, grazing land and other natural land classified as HBV in Sub-Saharan Africa for the Baseline scenario.

In South-East Asia, areas of HBV occur most frequently in unused forests and on other natural land, but also with a high proportion for cropland. Unused forest of HBV is converted mainly to grazing land, but also significantly to used forests, especially from 2040 until 2050 (Figure 16). Also other natural land is mainly converted to grazing land.

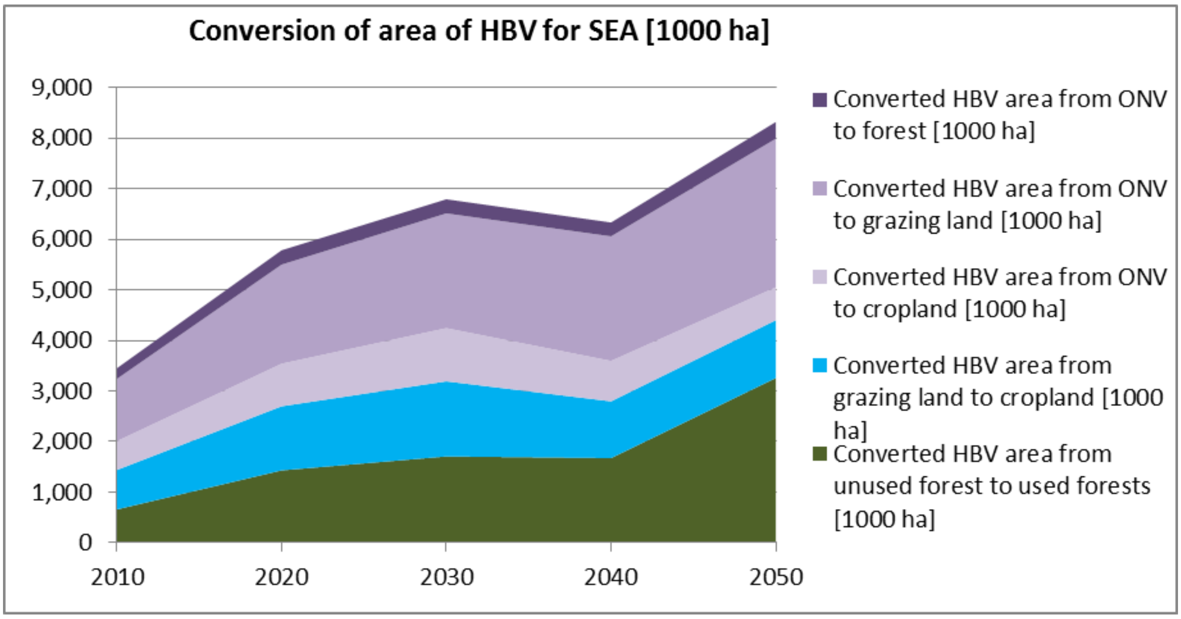

Figure 16: Development of annual area converted of unused forest, grazing land and other natural land classified as HBV in South-East Asia for the Baseline scenario.

3.1.3. Development of GHG emissions from land use activities

RoW emissions from land use have different trends in the Baseline scenario for different categories as can be observed from Figure 17. While deforestation emissions are decreasing, other land use change emissions, including the conversion of grazing land and other natural land to cropland, and also agriculture emissions are increasing. Increasing is also the sink from afforestation. **Total LULUCF in RoW is a net sink in 2000 but projected to turn into a source of CO_2 as of 2010. This is partly due to the forest management sink that is declining over the projection period, due to intensification of forest management. In addition emissions from the agriculture sector are constantly increasing.** It has to be noted that uncertainties associated with these estimates are very high. Especially forest management emissions at global level need to be interpreted carefully. The underlying database (e.g. age class distributions and management information) is very scarce and at global level such estimates are difficult due to different definitions of forest, carbon densities and pools considered in existing studies. The estimates as provided here do not cover emissions from grazing land nor RoW emissions from cropland.

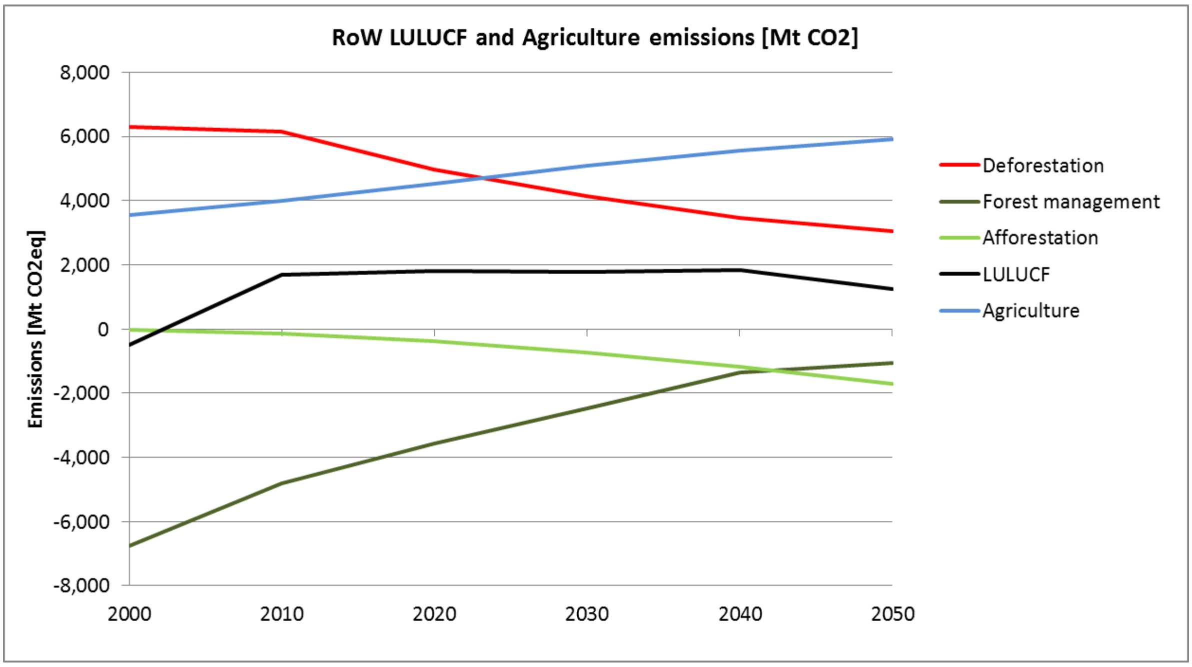

Figure 17: Development of Agriculture emissions and LULUCF emissions and removals in RoW for the Baseline scenario.

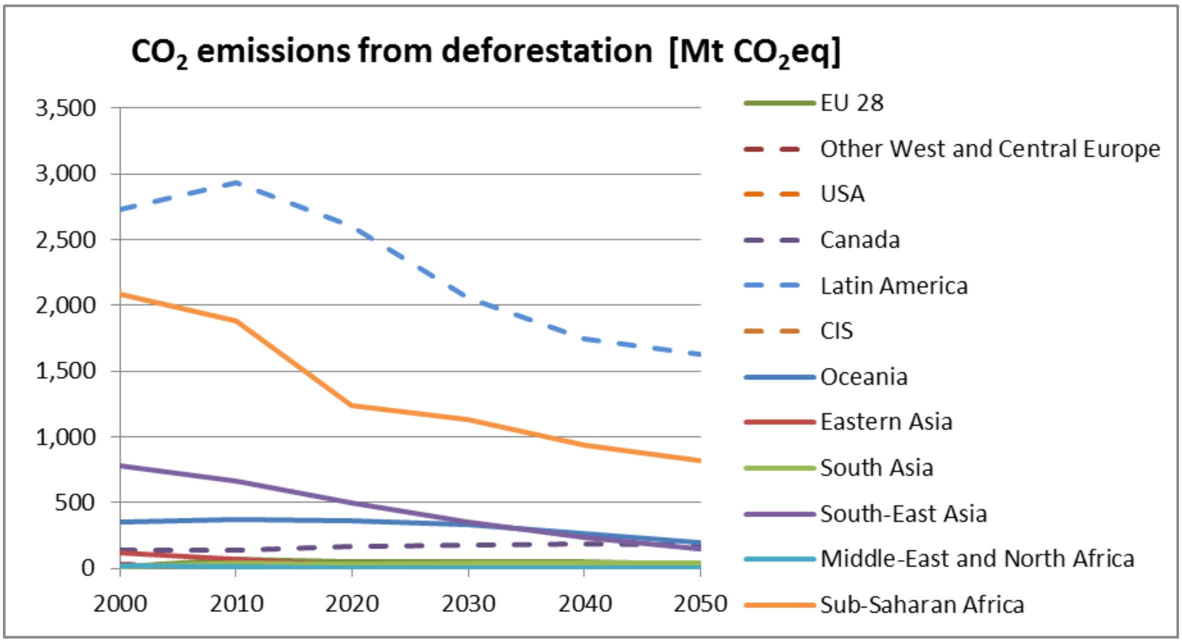

Figure 18: Development of CO_2 emissions from deforestation in 12 regions of the world for the Baseline scenario.

Deforestation is the main source of greenhouse gas emissions from forest activities, and GHG emissions from deforestation correspond directly to the modelled deforestation area (cf. Figure 9). Global GHG emissions from deforestation in 2010 are 6,295 Mt CO_2 and they decline to 3,053 Mt CO_2 in 2050 (Figure 18). GHG emissions from deforestation are the highest in Latin America (2010: 2,932 Mt CO_2) and in Sub-Saharan Africa (2010: 1,883 Mt CO_2) with the tendency to decline until 2050 (1,600 Mt CO_2 and 800 Mt CO_2; Figure 18).

The accuracy of deforestation emission estimates can be assessed by comparing different literature sources with estimates of this study (Figure 19). Historic data, but also estimates of the more recent time, show a large spread. This reflects the diversity of methods, approaches, data sources and assumptions that vary in studies estimating deforestation emissions. Estimates of this study tend to be at the higher end of emissions from deforestation calculated in recent studies. Decomposition into regions is therefore useful.

Figure 20 compares regional estimates from the literature with results of this study for the period 2000-2010. It seems that emissions from deforestation are overestimated for Africa and tropical America if looking at total emissions. The range of estimates found for Africa in the literature is remarkably low and does not reflect uncertainties associated with these estimates. Emissions from deforestation in Asia are in-line with literature values. However, for this region the spread of estimates is huge, spanning almost an order of magnitude from 250 to 2200 Mt CO_2. The results of this study fall into the ranges found by other studies. There are a number of assumptions that lead to the wide spread of estimates found. Most existing studies for comparison do not provide sufficient information to reconcile estimates and factor out sources for differences. When looking only at emissions from the biomass pool, estimates of this study are much closer to literature values. For Africa differences result probably from different carbon maps. Deforestation areas are similar to other studies (not shown). Estimates for Asia of this study do not include peat emissions that form a big source in that region and have been included in some studies. Including peat leads to considerably higher total deforestation emissions.

The uncertainties found from this comparison need to be considered when comparing policy scenarios. Even if the errors are relatively large, differences between policy scenarios can still be significant because uncertainties are more or less the same for all scenarios.

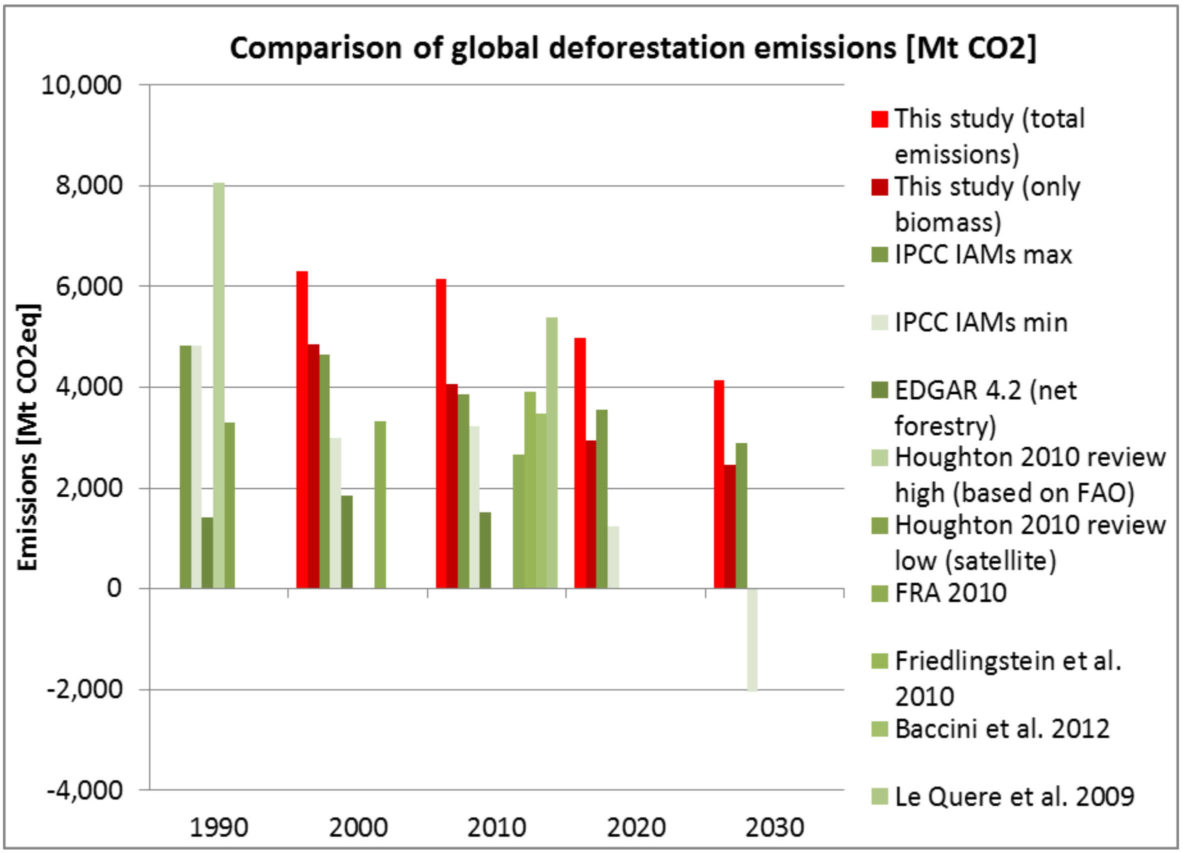

Figure 19: Comparison of global deforestation estimates from the literature and this study for the biomass pool and total. Note that estimates apply different definition of forest, different carbon densities and include different pools. This is causing the relatively large spread of estimates.

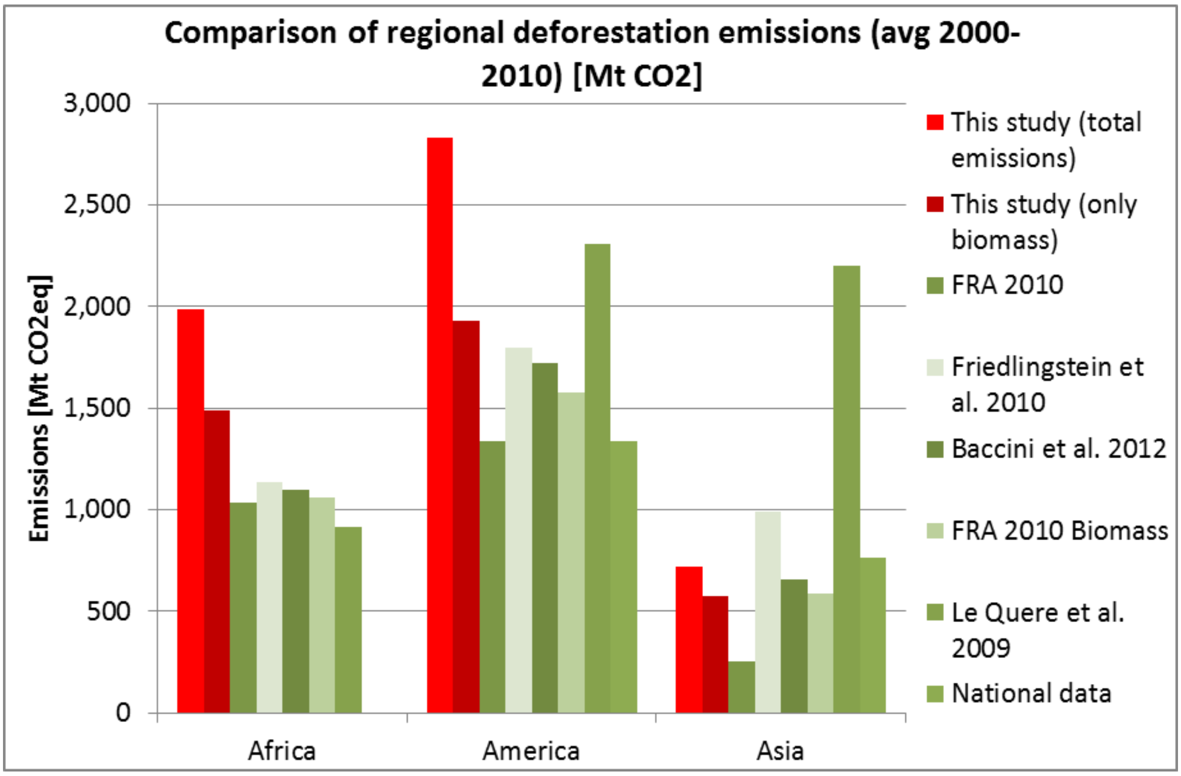

Figure 20: Comparison of regional deforestation estimates from the literature and this study (tropical forests only). Note that estimates apply different definition of forest, different carbon densities and include different pools. This is causing the relatively large spread of estimates.

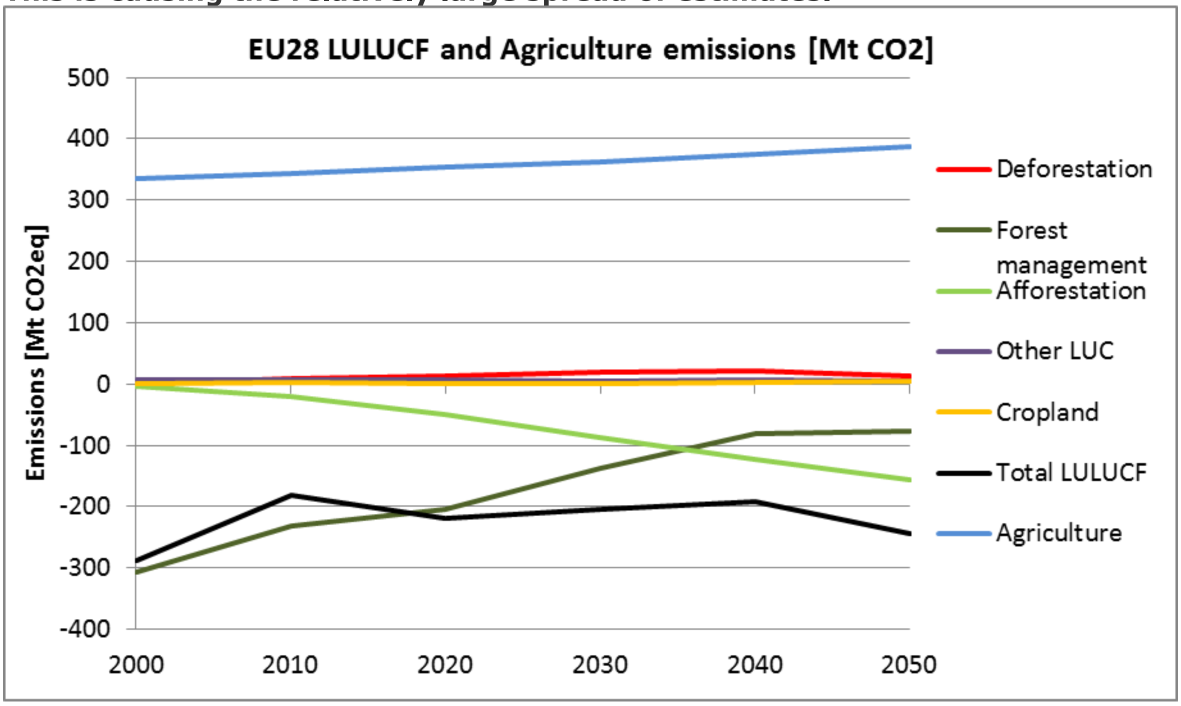

Figure 21: Development of Agriculture emissions and LULUCF emissions and removals (i.e. the sum of Deforestation, Afforestation, Forest management, cropland CO_2 and other land use change emissions) in EU28 for the Baseline scenario.

Figure 21 describes the development of emissions and removals of different activities in the LULUCF and agriculture sector from 2000 to 2050. **Overall net LULUCF emissions are a relatively stable net sink in the EU at around -200 Mt CO_2.** Deforestation emissions are decreasing slowly from 70 Mt CO_2 in 2010 to less than 50 Mt CO_2 in 2050. The current driver of deforestation in EU28 is mostly infrastructure. A decline of large infrastructure projects in EU countries is plausible and such a projection therefore not unlikely. Afforestation is a CO_2 sink that is continuously increasing over the period. In 2050 the net sink from afforestation is more than 150 Mt CO_2. The activity contributing the largest share to net LULUCF emissions is forest management. Figure 21 also shows that the Forest management sink for EU28 is declining from more than -300 Mt CO2 to about -100 Mt CO_2 in 2050. Forest aging and increased harvest is responsible for this trend. Forest management emissions (i.e. reduced sink) estimated in the projection are driven by the balance of harvest removals and forest increment rates (the growth of the biomass stored in a forest as a result of the growth of the trees with the age). Other land use change includes cropland and grazing land management and conversions between them. Removals (e.g. from grazing land management) are balancing emissions (e.g. from cropland) in this category.

Figure 22a compares estimates of emissions and removals from LULUCF and agriculture with UNFCCC reported data for two years in the period where both datasets are overlapping (2000 and 2010). This study shows lower removals from afforestation, which is due to the fact that only forests afforested after 2000 can be considered. UNFCCC instead includes older afforestation areas in its category "land converted to forest land". Deforestation estimates by the model are lower in 2000 and higher in 2010 compared to reported data. It is difficult to calibrate the model to historic rates. Deforestation drivers are different for different regions. A good agreement of the average over 2000-2010 is therefore deemed sufficient. The level of forest management net removals estimated by the models is similar to the sink reported by EU countries. However, while reported data show that the sink is rather stable between 2000 and 2010, the model estimates have a clear downward trend. Reported data are continuously revised by Member States whenever new data are available (e.g. new forest inventory information). Therefore the comparison can lead to a different result at a different point in time. Still it has to be noted that **the forest sink might be underestimated by the model compared to reported data**.

Differences between land use change emissions (other than deforestation) and agriculture emissions that turn out to be large are due to including different pools and activities making a direct comparison at this level of aggregation difficult (see also Box 1 on comparison with EU Reference projection).

Figure 22: Comparison of EU28 emissions estimated in this study with reported (2014) emissions and removals from UNFCCC reporting (JRC AFOLU tool-historical data 2014) and projected data from the 2013 EU Reference scenario.

Box 1: Comparison of EU28 LULUCF and Agriculture GHG projections

The comparison of projected land use GHG emissions for EU28 can be compared to other recent projections. A comparison with the projection published with the European Commission Trends to 2050 Report (EC, 2014) that describes the EU Reference scenario projection 2013 can be useful to enable as much as possible consistency between projections presented in this report and the EU Reference scenario 2013 but also clearly state differences.

A core element of the EU Reference scenario is what Member States intend to include in their energy systems, notably, the level of bioenergy they plan to use. The projection further includes all binding targets set out in EU legislation regarding development of renewable energies and reductions of greenhouse gas emissions, as well as the latest legislation promoting energy efficiency. Regarding LULUCF the scenario considers demand for bioenergy, wood, food and feed as well as land use policies up to 2012.

A comparison of the Baseline scenario projection from this study and the EU Reference projection for the years 2030 and 2050 is provided in Figure 22b. The level of net LULUCF emissions of both projections is farirly similar for both years. Both used the GLOBIOM/G4M models, however, it should be noted that a number of project specific updates of the two models has been done for this project and not the same input data is being used (for an elaboration of the scenario specifications see the Task 3 report). The EU Reference expects a sink of -214 Mt CO_2 in 2030, this study estimates the sink to amount -204 Mt CO CO_2. However, trends to 2050 are different. While the EU Reference sees a decline to -196 Mt CO_2, this study projects an increase to -245 Mt CO_2. The reasons are in differences between the pools and subcategories covered, differences in input data, but also in different emission and removal estimates for subcategories. For example are removals from afforestation in this study expected to be higher in 2050 (-156 Mt CO_2 compared to -130 Mt CO_2) related to a higer estimate of future prices of wood commodities. In 2030 both studies still agree very reasonably (-87 and -94 Mt CO_2). Another difference is the estimate of the sink from Forest management in 2050. While also for this category in 2030 levels seem to correspond (-137 and -126 Mt CO_2) this study sees a much stronger sink in 2050 (-77 compared to -24 Mt CO_2), directly related to a lower harvest level in the Baseline scenario of this study. Other LULUCF categories are very small and therefore relative difference large. Here differences might occur due to different activities considered.

Emissions from Agriculture are systematically lower in this study for both years. Differences are difficult to assess without looking at driver data and emissions factors, which goes beyond the scope of this study. It also has to be noted that the projection of Agriculture GHG emissions for the EU Reference scenario is based on the GAINS model. Due to the fact that the projections of Agriculture GHG emissions from this study are not calibrated to historic UNFCCC data, different methods are applied and different emission sources are covered by the models, differences are quite natural.

3.2. Comparison of impacts in Baseline and policy scenarios

3.2.1. Overview of impacts

More than 100 model variables related to about a dozen environmental indicators were initially defined and selected from GLOBIOM/G4M model output. All variables were screened and their relative and absolute changes over time and across policy scenarios calculated. In this first screening step general patterns and trends and differences between scenarios are supposed to be detected.

The following general observations can be made. Impacts on variables for **EU28** related to biodiversity tend to be most affected in terms of relative changes as their spread is largest (see Figure 23 and Figure 24). But also GHG and land impacts are large and range between 30 to -20% and 10 to -40%, respectively. Water impacts are relatively small but also much fewer variables were included. Impacts are increasing over time (compare Figure 23 for year 2030 and Figure 24 for year 2050). **Deviations from the Baseline scenario are smaller for the RoW** (compare a) and b) of the respective figures). Sticking out in RoW is the scenario simulating an increased demand for bioenergy in RoW. There is none of the scenarios clearly sticking out for EU28.

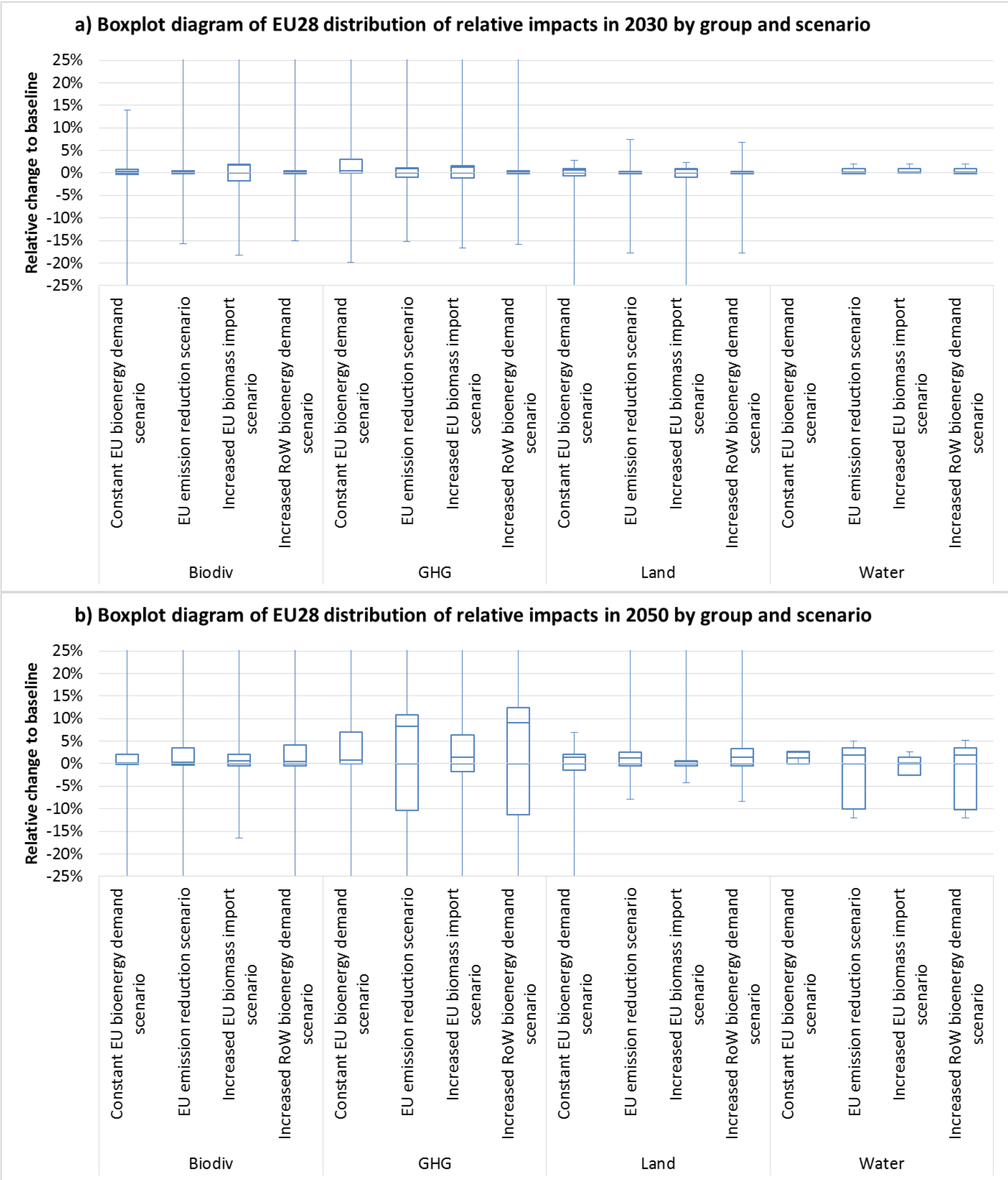

Figure 23: Distribution of relative differences between Baseline and different policy scenarios for a) 2030 and b) 2050 for grouped variables for EU28.

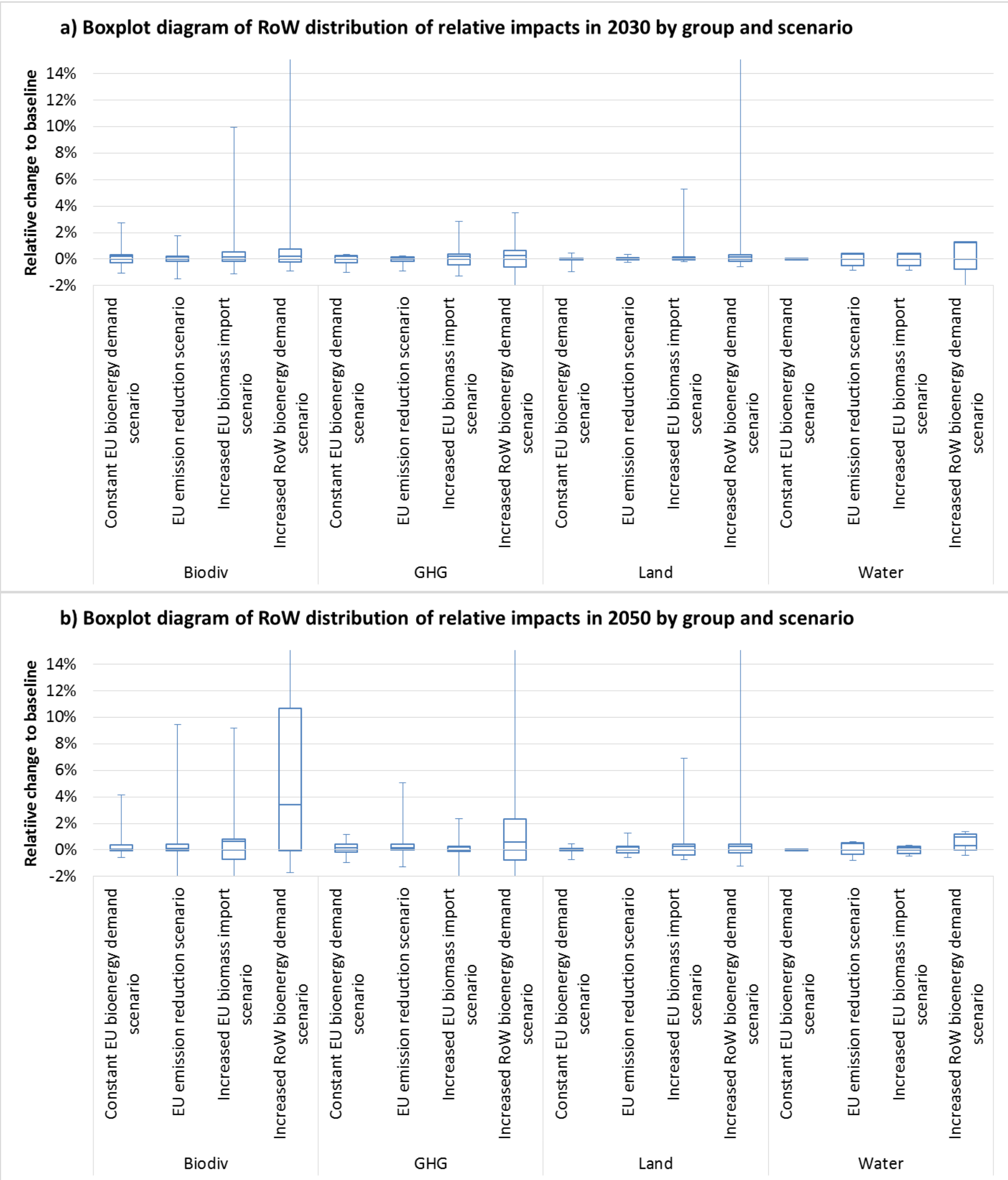

Figure 24: Distribution of relative differences between Baseline and different policy scenarios for a) 2030 and b) 2050 for grouped variables for the RoW.

3.2.2. Impacts on land use

In the following, impacts of the policy scenarios compared to the Baseline on land-use patterns are analyzed in more detail. In a first step the land use categories cropland, grazing land, forest (used and unused), and other natural land are covered. Secondly, results of land use shifts within the category forest are presented.

To enable readers to digest the data on differences of an indicator between Baseline and policy scenario and different years the results are presented in a figure including all relevant information at once. The figures include a graph a) that describes the development of the variable over time for different elements in the Baseline scenario. The trend from 2010 to 2030 and 2050 is summarized in a bar chart b). Finally differences in the policy scenarios compared to the Baseline for the years 2030 and 2050 are presented (figure c)). This presentation helps to evaluate the differences between scenarios against the background trends of the Baseline and also to point to changes in the magnitude and sign of impacts compared to the baseline over time. The figures showing areas present the increase (positive values) and decrease (negative values) of a land use category in comparison to the baseline. The figures cover all areas and changes. This is why the sum of area increases and decreases are balancing and positive and negative bars have the same size. Figure 25 shows differences identified for land use types within the EU28. In total, in EU28 the development of the Constant EU bioenergy demand scenario and Increased EU imports scenario are contrary to the development of the other two policy scenarios. **Compared to the Baseline scenario, the Constant EU bioenergy demand scenario leads to a lower amount of SRC area and higher amounts of other natural land** (including abandoned cropland and grazing land) and grazing land (2030 and 2050). While the total forest area (sum of used and unused forest) does not differ between the two scenarios too much, there are comparably large shifts within the forest leaving more used forest unused.

For the policy scenarios demanding higher shares of domestic biomass, differences to the Baseline scenario become evident only after 2030. Grazing land area and other natural land decline, whereas SRC area increases compared to the Baseline scenario. Dominating, however, is in these scenarios the shift from unused forest to used forest compared to the Baseline (Figure 25).

It is striking that some changes in the Baseline scenario override changes across scenarios for SRC, cropland and other natural land. This does not hold for grazing lands that are hardly affected under the Baseline scenario but show up to undergo losses until 2050 in those policy scenarios that assume increased biomass demand.

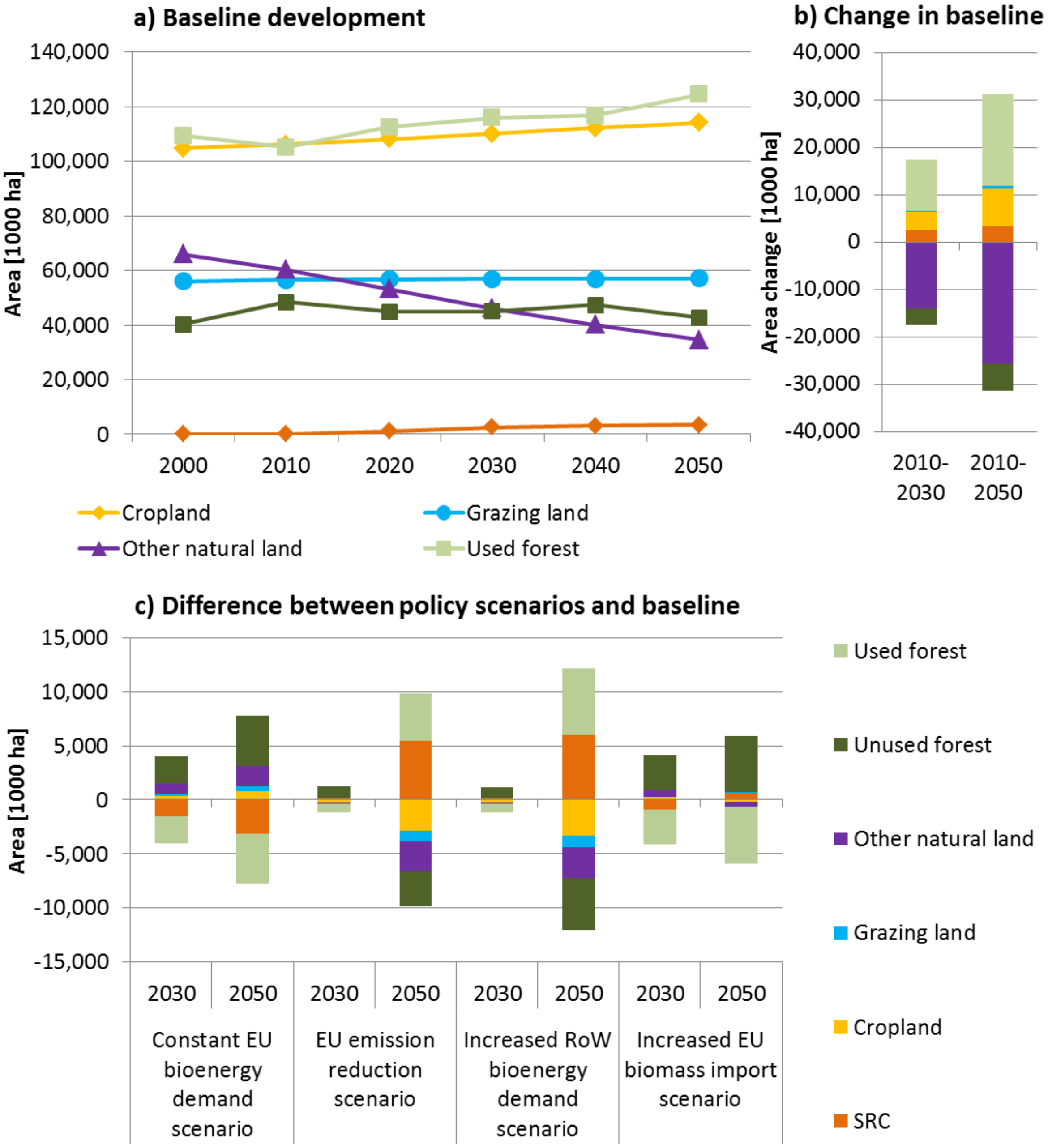

Figure 25: Projected land use changes for EU28 a) in the baseline, b) in the baseline between 2010 and 2030/2050 and c) in different scenarios and years compared to the baseline.

From a **global perspective (RoW)**, land use patterns in the Increased RoW bioenergy demand scenario differ most from the baseline scenario, especially in the year 2050. Changes in the other three policy scenarios seem to be almost not significant in this comparison (Figure 26). The impacts are related to the conversion of more unused forest to used forest and conversion of other natural land and cropland to SRC.

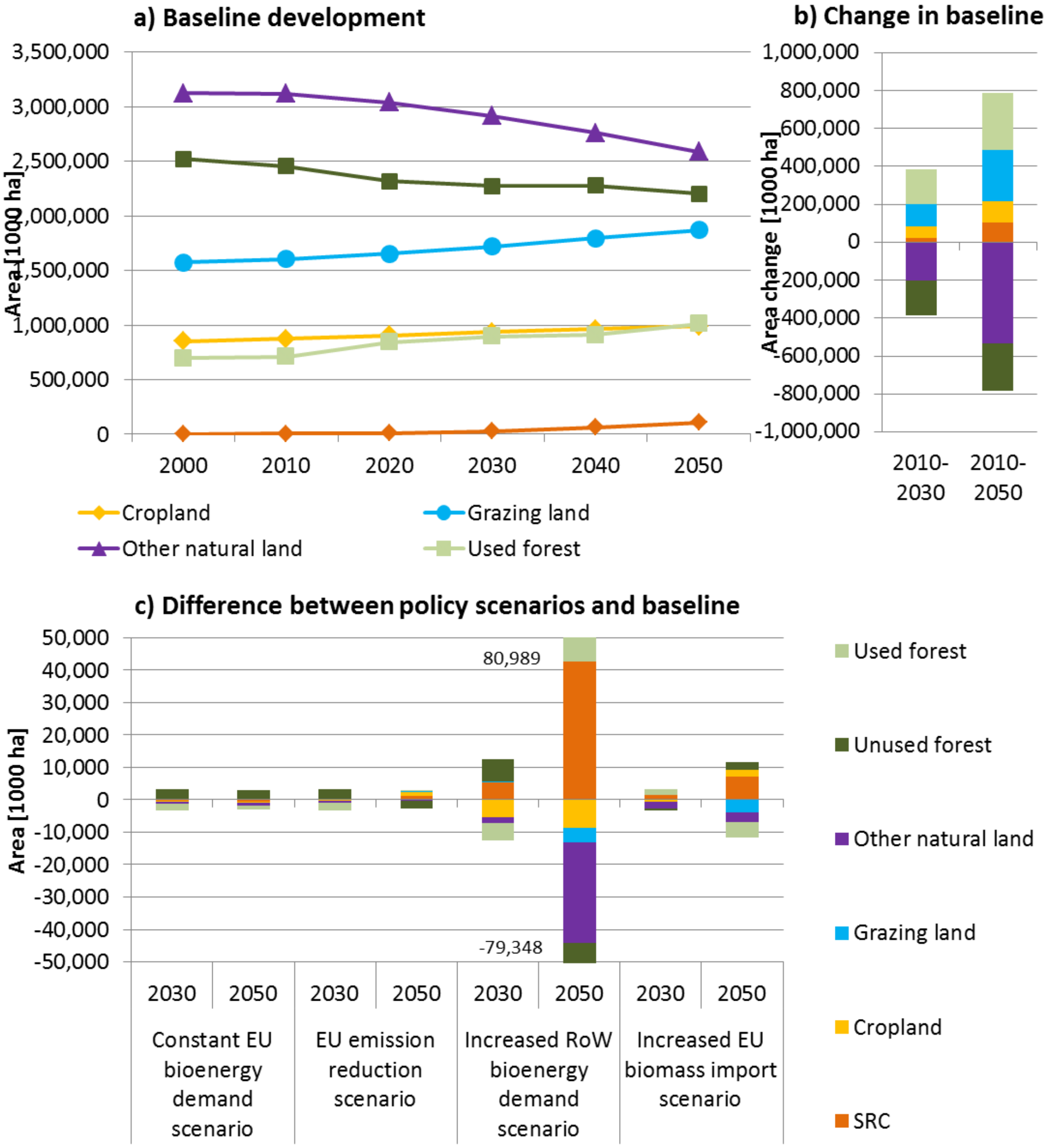

Figure 26: Projected land use changes for RoW a) in the baseline, b) in the baseline between 2010 and 2030/2050 and c) in different scenarios and years compared to the baseline.

3.2.3. Impacts on land with high biodiversity value

Impacts on land with high biodiversity value in the EU28 are comparably low due to the fact that only less than 0.3% of the total area in the EU28 is categorized as area of high biodiversity value according to the global biodiversity data set from UNEP-WCMC. The Constant EU bioenergy demand scenario shows less afforestation of other natural land with HBV compared to the Baseline. The other three policy scenarios allocate more other natural land with HBV to new forests (Figure 27). The amount of existing forest area with HBV is not affected at all, neither in the baseline scenario nor in policy scenarios.

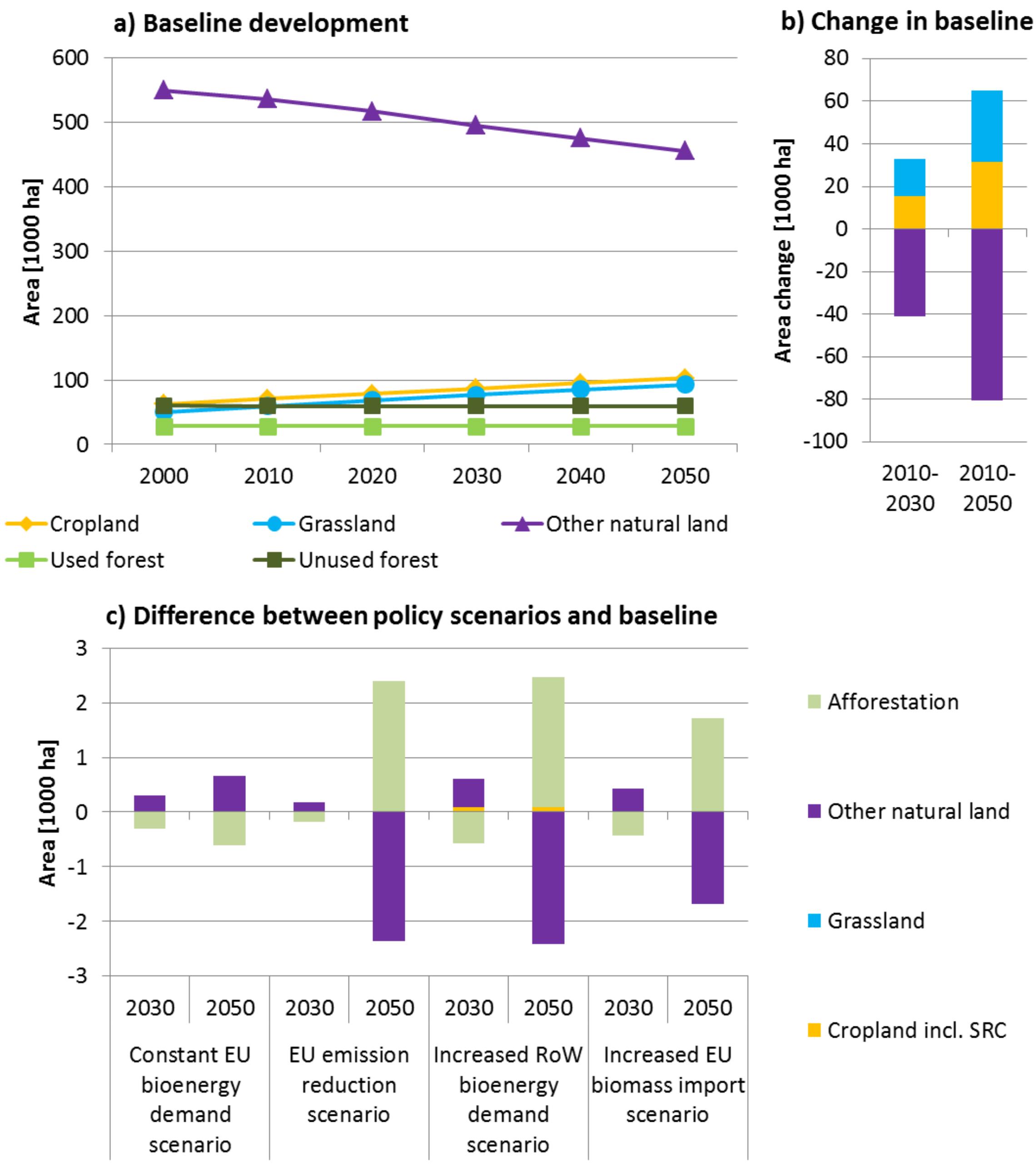

Figure 27: Projected changes of HBV areas in EU28 a) in the baseline, b) in the baseline between 2010 and 2030/2050 and c) in different scenarios and years compared to the baseline.

From a **global perspective (RoW),** the conversion of HBV land is more important because the data from UNEP-WCMC identify 20% of the global land area as highly biodiverse. Figure 28 gives the distribution of these 1,850 Mha on different land use categories in 2000. Unused forests form the largest share, followed by other natural land and grazing land.

The conversion of HBV land is not proportional to the initial distribution of HBV land in 2000 as the land use categories are affected differently by conversion under different scenarios. But it is proportional to the impacts on the overall land use pattern (see Figure 26). The land use shifts affecting HBV land differ most between the Increased RoW bioenergy demand scenario and the Baseline (Figure 29). In the other three policy scenarios other natural land with HBV is converted less intensively. Effects on forest area with HBV in the Increased RoW demand scenario show that used forest area is increased, unused forest and also afforestation area decreased compared to the Baseline. In addition cropland is increased, other natural land decreased.

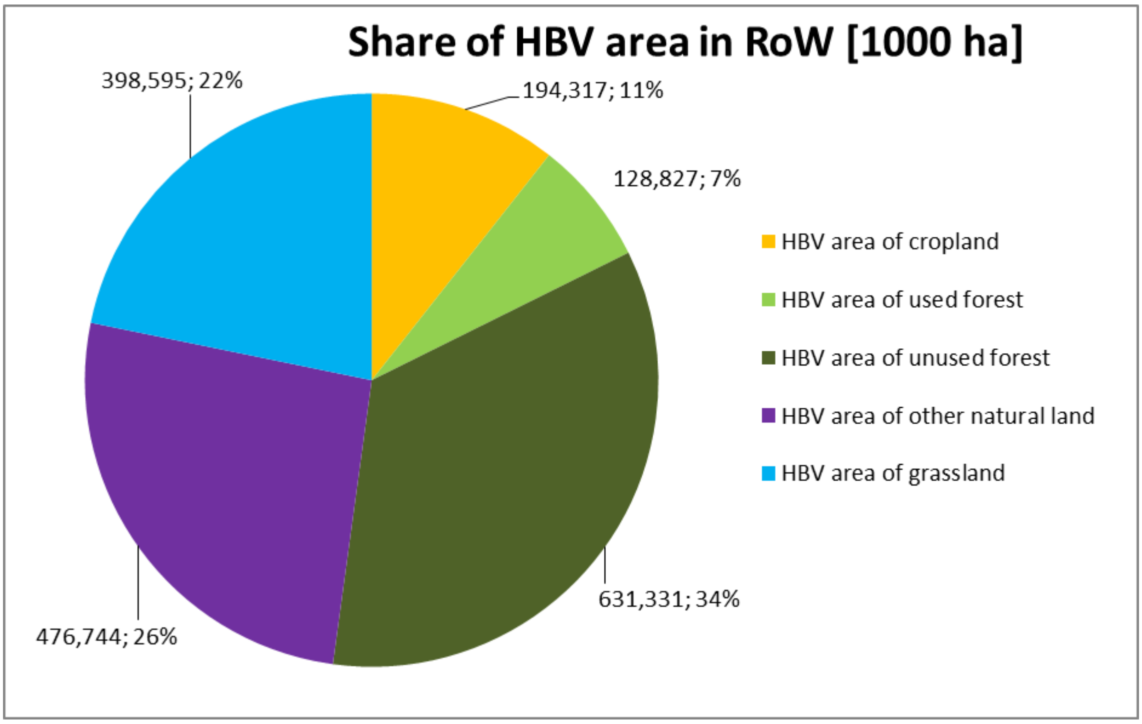

Figure 28: Distribution of areas with high biodiversity on land use categories for the RoW in 1000 ha (year 2000).

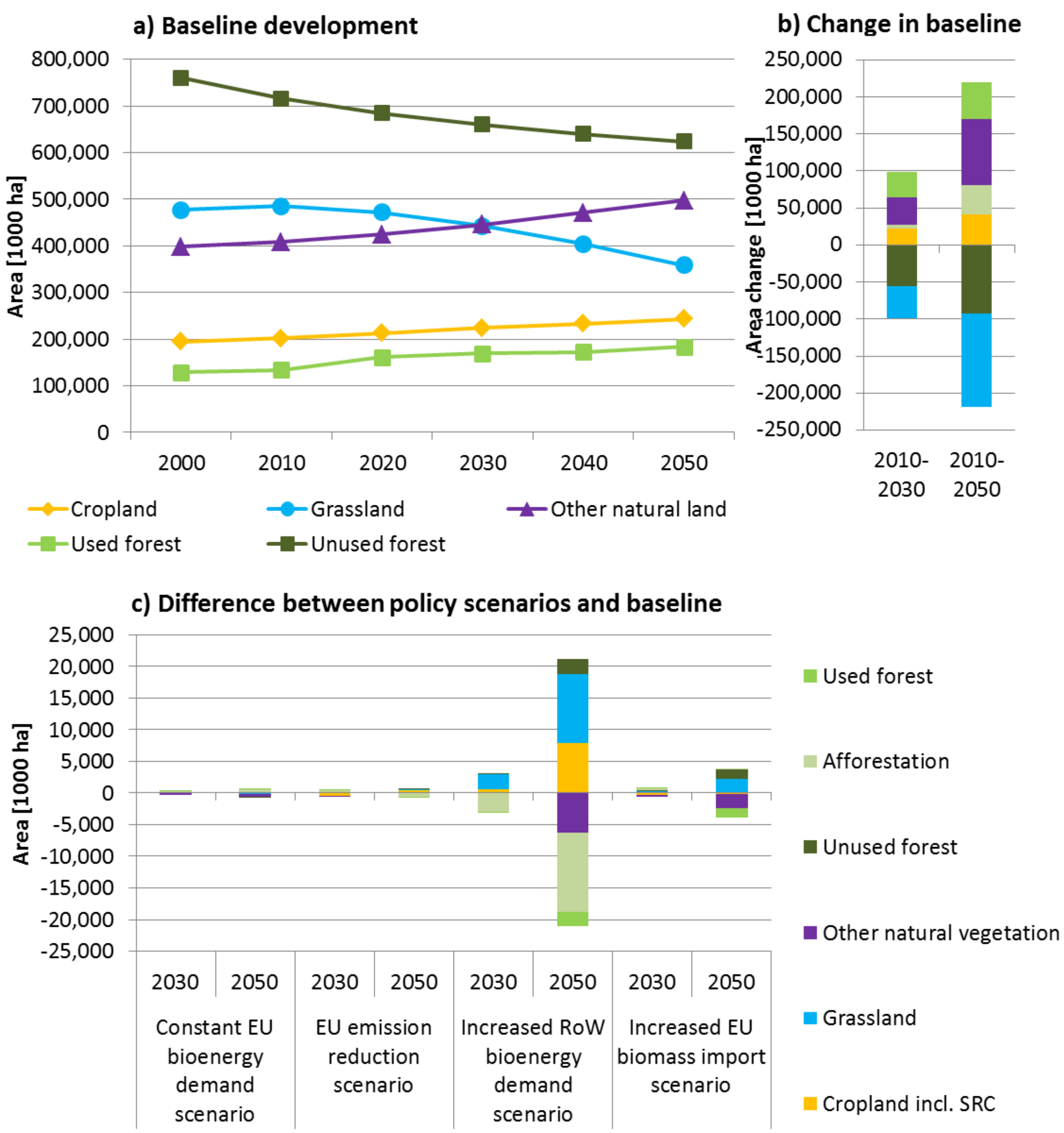

Figure 29: Projected changes of HBV areas in RoW a) in the baseline, b) in the baseline between 2010 and 2030/2050 and c) in different scenarios and years compared to the baseline.

3.2.4. Impacts on GHG emissions from land use activities

The model provides a number of variables related to different GHG emission sources and activities. Figure 30 displays forestry related emissions for EU28. It was already discussed that the sink from forest management is projected to decline in the Baseline. **Compared to this Baseline, forest management sink is declining more strongly in the long run in two policy scenarios with increased domestic biomass production** (positive bars in Figure 30). In 2050 EU emission reduction scenario and Increased RoW demand scenario show decreased deforestation emissions that are compensating for the loss of the forest sink to some degree. Also emissions from harvested wood products decrease/the sink increases. More products are being produced causing the stock of carbon stored in wood products to increase. In the Baseline there is already a strong increase of afforestation removals over time. Comparatively small are effects on afforestation removals between policy scenarios.

The scenarios are also affecting non- CO_2 emissions (Figure 31). While impacts in 2030 are rather limited, stronger effects can be noted for 2050, especially for those scenarios that lead to an increased use of biomass (be it imported or domestically sourced). Only the Constant EU bioenergy scenario results in increased emissions compared to the Baseline. The change in agriculture emissions can mainly be attributed to increased livestock production related to an increase of grazing and cropping land. In all other scenarios emissions from livestock and fertilizer input are lower. The changes in livestock emissions can be attributed to reduced bovine milk and meat production in EU28, a result of decreased grazing land area. While EU28 production of these food and feed commodities decrease in these scenarios, EU28 consumption is stable but to a higher degree relying on imports. Figure 31 also shows: differences between scenarios are smaller than the changes in the Baseline scenario between 2010 and 2030/2050. Figure 32 summarizes all GHGs and presents net LULUCF and Agriculture sector emissions. It is striking that compared to the Baseline all scenarios are reducing net emissions from LULUCF (between 5 and 18 Mt CO_2eq). Agriculture emissions are higher for the Constant EU bioenergy scenario but fully compensated by LULUCF CO_2 emission reductions.

Figure 33 and Figure 34 present changes in emissions from these two sectors for the RoW. Also here impacts become stronger over time. Hardly any differences can be noted when comparing forest management emissions with the Baseline across scenarios in 2030. All scenarios show a decreased sink (positive bars) in that year. Striking is the result for the Increased RoW demand scenario. In 2050 more than 140 Mt CO_2 are emitted more from forest management in this scenario compared to the Baseline. This is contrasted by reduced emissions from deforestation of about 40 Mt CO_2.

Livestock and other non-CO_2 emissions are not reacting consistently across scenarios compared to the Baseline (Figure 34). The strong reduction of livestock related GHG in 2050 in the Increased RoW bioenergy demand scenario is reflecting the increased competition between beef and milk production and bioenergy. Also for the RoW total net LULUCF and Agriculture emissions can be compared (Figure 35).

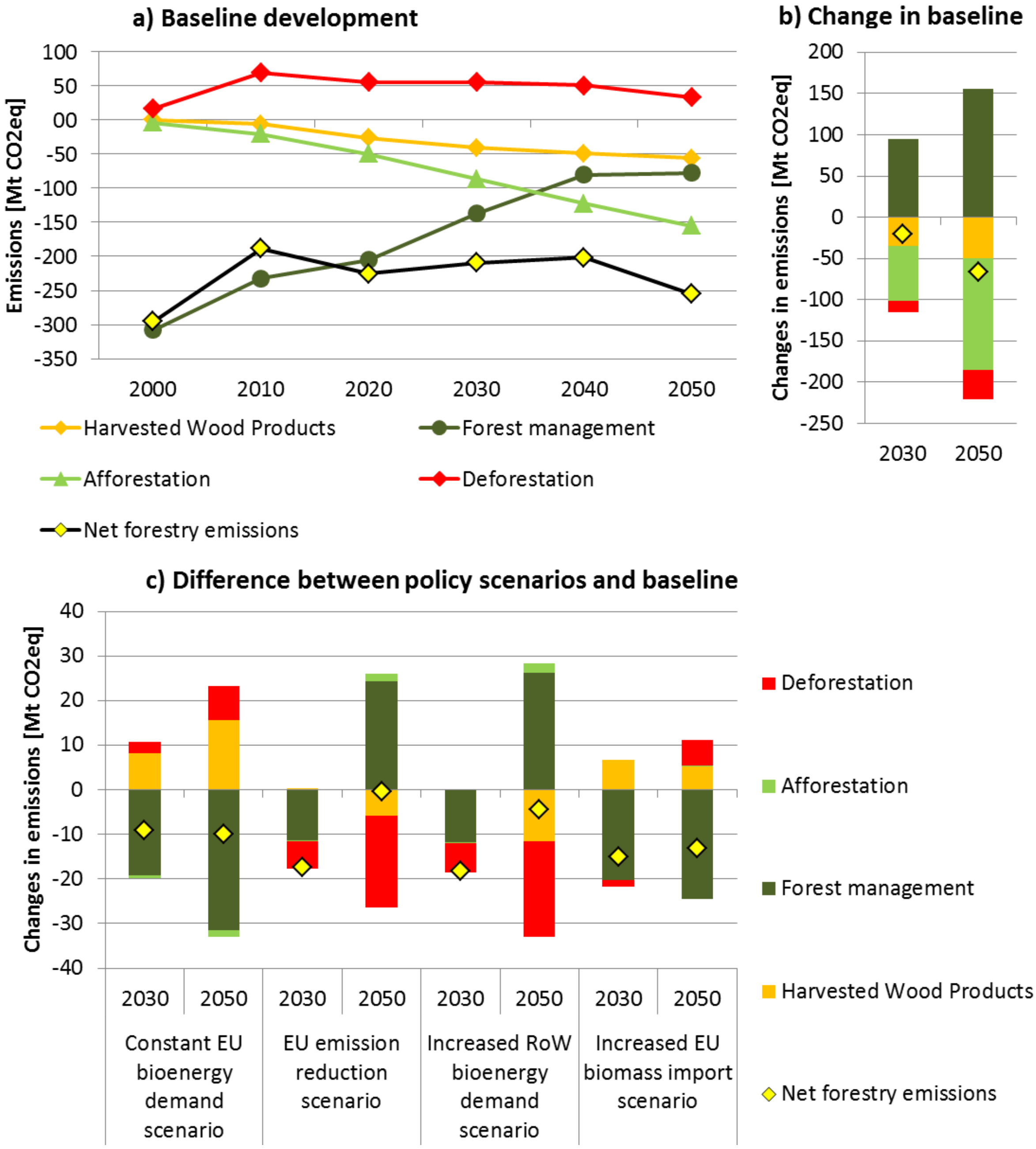

Figure 30: Projected Changes in forestry CO_2 emission and removals in EU28 a) in the baseline, b) in the baseline between 2010 and 2030/2050 and c) in different scenarios and years compared to the baseline.

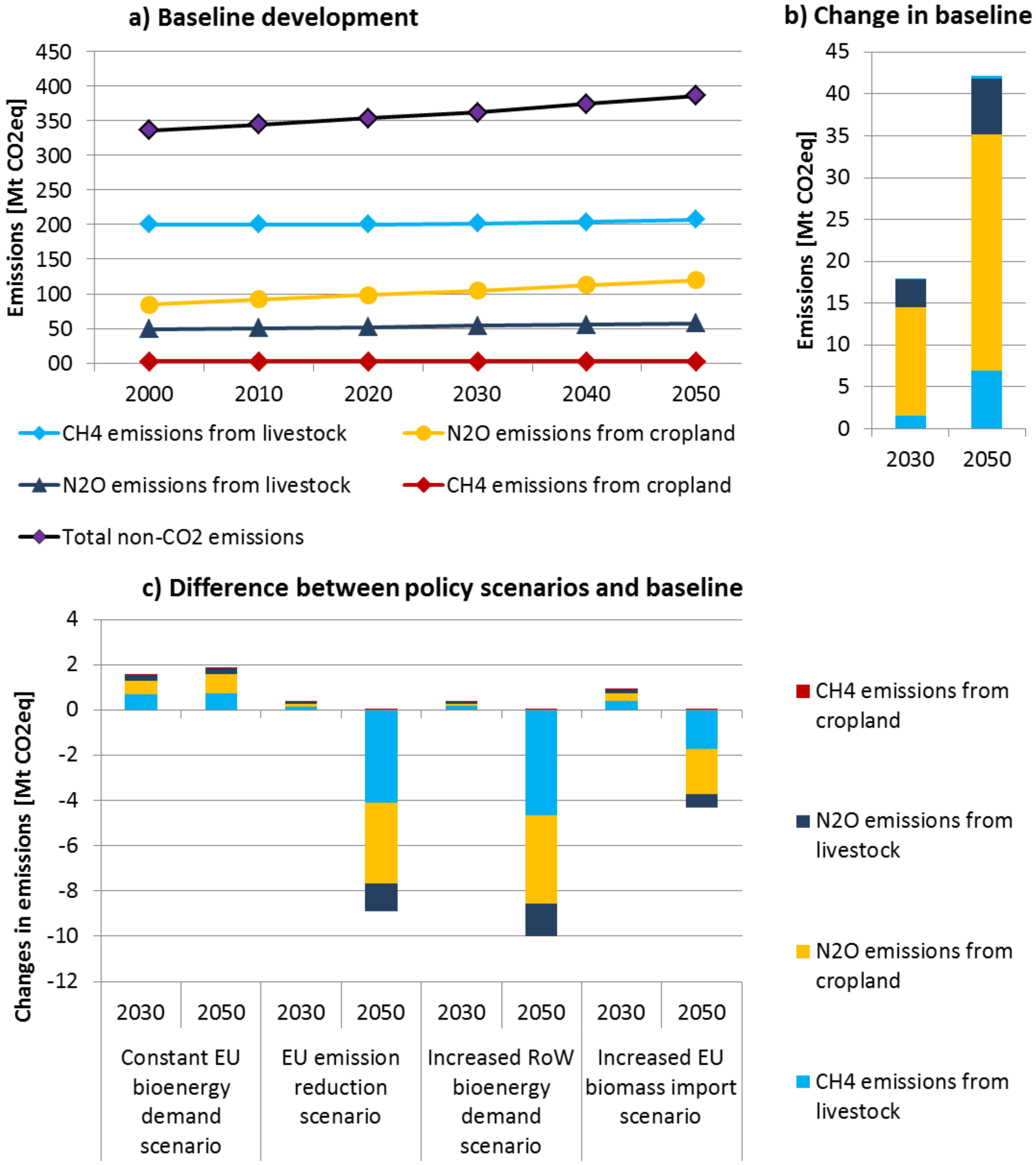

Figure 31: Projected changes in non-CO_2 land use emission in EU28 a) in the baseline, b) in the baseline between 2010 and 2030/2050 and c) in different scenarios and years compared to the baseline.

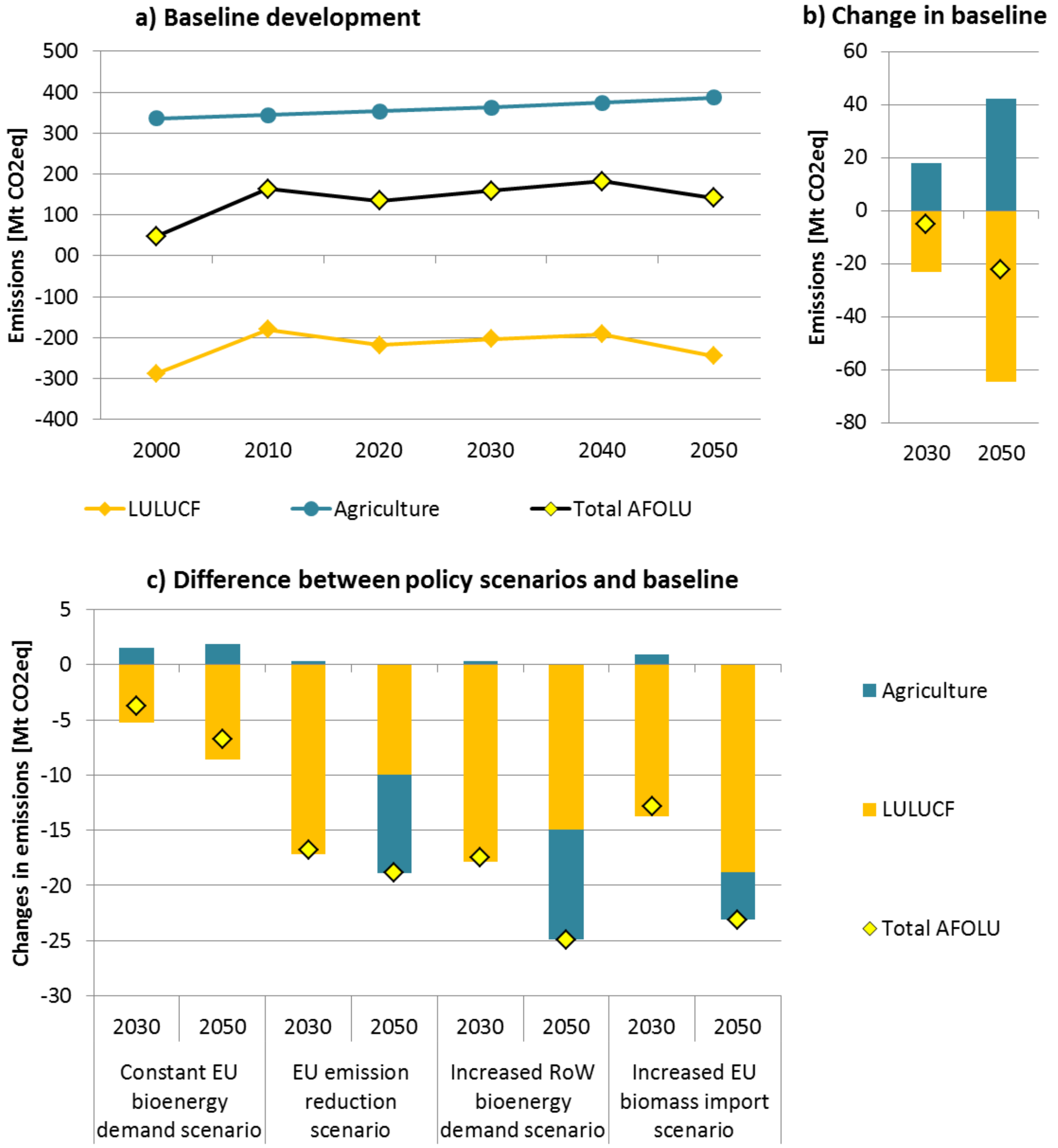

Figure 32: Projected changes in net LULUCF emissions and removals and Agriculture emissions in EU28 a) in the baseline, b) in the baseline between 2010 and 2030/2050 and c) in different scenarios and years compared to the baseline.

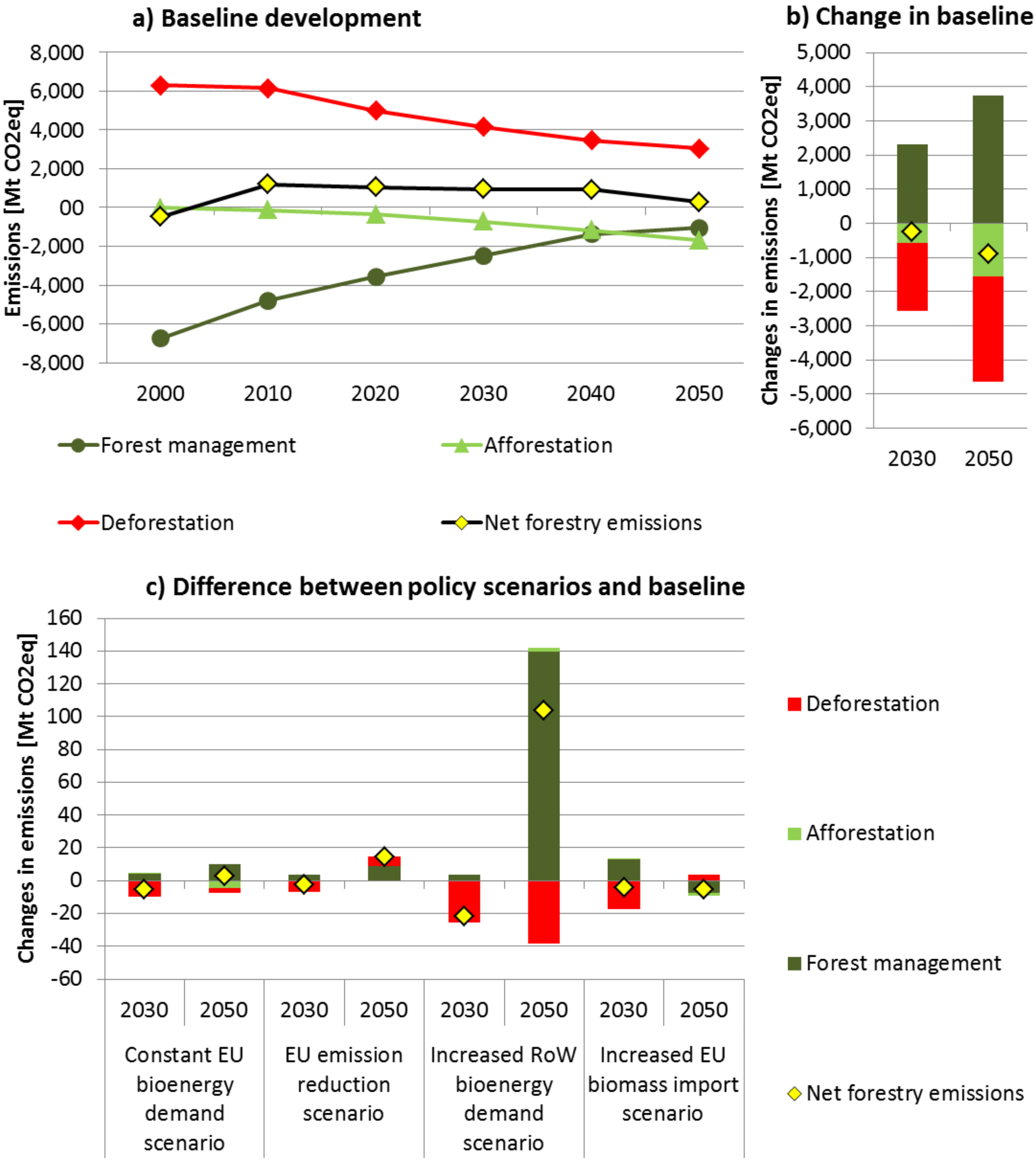

Figure 33: Projected Changes in forestry CO_2 emission and removals in RoW a) in the baseline, b) in the baseline between 2010 and 2030/2050 and c) in different scenarios and years compared to the baseline.

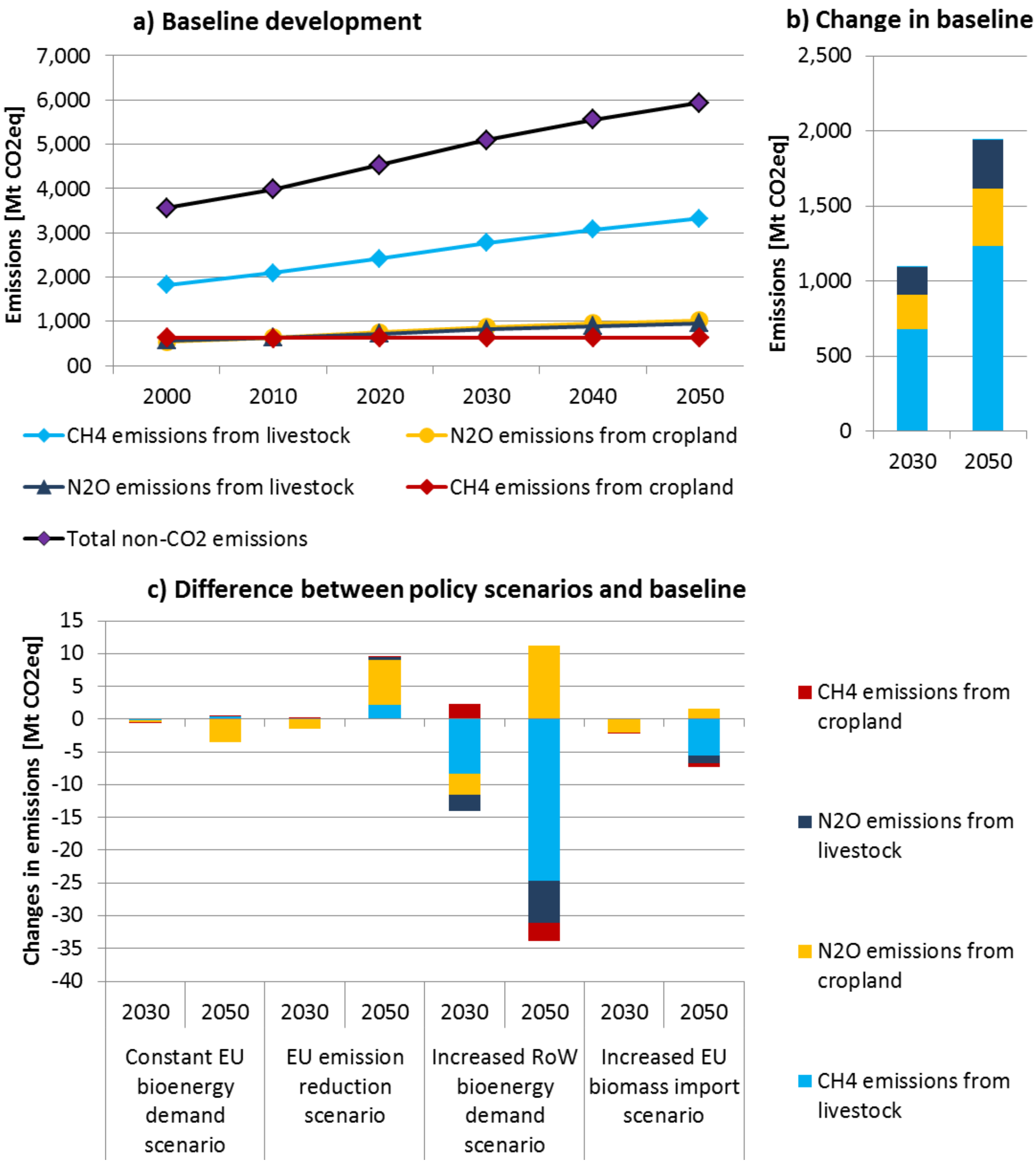

Figure 34: Projected changes in non-CO_2 land use emission in RoW a) in the baseline, b) in the baseline between 2010 and 2030/2050 and c) in different scenarios and years compared to the baseline.

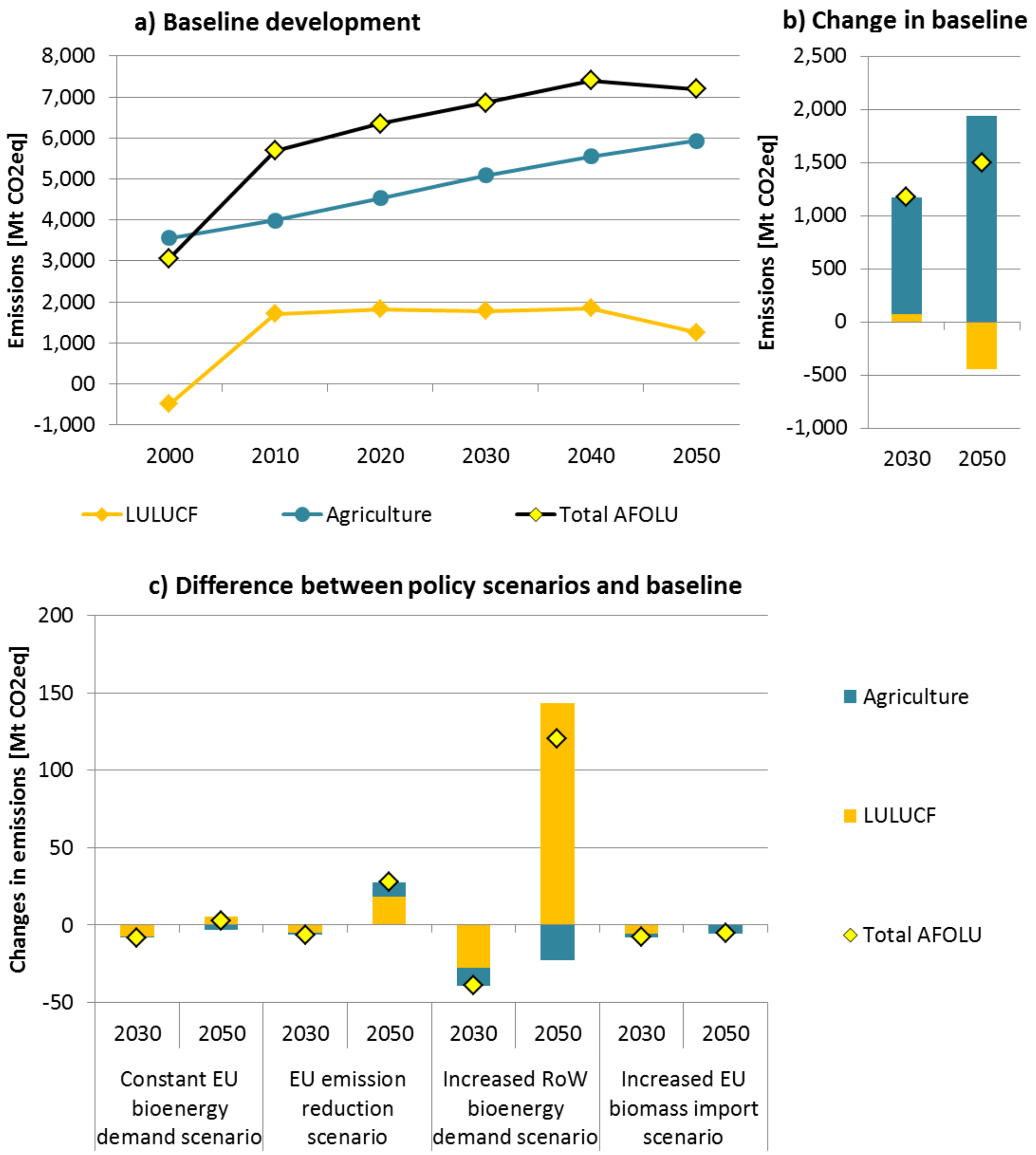

Figure 35: Projected changes in net LULUCF emissions and removals, Agriculture emissions and biofuel savings in RoW a) in the baseline, b) in the baseline between 2010 and 2030/2050 and c) in different scenarios and years compared to the baseline.

3.2.5. Impacts on the EU Forest management sink

The policy scenarios differ from the Baseline by assuming different production and use of forest biomass. This changes also the levels of harvest in these scenarios. If the forest increment remains largely unchanged (one could assume forest fertilization, change in species etc.), increased harvest levels directly impact the carbon balance of forests. More export of carbon through harvest means that the net sink of a forest is reduced or the net source increased. Figure 36 compares harvest from forest management (excluding a small amount of wood harvested from deforestation) and forest sink development for EU28. Harvest levels increase for EU28 at a level of 470

Mm3 in 2000 (lower left side of the panel). Harvest levels in 2050 range from 519 Mm3 to 615 Mm3. What Figure 36 shows is the response of the EU forest carbon balance to changes in future harvest levels. The development of the relationship between harvested volume and carbon sink is very similar for the scenarios. In all scenarios the sink is declining, most strongly in the scenario of Increased RoW bioenergy demand, from -232 Mt CO_2 in 2010 to -109 Mt CO_2 (Constant EU bioenergy demand) and -51 Mt CO_2 (Increased RoW bioenergy demand). The response of the sink is thus quite symmetrical: the scenario with the lowest harvest level after 2020 (Baseline) results in the strongest sink. Increased EU biomass import and Constant EU bioenergy demand scenarios both cause the sink to be 10-20 Mt CO_2 smaller than in the Baseline. About 100 Mm3 more are harvested in 2050 under the EU emission reduction scenario compared to the Baseline, decreasing the sink by about 50 Mt CO_2.

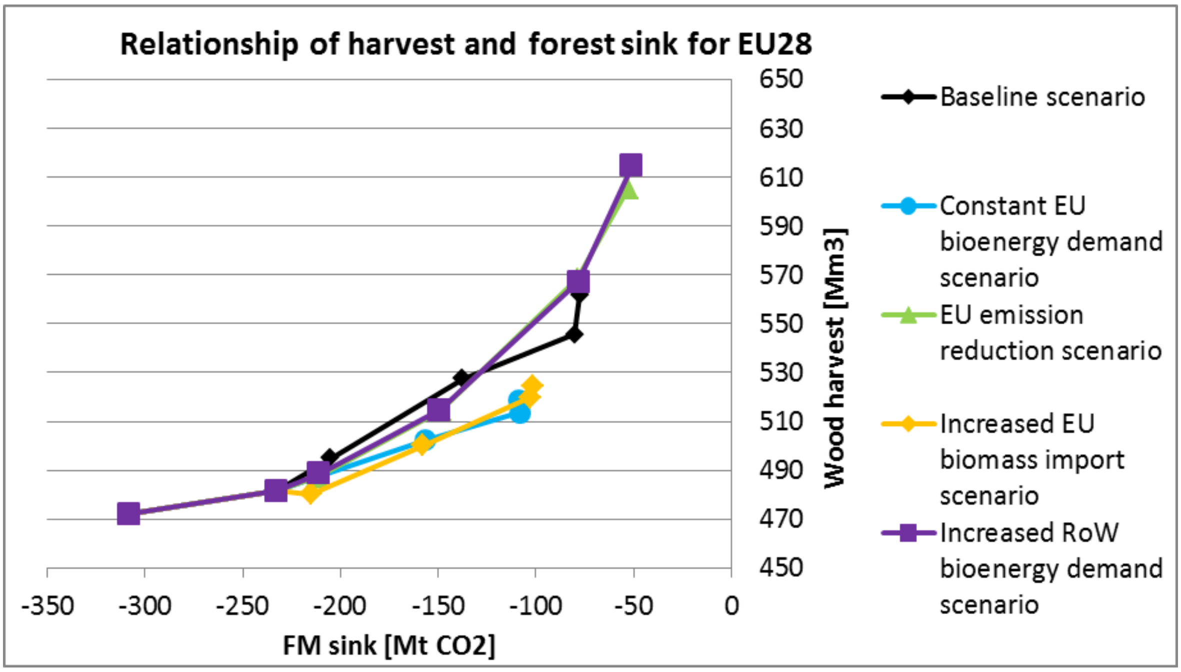

Figure 36: Relationship between the EU28 forest harvest levels and the forest carbon sink in baseline and policy scenarios. Harvest volume includes only stem wood harvested from managed forests and does neither include bark nor forest residues.

Figure 37 puts additional harvest volume compared to the Baseline in relation to caused decline in the sink. Across the scenarios the impacts per m3 are similar, stressing again the symmetry of the sink response. The impacts are different, however, for different years. The ratio of harvest volume to sink strength in 2050 is 5-50% smaller than in 2030. This is due to the fact that the average age of EU forests is higher in 2050. Older trees take up less carbon. Leaving the trees growing in the forest (this is the alternative to harvest) therefore causes less of a sink reduction.

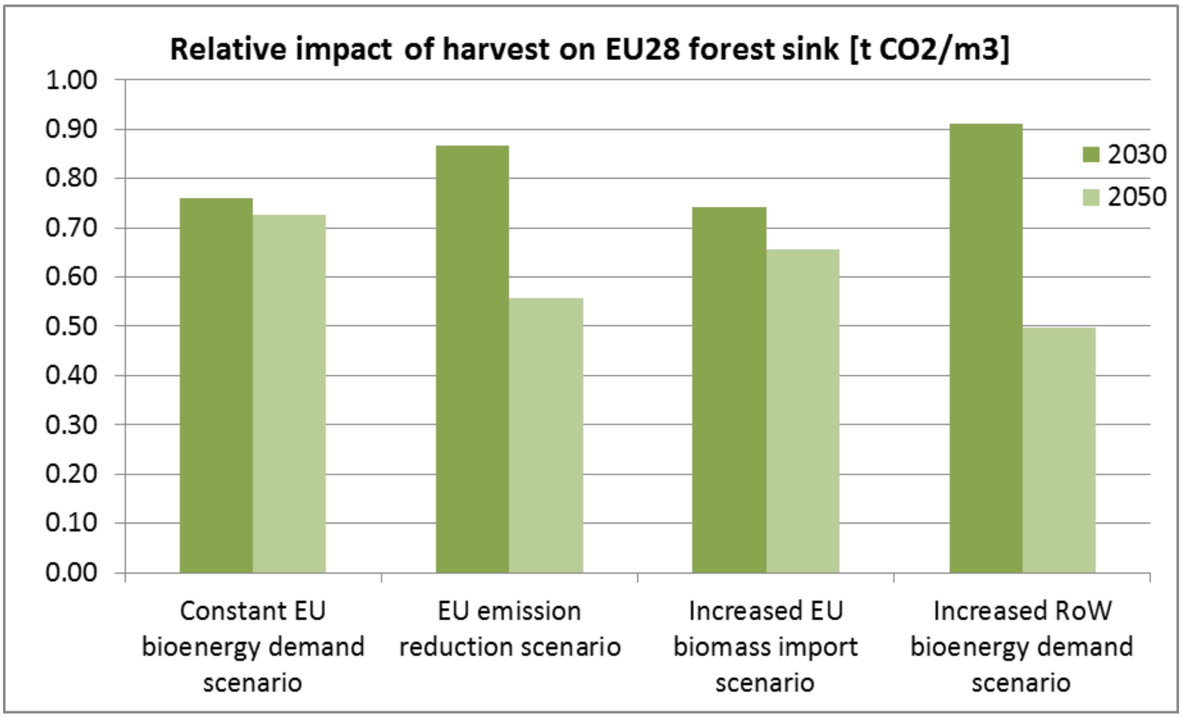

Figure 37: Impact of increased harvest on the EU28 forest sink relative to the baseline scenario (=1.0). The difference to the sink in the baseline scenario in Mt CO_2 is divided by the additionally harvested volume from forests in Mm3 compared to the baseline. This results in the sink reduction per additionally harvested m3.

Besides harvest levels, another measure for forest management intensity given out by the model is the rotation time. This is the average age at which trees are harvested. When wood demand is low, trees are harvested rather late, leading to an increased average forest age and also a reduction of the average increment of forests. When production is increased the rotation length is automatically shortened. This can, as a response, also increase the increment of the forest because more young trees exist that have higher growth rates. Figure 38 displays the difference of average rotation time in the policy scenarios compared to the Baseline. Symmetrically, the scenario with highest harvest rates also shows the shortest rotation time. Compared to the Baseline scenario, Constant EU bioenergy demand scenario and Increased EU biomass import scenario show longer rotations. Here management intensity is reduced.

The reduction of the rotation time in the other scenarios compared to the Baseline might result in higher productivity of the forest. It causes, however, also the loss of habitat for many species depending on large dimension trees, old tree age classes and dead wood. Without being able to explicitly model the loss of habitat, the average rotation time can serve as a proxy for the availability of old trees and habitat for species depending on them. Largest impacts would therefore be expected from the Increased RoW demand scenario on EU forests, causing average rotation time to drop by 4% in 2050. Similar impacts are expected for the EU emission reduction scenario.

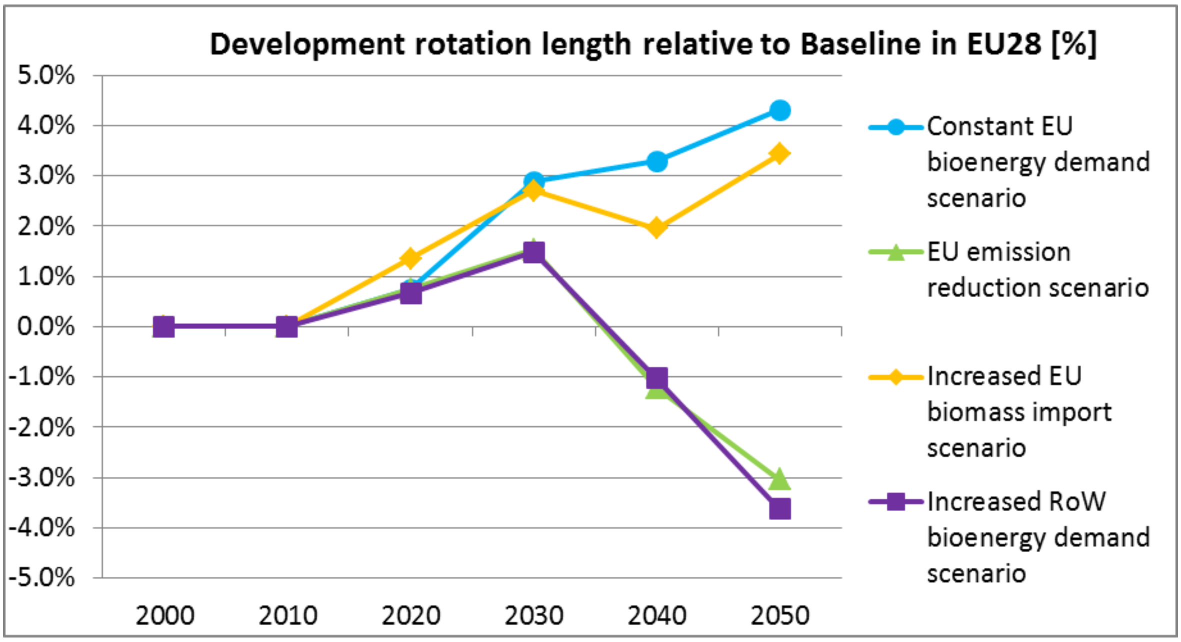

Figure 38: Comparison of forestry rotation length in policy scenarios with Baseline.

4. Results of Stage 2: Exploring implications of environmental constraints for biomass resource efficiency

4.1. Important environmental impacts found in Stage 1 and the implementation of specific constraints to reduce impacts

The analysis of environmental impacts in Stage 1 of the analysis revealed that a number of indicators show significant changes across scenarios. Only a very limited number of indicators can technically be converted into environmental constraints. In the following we summarize the performance of three selected indicators across scenarios and their use as environmental constraints.

4.1.1. Conversion of areas of High Biodiversity Value (HBV)

Areas with HBV can be identified by using existing maps of biodiversity hotspots (see Section 2.1 on the definition of indicators). Most of the HBV areas as defined in this project are located outside EU28, where also most of the conversion is expected (about 7 Mha until 2050 in the Baseline for RoW), as also seen across the policy scenarios (between 1-9 Mha). We investigate the implications of avoiding the conversion of any of these areas by constraining land conversion for HBV areas. This will have an impact on overall land availability for conversion and therefore have an impact on other model variables when constrained.

Areas defined as HBV are excluded from any land conversion above the developments seen in the baseline. The initial land use of such areas (in the year 2010) is not allowed to change through land conversion. However, the land might still contribute to sustainable production. For example HBV forest area will remain forest and (if actively managed in the year 2010) can supply biomass but cannot be converted to cropland. For some key biotopes, this assumption may be too lenient as they require no disturbances in an area, however, for other biotopes, a continued active and sustainable management is key for providing a suitable environment. The constraint is to be applied globally. It has to be noted that only a small amount of areas are classified as HBV within EU28.

The implementation of such a constraint will lead to more intensification of management in all land use categories on lands not considered of HBV. The import of biomass sources to the EU is expected to decrease as a large share of forests outside EU cannot anymore be used for production of biomass feedstocks as in the Baseline scenario.

4.1.2. Area of unused forest converted to used forest

The indicators 'used' and 'unused' forest area and the conversion between both are among those indicators that show significant differences between scenarios both for EU28 and for the RoW. Between 2010 and 2050, in the baseline in EU28, 5.6 Mha of forest are converted from unused to used (11.7% of unused forests in 2010). Across scenarios, the differences in 2050 are between -4.8 and +5.2 Mha in EU. For the RoW, the largest change in the indicator among policy scenarios as compared to baseline is 80 Mha in 2050 (3.6% of unused forests in 2010). As a comparison, the change in the baseline between 2010 and 2050 for RoW is 253 Mha (10%).

This indicator is a good proxy for assessing changes in the intensity of forest management due to increased biomass demand. Technically, the area of unused forest can rather easily be constrained to the same developments as in the Baseline. For the constrained scenario, the model will not be allowed to convert unused forest to used forest above the level as observed in the Baseline scenario in EU. The constraint is applied for each MS within the EU. No constraint is imposed for the RoW.

It is expected that the constraint will lead to 'used forest' within EU being used more intensively to fulfill increasing wood demand. Also, imports of biomass are expected to increase significantly.

4.1.3. Conversion of other natural land

In the Baseline scenario in EU28, about 40% of "other natural land" (25 Mha) is converted between 2010 and 2050; in the RoW, it is 500 Mha (-17%). Other natural land consists of various types of land that are not very homogenous (a mixture of land that cannot be properly classified such as unused cropland (if not fallow) or unused grassland, including natural grasslands). Across scenarios differences for EU28 are between +1.9 and -2.9 Mha compared to the baseline in 2050 (5.5% to -8.4%), for the RoW differences are up to -30 Mha (-1.2%).

For the implementation into the model as a constraint no conversion of this category to any other land use beyond baseline levels is allowed. One exception from this rule is that the land can be converted to afforestation. The constraint is applied to EU28. It is expected to lead to an intensification of management of remaining land and more conversion of other land use categories.

4.2. Exploring implications of single constraints for biomass resource efficiency in the EU Emission reduction scenario

4.2.1. Implications for production of biomass in EU

As stated earlier, land of HBV is mostly located outside EU. Nevertheless there are implications for biomass production for EU28 when a constraint on HBV is implemented: sawlogs harvest increases in EU by 5 Mm^3 in 2030, and by 20 Mm^3 in 2050 (see Figure 39) in the HBV constrained scenario as compared to the unconstrained EU Emission reduction scenario, where 272 Mm^3 and 315 Mm^3 of sawlogs are harvested respectively. At the same time, less pulpwood is harvested in EU28.

If forests in EU28 are protected from further intensification (i.e. conversion of unused forest into used forest), in 2050 both harvest of sawlogs and pulp logs is significantly reduced by in total almost 60 Mm^3. A relatively large share (about 30%) is compensated by the increased production of wood from SRC for bioenergy production.

An opposite effect can be observed if other natural land in EU is protected from conversion: There is less SRC biomass production in EU that would be typically established on these lands (abandoned cropland and grazing land). At the same time, a small increase in the harvest of pulpwood occurs to compensate for the decreasing availability of SRC.

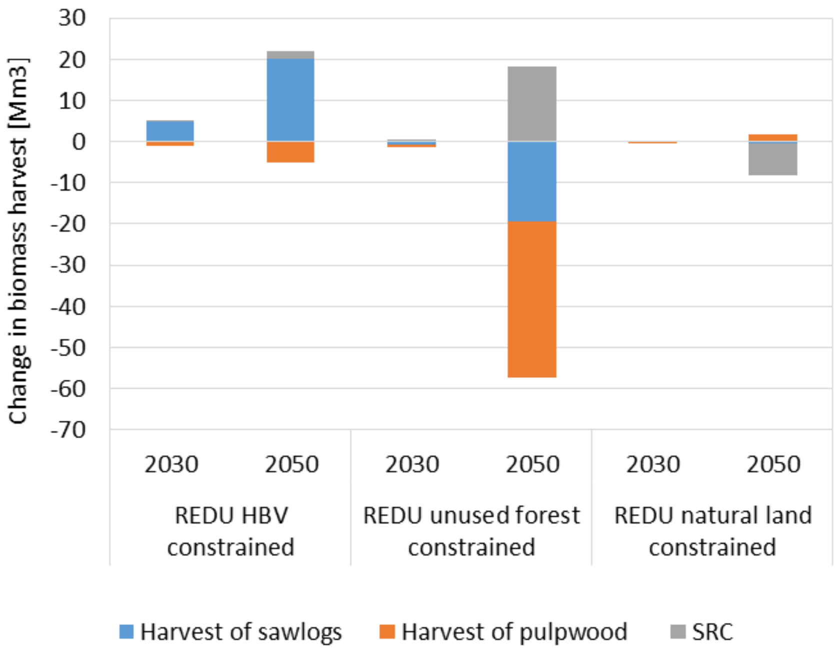

Figure 39: Change in biomass production in EU across constrained scenarios compared to the (unconstrained) EU Emission reduction scenario.

4.2.2. Implications for trade of biomass

Changes in EU biomass production that can be observed across the three constrained scenarios have implications for biomass trade between EU28 and RoW. The protection of HBV land leads to decreased EU net-imports of sawlogs and pulpwood, wood pellets and industrial by-products in 2050 (see Figure 40) as the constraint has a high effect on land use outside EU28. At the same time, the constraint leads to increasing net-export of sawnwood from EU28 to RoW and a small decrease in the net-import of chemical pulp. The export of sawnwood from EU28 to RoW increases by 2 Mm^3 in 2030, and by 9 Mm^3 in 2050 (compared to 18 Mm^3 and 29 Mm^3, respectively, in the EU Emission Reduction scenario without restrictions). This increase in export of sawnwood from EU28 is directly related to the reduced availability of biomass sources in regions with high shares of HBV areas, which in turn decreases the competitiveness of the forest based industries within these regions.

Constraining either land use change from unused forest to used forest or the conversion of other natural land to cropland or grazing land causes an increased import of raw biomass sources to increase in 2050. This is especially true for wood pellets of which more than 16 Mm^3 (in the case of protection of unused forest) or 3 Mm^3 (protection of other natural land) more imports are expected (compared to 52 Mm^3 in the EU Emission Reduction scenario without restrictions). The increase in EU28 import of wood pellets is mostly expected to enhance the trade with USA, Canada, and the former Soviet Union. In the case of constraining land use change from unused forest to used forest, the net-import to EU28 of sawlogs and pulpwood also increases to satisfy the domestic demand of wood for material purposes. The main trade partners for the roundwood is the former Soviet Union, thereby strengthening the trade of wood between EU and the former Soviet Union even further than that of current levels.

In terms of trade of sawnwood and chemical pulp, constraining the conversion of other natural land to cropland or grazing land is noted to have a minor impact on the net trade both in 2030 and 2050. On the other hand, constraining land use change from unused forest to used forest is found to decrease the net-export of sawnwood and slightly increase the net-import of chemical pulp. This is directly related to the decrease in availably of raw biomass sources within EU28 which cannot economically be fully compensated by an increase in import of roundwood.

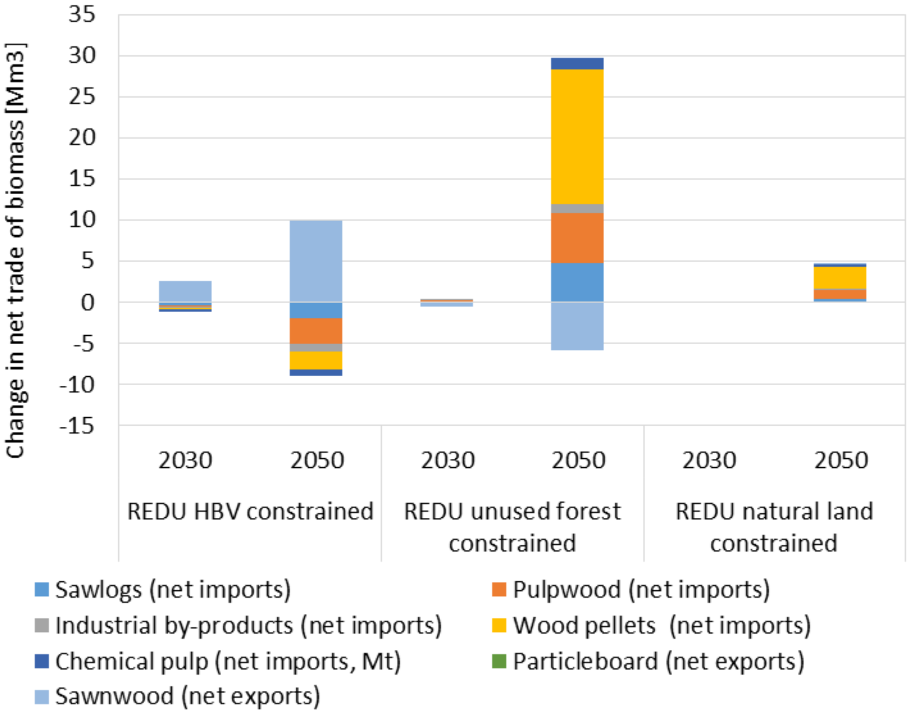

Figure 40: Change in EU net trade across constrained scenarios compared to the EU Emission reduction scenario.

4.2.3. Implications for biomass use

Besides increased imports and decreased export, another response to reduced availability of biomass in the constrained scenarios is reduced consumption of semi-finished products and changes in the compositional use of biomass for material and energy purposes. The intensity of reduction of biomass consumption depends on the impacts of price changes and price elasticities used to represent consumers' willingness to pay for products. Change in biomass sources used for material and energy purposes, when technically feasible, is driven by changes in the market price of feedstocks and industries capabilities to pay for feedstocks. Figure 41 presents effects of the implemented constraints on domestic production of semi-finished wood products and biomass use for material and energy use.

The global constraint on HBV area conversion increases the competitiveness of sawnwood produced within EU28, through the reduced availability of biomass in regions with high shares of HBV areas. EU28 production of sawnwood increases by 2 Mm^3 in 2030 and by 9 Mm^3 in 2050 (compared to 131 Mm^3 and 155 Mm^3, respectively, in the EU Emission Reduction scenario without restrictions). This is shown in Figure 41a as an increased use of sawlogs for material: the increase is almost 5 Mm^3 in 2030, and 18 Mm^3 in 2050. All of this increase in production is exported from the EU28 to the RoW (see Figure 40). Conversely, EU production of pulpwood decreases marginally: the use of pulpwood for material decreases by about 0.5 Mm^3 in

2050 for the domestic market (Figure 41a). This can be attributed to the increase in availability of industrial by-products from sawmills.

If unused forest conversion is constrained, the use of sawlogs, pulpwood and industrial by-products decreases as prices for logs increase with reduced availability from domestic sources. Of the forest based industries, the scarcity of biomass feedstock is most strongly impacting the use of sawlogs for material, which decrease by almost 15 Mm3 in 2050. The use of pulpwood for material also decreases by about 7 Mm^3 in 2050 (Figure 41a).

Hardly any effect can be observed on material use of wood if constraints of the conversion of other natural land are introduced as this does not directly impact the availability of wood for material purposes. A small decrease can be observed in the use of pulp wood for material, related to the increasing use of roundwood for energy (Figure 41a).

In terms of the response to the constraints in energy use of biomass, it should be noted that the total demand of bioenergy is completely inelastic. In other words, the total demand of biomass for energy purposes is not impacted by changes in prices of feedstocks. This is a model assumption where the given bioenergy demand from PRIMES always must be fulfilled. Therefore in total the volume of biomass used for energy does not change. However, the compositional use of biomass for energy is price elastic so that the cheapest biomass resources will always be used before more expensive resources are used.

A shift in the use of wood can be observed for all constraints, both driven by changes in availability of raw biomass sources, availability of industrial by-products, and changes in the prices of feedstocks (Figure 41b). What can be observed is that **more industrial by-products are used for energy instead of roundwood if constraints on HBV land apply**. This is directly driven by the increasing availability of wood chips from sawnwood production. In the case **when EU unused forest is prevented from conversion beyond the Baseline development, more imported pellets and SRC wood is used instead of roundwood for energy**, directly driven by the increasing scarcity of forest biomass resources within EU28. Pellet imports also increase (but much less) if the conversion of other natural land is not allowed; SRC wood imports are reduced, instead.

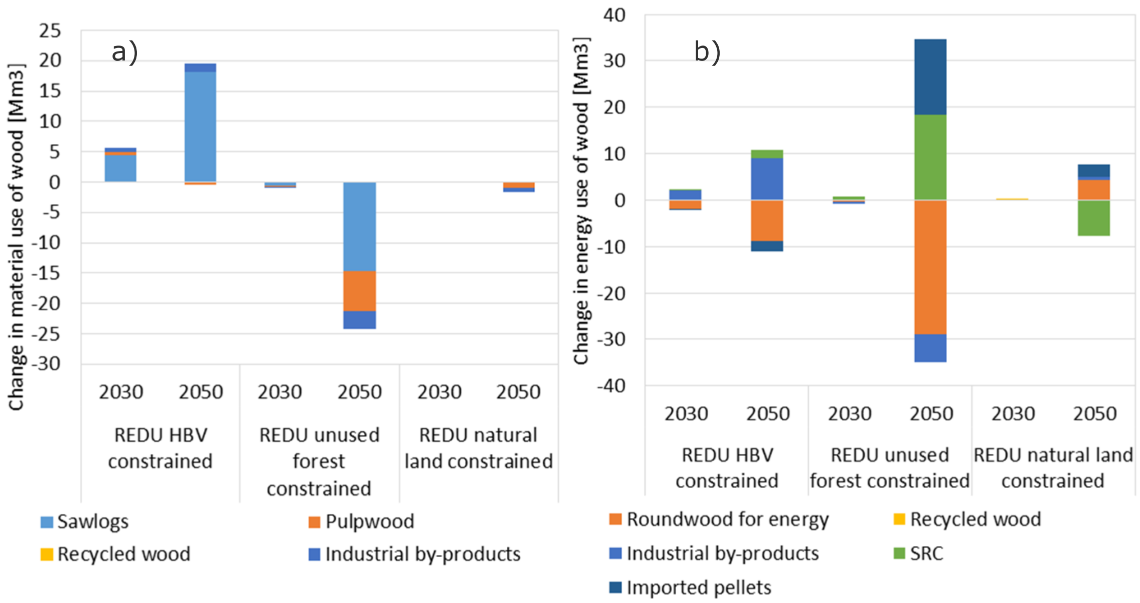

Figure 41: Change in biomass use in EU for a) material use and b) energy use across constrained scenarios compared to the EU Emission reduction scenario.

4.2.4. Implications for land use in EU and the RoW

If land of HBV is protected from being converted, areas that are not protected experience higher pressure for biomass production. This leads, in EU, to an increased conversion of unused forest to used forest, i.e. an intensification of forest management on areas that are not considered of HBV (see Figure 42).

A constraint on the conversion of unused forest in EU prevents intensification in forest management compared to the EU Emission reduction scenario. But also other land areas are affected. At the expense of grazing land, cropland and other natural land, SRC production in EU28 is expanded in 2050 to compensate for reduced biomass supply from EU forests. A constraint on the conversion of other natural land would result in a total forest area in EU28 that is almost 2 Mha larger compared to the EU emission reduction scenario but also compared to other constrained scenarios where total forest area is less affected.

Land use in RoW is mostly affected by the constraint that targets HBV areas, which are mostly located outside EU (see Figure 43). Already in 2030 this leads to a relative reduction of cropland area compared to the EU Emission reduction scenario and leaves more other natural vegetation but also grazing land unconverted. Forest area in RoW does not increase in the constrained scenario of HBV conversion. In fact the net balance (only this can be assessed here) shows a reduction of forest area in the medium-term (in 2030). This is caused by an expansion of cropland and grazing land into lands that are less fertile than those areas protected by the constrained scenario. The effect of the constraint on used forests in RoW is not persistent over time. While in 2030 its area is increased (most likely at the expense of unused forest), in 2050 the area of used forest decreases due to deforestation.

There is a **significant conversion of unused forest to used forest (more than 5 Mha) in the RoW that is accompanied with constraining forestry intensification within EU**. The area affected is of a similar size compared to the area prevented from conversion in EU (cf. Figure 42).

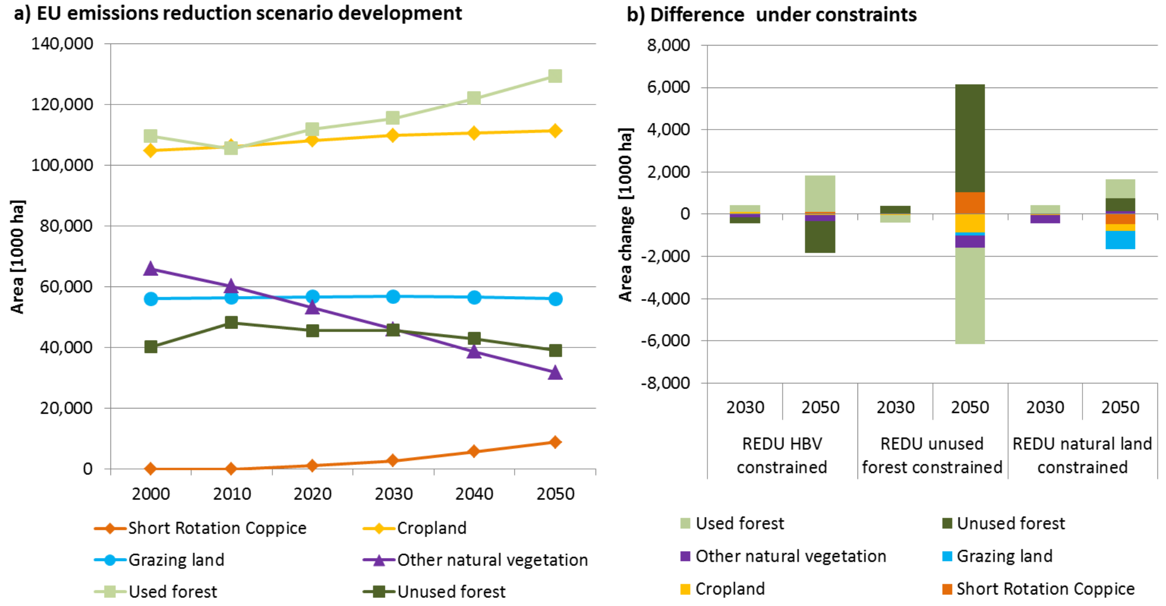

Figure 42: EU land use in the EU emission reduction scenario (a) and implications of single environmental constraints (b).

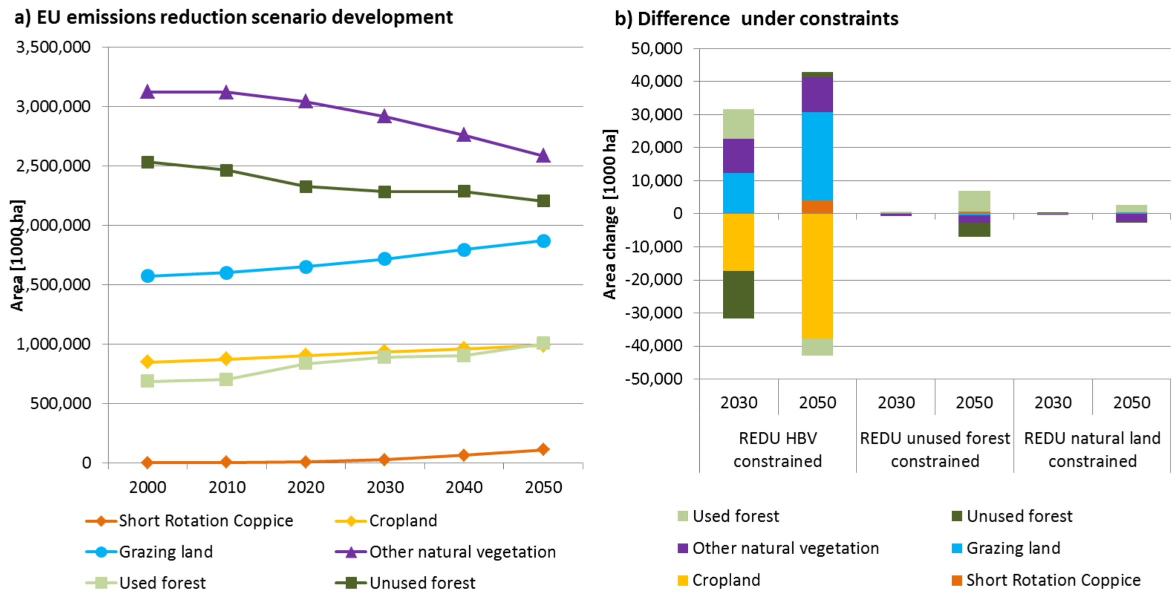

Figure 43: RoW land use in the EU emission reduction scenario (a) and implications of single environmental constraints (b).

4.2.5. Implications for GHG emissions from the land use sector in EU and RoW

Constraints of land use changes regarding areas of High Biodiversity Value, unused forest and other natural land have implications for GHG emissions from the land use sector **in EU** (see Figure 44). If areas of HBV are excluded from conversion it can be observed that in EU28 forests are more intensively used and the carbon sink in those forests is reduced compared to the unconstrained EU Emission reduction scenario (shown as relatively higher emissions). Emissions from Harvested Wood Products

(HWP) are reduced, i.e. the sink is increased. Emissions from deforestation are also reduced in EU. The net sum of forestry emissions under this constraint is negative (i.e. emissions are reduced, about -5 Mt CO_2 compared to the EU Emissions reduction scenario in 2050). **In 2050 all constrained scenarios yield lower net emissions from forestry in EU compared to no constraints**. The effect in EU is the largest when unused forests are protected from conversion in EU28 (-24 Mt CO_2). Here the largest contribution results from an increased sink in EU forests, compensated to some degree by increased emissions/a reduced sink from HWPs. Constraining conversion of natural land in EU28 reduces emissions from deforestation in EU28. This is the result of EU28 forests becoming more valuable if other natural land is not available for wood production e.g. in SRC plantations.

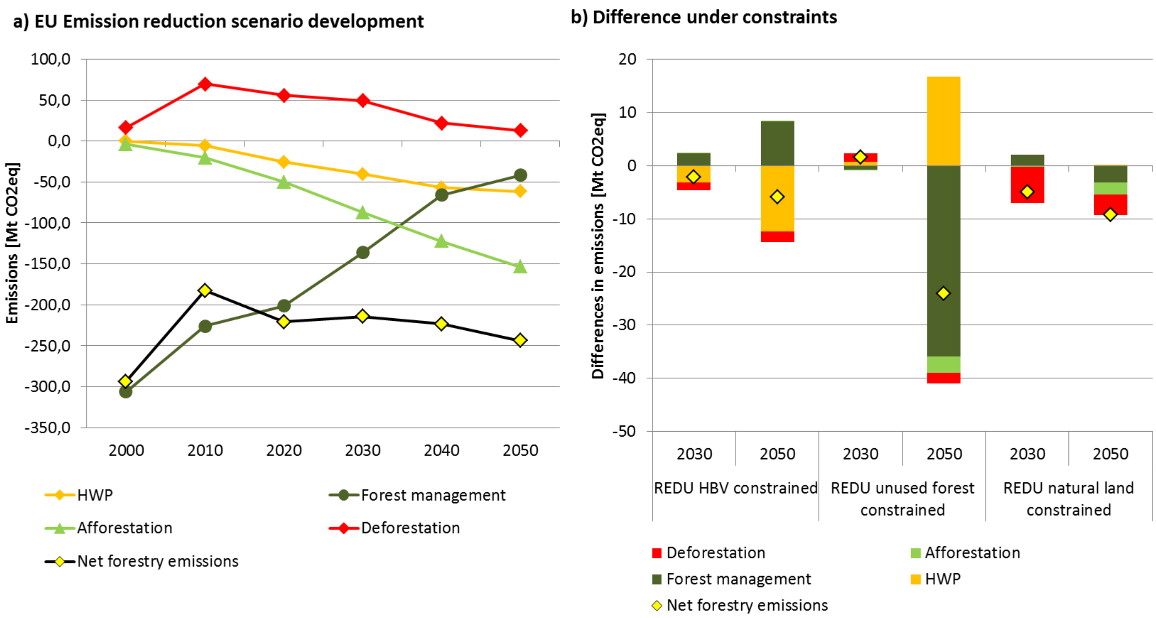

Figure 44: EU forestry emissions in the EU emission reduction scenario (a) and implications of single environmental constraints (b).

The net balance of GHG emissions from forestry **in RoW** are displayed in Figure 45. In a scenario where conversion of land with high biodiversity value is constrained, emissions from deforestation will be decreased by 3 and 17 Mt CO_2 in 2030 and 2050. These emission reductions compared to the EU Emission reduction scenario are compensated by reduced removals from afforestation. Existing forest with high biodiversity value is protected from conversion but also other natural land and other non-forest land use classes with these properties are not any more available for afforestation. In total, net forestry emissions increase for RoW in 2050 if HBV areas are not converted, a clear trade-off. The effect on emissions from forest management is less consistent over time and reflects more shifts of management intensity and biomass production away from cropland towards managed forests. Increased forest management emissions of about 15 Mt CO_2 can be observed in 2050 in a scenario where unused forests in EU28 are not available for intensification. The constraint on other natural land, instead, decreases net forestry emissions in RoW slightly in 2030 and 2050. So **the constraint on conversion of EU natural land reduces the net-emissions from the forest sector both in EU and RoW**. **In all other constrained scenarios, the forestry GHG emissions impacts go in opposite directions in EU and RoW**.

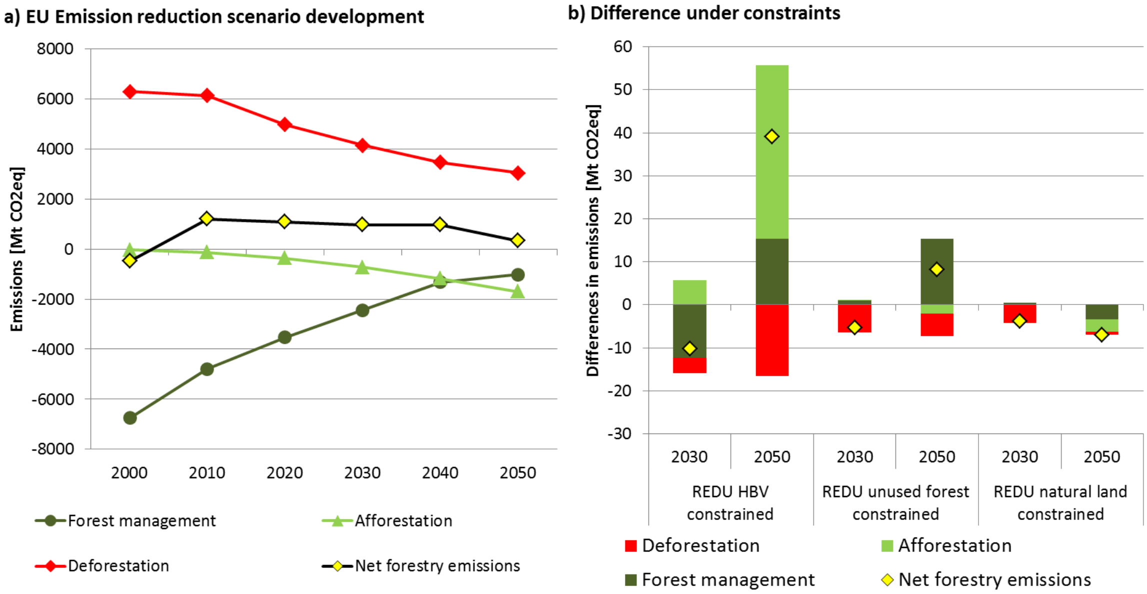

Figure 45: RoW forestry emissions in the EU emission reduction scenario (a) and implications of single environmental constraints (b).

Figure 46 describes changes of net GHG emissions from the land use sector **in EU28** aggregated to total LULUCF (CO_2) and total agriculture (non-CO_2) emissions compared to the EU Emission reduction scenario. Changes in net LULUCF emissions dominate changes across all scenarios and in all years. **In the long-term, all constraints lead to net GHG emission reductions in EU**. In 2050, net EU land use emissions would relatively be reduced by more than 5 Mt CO_2 with a constraint on the conversion of HBV land, by more than 25 Mt CO_2 with a constraint on unused European forests, and by more than 10 Mt CO_2 with a constraint on the conversion of other natural land. Figure 47 shows that **these relative emission reductions in EU are associated with increases in emissions in RoW in 2050 in the case of a scenario where EU forest management is not intensified (unused forest constraint). Other constraints lead to net GHG emission reduction in RoW**. This is especially true for constraints on HBV areas where large emission reductions compared to the reference can be observed for agricultural emissions. This is due to a reduction in global meat and milk production by 8 Mt of meat and 2 Ml of milk, (about 1-2% of total production). As the conversion of HBV areas to grazing land for cattle is limited, prices for meat and milk increase compared to the unconstrained scenario. This effect is more pronounced in the RoW than in EU28.

In the global sum of net land use emissions (EU + RoW), all scenarios with constraints result in emission reductions compared to the EU Emission reduction scenario (Figure 48). This means that there are **synergies of constraints to protect biodiversity, unused forests and other natural land from conversion regarding global net GHG emissions from the land use sector**. However, there are regional differences (here we show only EU28 and RoW) and the effect differs for LULUCF and agriculture emissions.

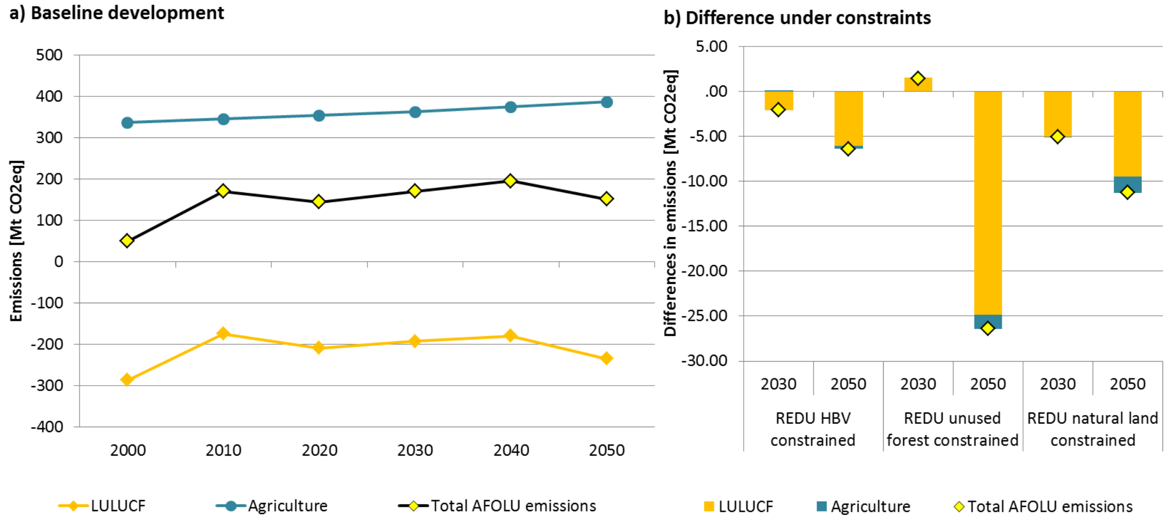

Figure 46: EU net land use emissions in the EU emission reduction scenario (a) and implications of single environmental constraints (b).

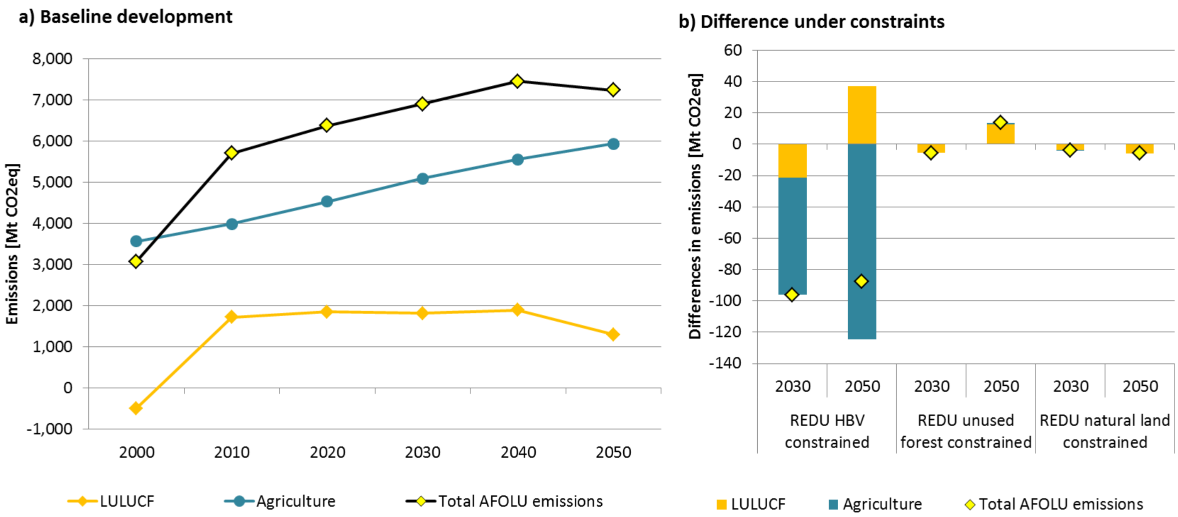

Figure 47: RoW net land use emissions in the EU emission reduction scenario (a) and implications of single environmental constraints (b).

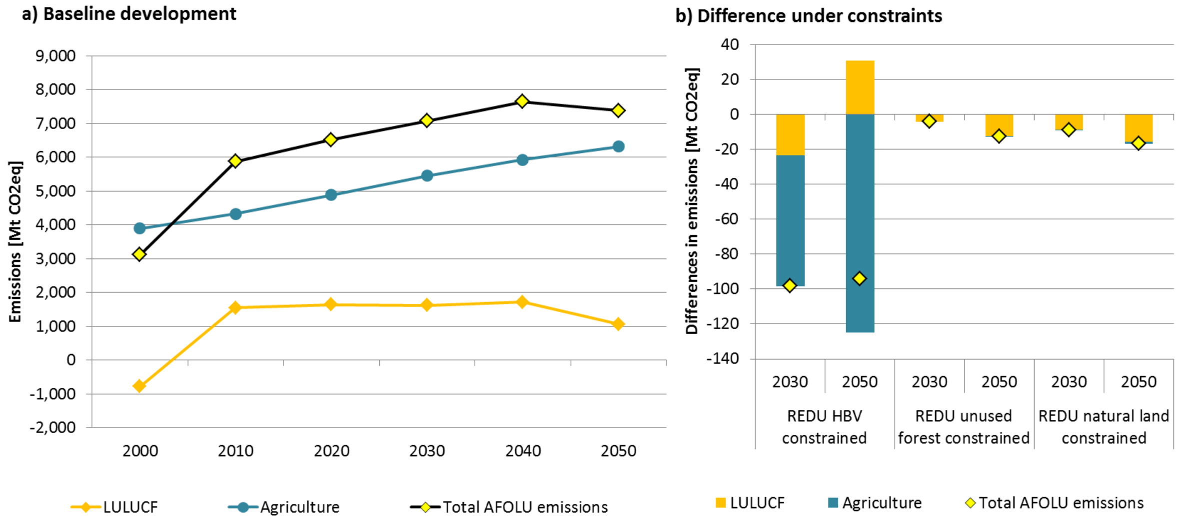

Figure 48: Global net land use emissions in the EU emission reduction scenario (a) and implications of single environmental constraints (b).

4.3. Exploring implications of combined constraints for biomass resource efficiency across scenarios

In this section, we analyze the implications of simultaneously applying all sustainability constraints (protecting HBV land, restricting conversion of unused forest into used forest to Baseline level, and restricting other natural land conversion to Baseline level) on the policy scenarios (cf. Figure 1, dimension 2).

4.3.1. Implications for production of biomass in EU

As shown in Figure 49, the effects for EU are relatively minor in 2030, but are considerably amplified by 2050, especially for the EU emission reduction and Increased RoW bioenergy demand scenario. For the EU emission reduction scenario, applying all constraints simultaneously provides overall the same impact on the EU forests as only applying the unused forest constraint. That is, the combined sustainability constraints result in 2030 in a 2.4 Mm^3 increase in sawlog harvests and a 2.7 Mm^3 decrease in pulpwood harvests. In 2050, the sustainability constraints would result in a total reduction of 57 Mm^3 in the EU biomass harvests, leading into 20 Mm^3 more SRC demanded to satisfy the bioenergy demand. This effect of the combined sustainability constraints is accentuated in the Increased RoW bioenergy demand scenario, where the bioenergy demand increases globally, putting more pressure to increase EU harvests already without constraints. With the combined implementation of all sustainability constraints, the forest harvests within the EU would be decreased by 70 Mm^3 in 2050, and the SRC harvests would increase by 29 Mm^3 – a considerable increase in a scenario where SRC is seen to grow into a major bioenergy feedstock already in the original scenario (where 172 Mm^3 of SRC and 718 Mm^3 total forest harvests in 2050; see Task 3 report for further details).

The impacts of the sustainability constraints are more modest in the two other policy scenarios, the Constant EU bioenergy demand and the Increased EU biomass import scenarios. In these scenarios, sustainability constraints increase EU forest harvests in 2050 by 9 Mm^3 in the Constant EU bioenergy demand scenario, and by 10 Mm^3 in the Increased EU biomass import scenario, as compared to the same scenario unconstrained. The main reason for this development is the protection of HBV areas outside of the EU: when no conversion is allowed for these areas, the EU imports of roundwood will decrease (see next section) and harvest pressure in the domestic forests is increased. In these two scenarios, the harvest levels in the unconstrained scenarios are below the Baseline scenario harvest level. Hence it is possible to increase the harvests to some extent, and still fulfill the constraint of keeping the conversion of unused forest at the level of the Baseline scenario. For the Increased EU biomass import scenario, this increase is not sufficient to satisfy the demand for bioenergy feedstocks within the EU: hence, also SRC production in 2050 increases by 3.5 Mm^3 compared to when no sustainability constraints are implemented.

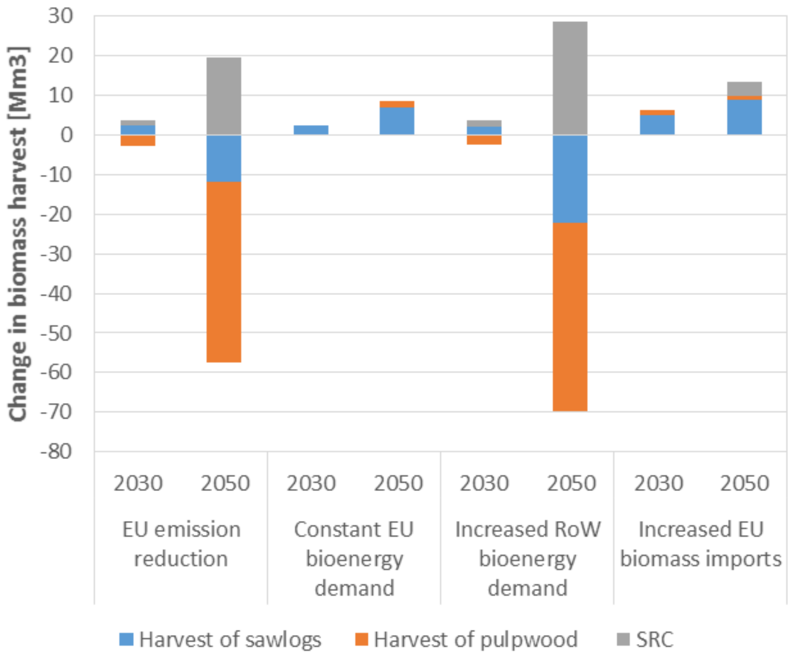

Figure 49: Difference in EU biomass production in constrained policy scenarios compared to unconstrained scenarios.

4.3.2. Implications for trade of biomass

As was seen already for single sustainability constraints, changes in EU biomass production observed across the constrained scenarios have implications for biomass trade between EU28 and RoW. The considerable decrease in the total EU forest harvests in the EU Emission Reduction and Increased RoW bioenergy demand scenarios as compared to their unconstrained cases leads to increased biomass EU imports, especially imports of sawlogs, pulpwood and wood pellets (Figure 50). Especially for the EU Emission Reduction scenario, the wood pellets imports in 2050 increase by almost 16 Mm^3 when all sustainability constraints are applied: a 30% increase compared to the unconstrained scenario (Task 3 report).

For the Increased RoW bioenergy demand scenario, the increase in net imports of wood pellets is more modest than for the EU Emission Reduction scenario, but the EU sawlogs and pulpwood imports increase almost similarly to the EU Emission Reduction scenario: an 11 Mm^3 increase compared to the unconstrained scenarios. The reason for this development is that the sustainability constraints reduce heavily the availability of industrial-quality roundwood in the EU by constraining the conversion of unused forests. However, the imported pellets are sourced from outside the EU. An increased RoW bioenergy demand, combined with decreased availability of wood because the HBV areas are not allowed to be used, results in a relatively small increase in the EU imports of wood pellets in the Increased RoW bioenergy demand scenario compared to EU Emission Reduction scenario.

The impacts on the wood biomass trade of the combined sustainability constraints are only minor for the Constant EU bioenergy demand scenario. However, in the Increased EU biomass import scenario, the impacts are clearly seen already in 2030, and increased further in 2050. For the Increased EU biomass import scenario, the predominant impact of HBV area protection, affecting especially areas outside the EU, is seen clearly: sawlogs, pulpwood and EU pellet imports decrease considerably. Instead, domestic wood harvests are increased, as seen above. In this scenario, EU biomass trade was encouraged by decreasing the trade costs. The results show that the impacts of such incentives will clearly have a more limited effect if sustainability constraints are applied for the sourcing of biomass.

In the Constant EU bioenergy demand and Increased EU biomass import scenarios, the sustainability constraints slightly increase EU sawnwood exports. The increase is seen in 2030 for all scenarios, and also in 2050 - especially for the Constant EU bioenergy demand scenario, where the EU sawnwood exports are 4 Mm^3 larger when the sustainability constraints are applied. This is explained by a reduced availability of sawlogs outside of the EU, as most of the protected HBV areas are located outside the EU. However, in 2050 in the EU emission reduction scenario and the Increased RoW bioenergy demand scenario, EU sawnwood exports are smaller than in the scenarios without sustainability constraints. The difference is especially large in the Increased RoW bioenergy demand scenario, where the EU sawnwood exports are almost 5 Mm^3 smaller than if the combined sustainability constraints were not considered. In this scenario, the domestic harvests within the EU were much larger than in the Baseline scenario. Constraining conversion of unused forests to Baseline level leads to a large reduction in harvests, which will cause a notable decrease of the possibilities to export sawnwood from the EU.

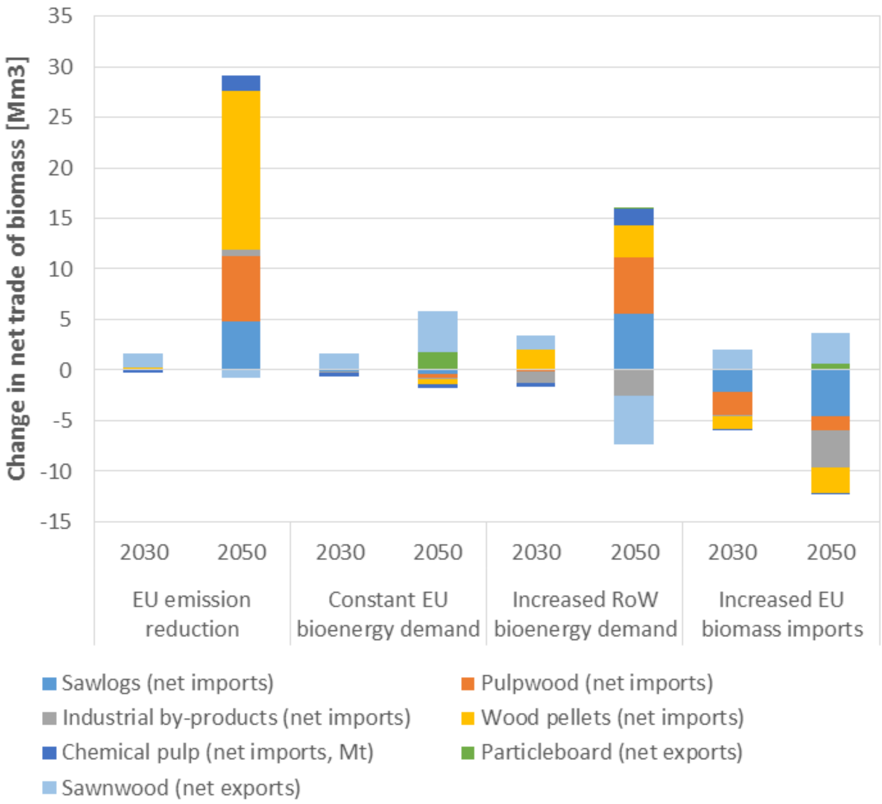

Figure 50: Differences in net trade in constrained policy scenarios compared to unconstrained scenarios.

4.3.3. Implications for biomass use

In all policy scenarios, there is a small increase in the use of sawlogs for material by 2030, driven by increased demand for EU sawnwood exports (Figure 51). However, as seen for trade, there is a difference between the scenarios in terms of the effects as of 2050. In the EU Emission Reduction and Increased RoW bioenergy demand scenarios, the use of sawlogs is smaller in 2050 in the fully constrained scenarios as compared to the unconstrained ones, leading to considerably less sawnwood production in 2050. In addition, for these two scenarios the composition of biomass use for material and energy purposes is changed, with more SRC and imported pellets used to energy instead of domestic roundwood or industrial by-products. In the Constant EU bioenergy demand and the Increased EU biomass import scenarios, the use of sawlogs increases to some degree in 2050 instead.

The sustainability constraints decrease the availability of industrial roundwood considerably on the material side, decreasing sawlog use for material by 7 Mm^3 in the EU Emission Reduction scenario in 2050. Pulpwood use for material use decreases even more, 10 Mm^3 in 2050. In addition, there is a reduction of more than 33 Mm^3 in the roundwood used directly to energy in 2050; this is a reduction of 42% from the unconstrained EU emission reduction scenario. While the material production is not constrained in the model, allowing the total material production level to decrease, bioenergy demand was fixed so that it needs to be fulfilled. As the sustainability constraints reduce availability of domestic forest biomass for bioenergy, the constraints are seen to lead to increases in SRC (20 Mm^3, or 12% increase to EU Emission Reduction scenario without constraints in 2050) and especially imported wood pellets (16 Mm^3, or 31% increase). The same development for wood pellets is seen also in the Increased RoW bioenergy demand scenario, where the SRC development is exacerbated following the relatively smaller potential to increase wood pellet imports.

For the other two scenarios, the Constant EU bioenergy demand and Increased EU biomass import scenarios, the effects of sustainability indicators are negligible for use of wood biomass for energy production. However, contrary to EU Emission Reduction and Increased RoW bioenergy demand scenarios, material production is seen to increase in Constant EU bioenergy and Increased EU biomass import scenarios if sustainability constraints are applied. This is driven by the increased EU exports of sawnwood, which increase the use of sawlogs for material by 6.5 Mm^3 in 2050 in the Constant EU bioenergy demand scenario and by 4 Mm^3 in 2050 in Increased EU biomass import scenario. The increase in sawnwood exports is possible because of the originally lower harvest level in these scenarios compared to the Baseline. In the other two scenarios the harvest level was originally much higher than in the Baseline, which is why the constraints have a much stronger effect.

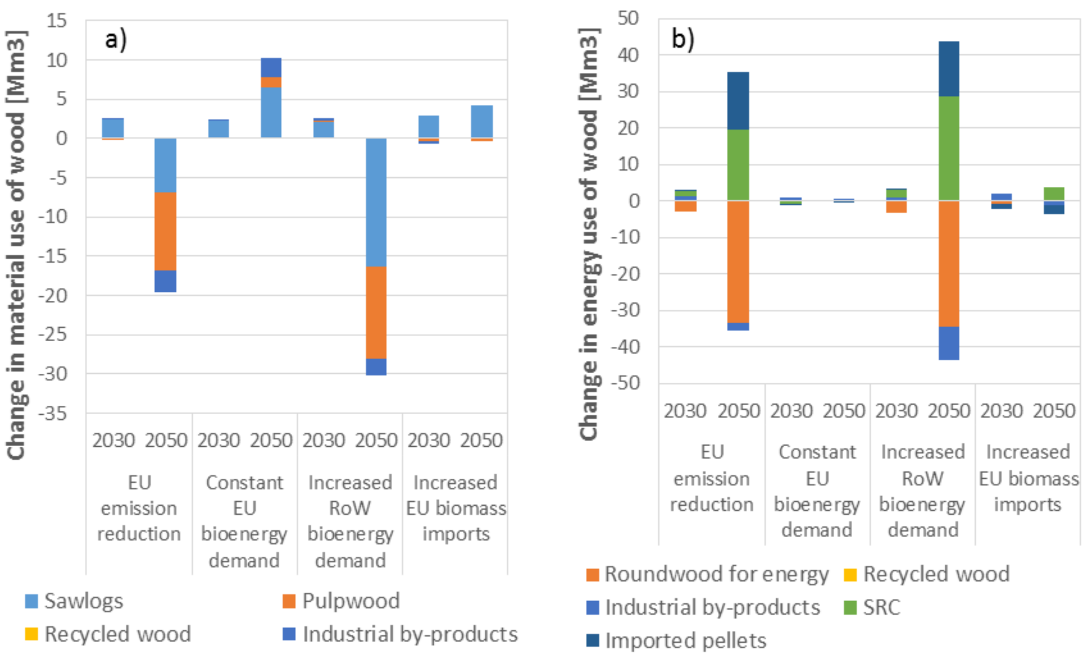

Figure 51: Differences in biomass use for a) material use and b) energy use in constrained policy scenarios compared to unconstrained scenarios.

4.3.4. Implications for land use in EU and the RoW

The constraints regarding the conversion of unused forest, other natural land and areas of HBV have also implications for land use in EU and RoW (Figure 52 and Figure 53). To assess the order of magnitude of the impacts of these constraints, these two figures can be compared to Figure 25c and Figure 26c that show differences of policy scenarios against baseline.

Overall, across all scenarios, the constraints have largest implications for the area of used and unused forests. However, these areas are affected in opposite directions. In the EU emission reduction and the Increased RoW bioenergy demand scenarios, the application of the constraints leads to an increase of unused forest in EU by 5-6 Mha. This is because less unused forest is converted to used forest, but also due to reduced deforestation (compare light and dark green bars in Figure 52).

This effect is reversed when the constraints are applied to the Constant EU bioenergy demand and the Increased EU biomass import scenarios. In both cases, the area of used forest increases. This is only to some degree due to the conversion of unused forest (which is constrained to Baseline levels) but rather due to afforestation. Indeed, when compared to the Baseline, the Constant EU bioenergy demand and Increased EU biomass import scenarios showed higher areas of unused forest in 2050, while for the other two scenarios with higher domestic biomass production, there was less unused forest (Figure 26c). Therefore, when constraints are applied, the policy scenarios resemble more the Baseline scenario, meaning that unused forest area increases in the EU emissions reduction and the Increased RoW bioenergy demand scenarios and decreases in the other two. Across all scenarios, the set of constraints applied lead to a reduction in other natural land, which is converted to forests. It is striking that, **for most scenarios, the area of SRC increases until 2050 when constraints on environmental sustainability are applied**. In these scenarios, other cropland is reduced in 2050 if land use is constrained. An exception is the Constant EU bioenergy demand scenario.

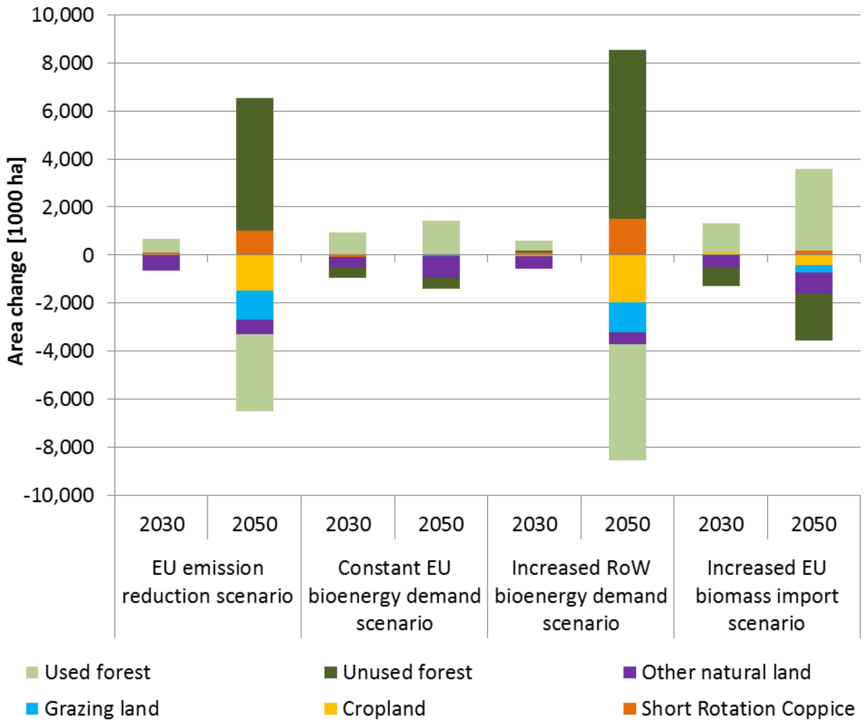

Figure 52: Differences in EU land use in constrained policy scenarios compared to unconstrained scenarios.

While the effect of constraints impacts land use in EU differently in different scenarios, the constraints have a very similar effect on all scenarios for the RoW, which is also consistent over time (Figure 53): **Grazing land, used forest and other natural land increase, mainly because they form large shares of HBV land. Also, there are more SRC areas when the constraints are applied as compared to unconstrained scenarios.** These expansions come at the expense of cropland and unused forests. It has to be noted that the figure shows the net balance of area changes. The constraints protect productive land from conversion. The land that can be converted is less fertile and therefore more grazing land has to be created on non-HBV to compensate for the loss in productivity. Therefore the net balance of land use results in more grazing land under constraints. In total, the areas affected are about

40 Mha. Especially the constraint on the conversion of HBV areas is relatively strong as it constrains any land conversion of HBV land, leading to implications that go beyond the actual impacts observed in stage one of the analysis of most scenarios (around 10 Mha). Therefore there are rather small differences between scenarios regarding the effect of constraints.

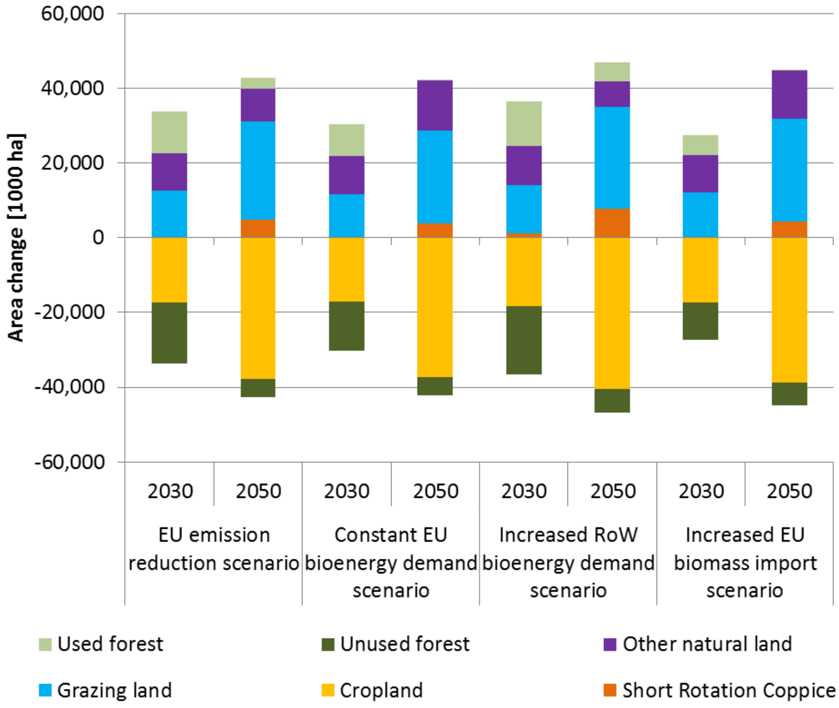

Figure 53: Differences in RoW land use in constrained policy scenarios compared to unconstrained scenarios.

4.3.5. Implications for GHG emissions from the land use sector in EU and RoW

The land GHG implications of applying constraints on policy scenarios are displayed in Figure 54 and Figure 55. Consistently to the land use figures, the reduction in intensity of forest management, as a result of constraints, leads to an increased sink in existing forests for the EU emission reduction and Increased RoW bioenergy demand scenario. This is contrasted by decreases of the Harvested Wood Products sink/increases of emissions. For the other scenarios, implications for forest management emissions are limited. **Net EU forestry emissions are reduced in all scenarios between 7 to almost 40 Mt CO_2 if constraints are applied.** In addition to increases in the forest sink, reduced emissions from deforestation contribute to the net emission reduction as well as removals from afforestation.

Impacts of the sustainability constraints for the RoW are dominated by reductions in GHG removals from afforestation (Figure 55). This is not obvious from the land use implications discussed above (Figure 53), where the net area of used forest is increased under constraints. This emphasizes the importance of gross area changes that are revealed when looking at changes in emissions. Constraints on land conversion shift land use across the landscape with implications for productivity. For example: even if a net area of a certain land use category is not changing the average growth rate on this area might be different.

Despite the fact that deforestation emissions are reduced under the constraints, all policy scenarios show a net increase of RoW forestry emissions in the long run (in 2050), by an amount of 20 to 60 Mt CO_2.

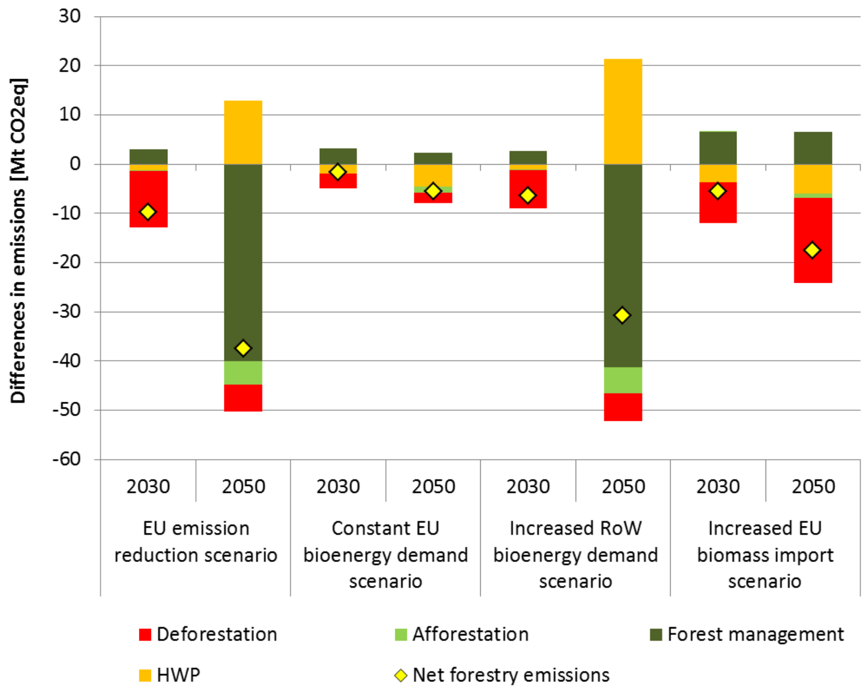

Figure 54: Differences in EU forestry emissions in constrained policy scenarios compared to unconstrained scenarios.

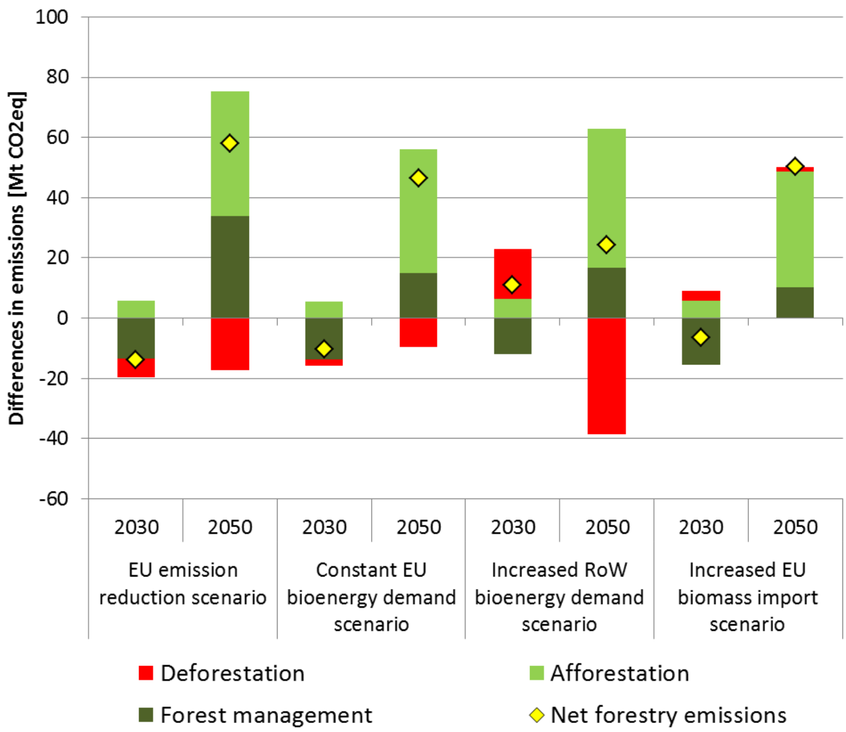

Figure 55: Differences in RoW forestry emissions in constrained policy scenarios compared to unconstrained scenarios.

Total net land use emissions include forestry, other land use and land use change (LULUCF) and agriculture non- CO_2 emissions. Figure 56 presents net land use emissions for EU28 as difference between constrained and unconstrained policy scenarios. As observed for forestry emissions in all scenarios net emissions are reduced by up to 40 Mt CO_2 eq. (EU emission reduction scenario) when constraints are applied. Agriculture emissions are not affected except for two scenarios. The magnitude of reduction, however, is different. Largest reductions associated with environmental constraints are achieved in the EU emissions reduction and the Increased RoW bioenergy demand scenarios.

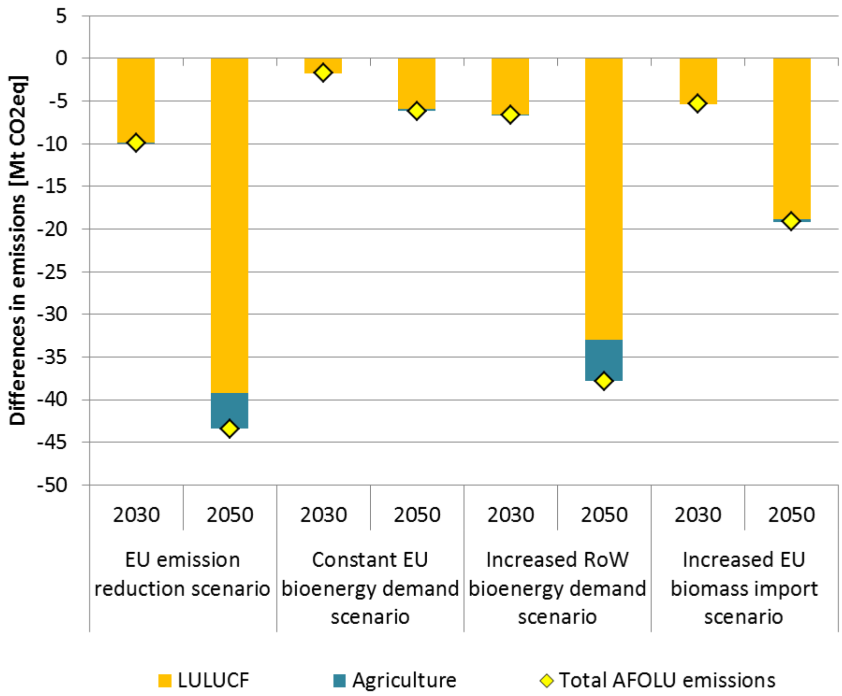

Figure 56: Differences in EU net land use emissions in constrained policy scenarios compared to unconstrained scenarios.

In the RoW agriculture emissions are more affected by constraints than in EU (Figure 57). Figure 47b has shown that especially the constraint on HBV area conversion contributes most to this effect. **Net land use emissions in all scenarios are reduced by the sum of constraints but only due to the large reductions of agriculture emissions of more than 100 Mt CO_2 eq.**

The dominance of agriculture is also to be noted when looking at global (RoW + EU) net land use emissions (Figure 58) and is the strongest for the Increased RoW bioenergy demand scenario, under which more than 150 Mt CO_2eq. are avoided if globally areas of HBV and EU-wide unused forests and other natural land are conserved. While the implications for agriculture GHG emissions of constraints are consistent across all scenarios, the effect for LULUCF emissions is less straight forward. In all four scenarios the combined constraints decrease net LULUCF emissions for RoW in the short run (2030) and increase them in the long run (2050) but with different intensity, ranging in 2050 from 16 Mt for the Increased RoW bioenergy demand scenario to almost 60 Mt in the EU emission reduction scenario. In the global sum of net land use emissions (Figure 58), **net land use emissions in all scenarios are reduced when jointly combining the environmental constraints, due to**

large reductions of non-CO_2 emissions from the agriculture and livestock sectors. This is due to increased prices for livestock products and thus reduced demand due to elasticities. Under HBV constraints only less fertile land is available, leading to higher costs of conversion and more grazing land to be created to compensate for relative productivity losses.

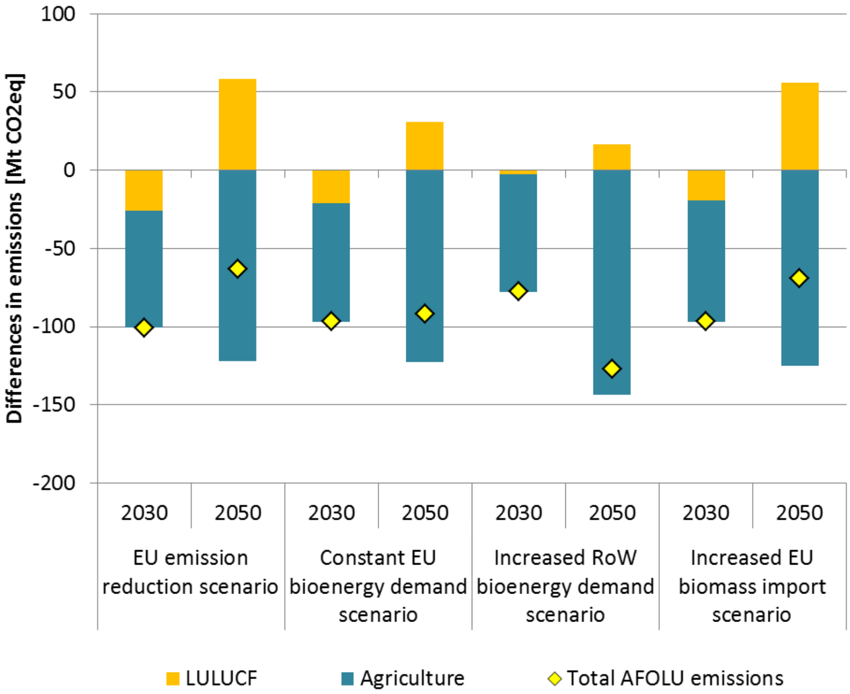

Figure 57: Differences in RoW net land use emissions in constrained policy scenarios compared to unconstrained scenarios.

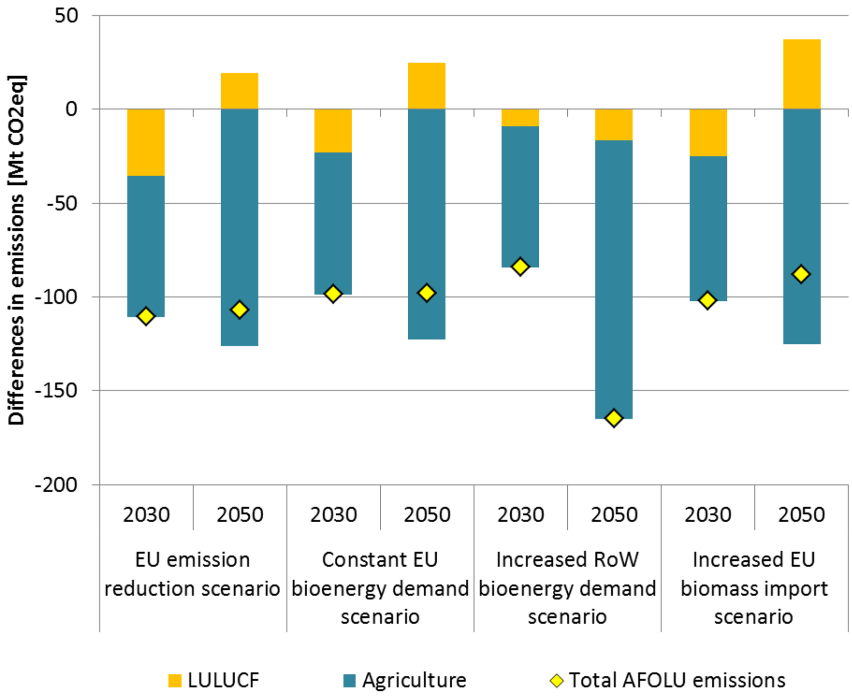

Figure 58: Differences in global net land use emissions in constrained policy scenarios compared to unconstrained scenarios.

5. Summary and Conclusions

This report describes methods and results of Task 4 of the ReceBio project. A method for assessing environmental impacts was developed that is based on two approaches: a) a comparison of different scenarios with varying biomass demand and b) the introduction of constraints into the model that aim at reducing specific environmental impacts.

When comparing Baseline and policy scenarios for EU28 the chosen indicators for assessing environmental impacts related to biodiversity, GHG and land use tend to be affected most. Water impacts are relatively small but also much fewer variables could be included. In general, for most environmental aspects deviations from the Baseline scenario are of similar size or smaller for the RoW compared to impacts on EU28, except for the scenario simulating an increased demand for bioenergy in RoW.

Land use in the Baseline scenario in EU28 is characterized by an increase of cropland (including SRC) and total forest area at the expense of other natural land (abandoned cropland, unused grassland, etc.). Also for the land use pattern in the Rest of the World (RoW), a clear increase of cropland and a decrease of other natural land can be observed. Outside EU28 the grazing land area increases while the area of unused forest decreases. The reasons for the loss differ and can either be the conversion to used forests as well as conversion to cropland or grazing land. The dynamics of forest area change differ for world regions. The conversion of forest in certain regions of the world is contrasted by the expansion of forest area through afforestation in other parts of the world.

Compared to the Baseline scenario, the Constant EU bioenergy demand scenario leads to a lower amount of cropland area and higher amounts of other natural land in EU28, which is related to a considerably reduced area of SRC. While the total forest area does not differ between the two scenarios too much, there are comparably large shifts within the forest from used forest to unused. As expected, the land use patterns in the Increased RoW bioenergy demand scenario differ most from the baseline scenario, when looking outside EU28, especially in the year 2050. Changes in the other three policy scenarios seem to be almost not significant in this comparison (Figure 26). The impacts are related to the conversion of more unused forest to used forest and conversion of other natural land to cropland, which is directly related to an increase in the bioenergy demand in RoW.

The indicator unused forest area is a good proxy for assessing changes in the intensity of forest management due to increased biomass demand. If forests in EU are protected from further intensification (i.e. through constrained conversion of unused forest into used forest) globally an increased production of SRC can be observed (comparably less SRC is established if constraints are put on the conversion of other natural land in EU). In addition, there is a significant conversion of unused forest to used forest in the RoW that is accompanied with constraining forestry intensification within EU. This area is exceeding the area constrained in EU28, so globally slightly more forest area is converted if the constraint is applied in EU.

The impacts of sustainability constraints increase EU forest harvests in 2050. The main reason for this development is the protection of HBV areas outside of the EU: when no conversion is allowed for these areas, the EU imports of roundwood will decrease and harvest pressure in the domestic forests is increased. For all scenarios, until 2050, the area of SRC increase when combined constraints on environmental sustainability are applied. In the RoW, grazing land, used forest and other natural land increase mainly as a consequence of environmental constraints on HBV land.

The development of **areas of high biodiversity value** (HBV) is a key indicator for assessing effects on biodiversity. The conversion of these areas is very likely related to a loss of biodiversity. Already in the Baseline scenario in many regions of the world a significant conversion of areas of HBV (including forest, grazing land, cropland and other natural land) is occurring in the model until 2050. Impacts of the policy scenarios on HBV land in the EU28 are comparably low due to the fact that only small areas fall in the category of high biodiversity value. From a global RoW perspective, the conversion of HBV land is more relevant as the relative share of land classified as HBV is larger. Unused forests form the largest share, followed by other natural land and grazing land.

If land of HBV is protected from being converted, more pressure for biomass production is noted from the areas that are not protected associated with more land conversion. Constraining the conversion of land with high biodiversity value has implications for biomass production for EU28 leading to decreased EU net-imports of feedstocks for material and energy use (sawlogs and pulpwood, wood pellets and industrial by-products), and more domestic harvest (used for HWP production for exports).

Net GHG emissions from LULUCF in the Baseline scenario form an overall relatively stable net sink in the EU. The forest sink, however, is projected to decline; and more strongly in the two policy scenarios with increased domestic biomass production, which is in-line with other reports and scientific publications. Comparatively small are effects on afforestation removals between policy scenarios. The scenarios are also affecting non-CO_2 emissions. In particular, an increase in bioenergy demand is noted to lead to some agricultural emissions related to food and feed production being "exported" from EU to RoW. Looking at total net LULUCF and Agriculture sector emissions, it is striking that, compared to the Baseline; all scenarios reduce net GHG emissions from LULUCF. Agriculture emissions are higher for the Constant EU bioenergy scenario but fully compensated by LULUCF CO_2 emission reductions.

Consistently to the land use figures, the reduction in intensity of forest management, as a result of constraints, leads to an increased sink in existing forests for the EU emission reduction and Increased RoW bioenergy demand scenario. This is contrasted by decreases of the HWP sink/increases of emissions. For the other scenarios, implications for forest management GHG emissions are limited. Net EU forestry emissions are reduced in all scenarios between 7 to almost 40 Mt CO_2 if constraints are applied. Despite the fact that deforestation emissions are reduced, all policy scenarios show, under the constraints, a net increase of GHG emissions in the long run (in 2050), by an amount of 20 to 60 Mt CO_2.

In the global sum of net land use emissions, all scenarios with constraints result in less GHG emission compared to the unconstrained scenarios. It has however to be noted that this is only due to large reductions of agriculture GHG emissions, of more than 100 Mt CO_2eq. Global LULUCF emissions are higher with constraints for three of the four scenarios in 2050 (exception is the Increased RoW bioenergy demand scenario).

This means that overall there seem to be clear **synergies** at EU level of protecting biodiversity, avoiding the intensification in unused forests and the conversion of other natural land regarding global net GHG emissions from the land use sector. However, the effects are different for different sectors, different for different time horizons and also different for EU and RoW as reduced production in EU is pushed abroad leading to higher RoW LULUCF emissions in the long run but lower total GHG emissions.

Acronyms

EU	European Union
GHG	Greenhouse gas
G4M	Global Forest Model
GLOBIOM	Global Biomass Model
HBVA	High Biodiversity Value Area
HWP	Harvested Wood Products
UNEP-WCMC	United Nations Environment Programme - World Conservation Monitoring Centre
LULUCF	Land Use, Land Use Change and Forestry
RoW	Rest of the World, excluding EU
SRC	Short Rotation Coppice (sub-category of cropland)
WDPA	World Database on Protected Areas

Annex 1

Below follow a more detailed explanation of the Task 3 indicators that are screened and the model variables that are used to underline their development.

Production of biomass for EU by biomass type

The GLOBIOM model provides information about the production of a number of important biomass sources. The biomass production sources are endogenous variables of the model and were analyzed directly.

The main types of biomass products that were covered and analyzed are:

- Harvest of roundwood from forest. This is an aggregate category comprising of felled or otherwise harvested and removed wood, with or without bark. It includes sawlogs and veneer logs; pulpwood, round and split; other industrial roundwood, and also branches, roots, stumps and burls (where these are harvested). It is reported in cubic metres solid volume.
- Forest chips. Forest chips are fresh wood chips made directly of wood that is harvested from the forest, used for energy production, and has not had any previous use (as opposed to *wood chips* from industrial by-products). There are several raw material types of forest chips:
    - Tops and branches removed from trees during final felling
    - Sawlogs that are rejected being unsuitable for material purposes due to decay etc.
    - Delimbed small size stems or un-delimbed small-size trees from thinnings.
    - Pulpwood size logs allocated to energy production from thinning or final felling.
    - Tree stumps.
- Industrial-by products. This category includes industrial chips, sawdust, shavings, trimmings and bark. They are supplied as by-products available in proportions from the processes of wood products industry, mainly sawmilling but also wood based panels and joinery production. Industrial by-products have to be clean and they are not altered by any chemical process. They are important raw materials for pulp, wood based panels (Particleboard, MDF/HDF) and wood pellet production as well as in bioenergy production as such.
- Woody biomass from short rotation coppice. This category covers short rotation coppices are formed by tree plantations established and managed under an intensive, short-rotation regime on agricultural land. They can be established with quickly growing species such as poplar and willow, and managed under a coppice system in a two-to-five-year rotation.
- Woody biomass from perennials. This category covers woody biomass from species such as miscanthus and reed canary grass that can be established and used to produce biomass for energy purposes.
- Agricultural and livestock products are covered such as: rice, wheat, other cereals, oilseeds, sugar crops, other crops, ruminant meat, monogastric meat and eggs, milk, and crop residues.

Land use

The main land use types are covered by the model and it endogenously calculates the change between these land use types. We indicate the amount of land use change that can be expected to occur between these various classes:

- Used and Unused Forest[5]
- Plantations
- Cropland
- Grazing land
- Other natural land

Change in production patterns (forest intensification, change of agricultural crop)

For this indicator we evaluate and analyze the following aspects

- Forest intensification: This is expressed in terms of change in forest rotation periods and change in amount of wood from harvesting operations. Both of these two aspects are covered by the model with internal parameters.
- Agricultural intensification: This will be expressed in terms of change in crop yields and how it evolves over time for the various regions.

Use of biomass in relevant sectors

For this indicator we monitor the amount of biomass that is being used by the forest-based industries, for other woody products, as well as the amount of biomass that is being acquired and used for energy production.

Import and export of biomass

For this indicator we monitor the amount of biomass that is being traded between EU28 and the rest of the world. This covers both import and export and is expressed in terms of trade with the main regions as covered by the GLOBIOM model.

Trends of price indices and ranges for different biomass types

For this indicator we monitor the annual producer price of the various biomass types and see how it evolves over time for the EU-28 and other regions of importance. The main aspect of interest is here the relative increase/decrease in price over time that is driven by cost fundamentals (the need for longer transport, acquisition of more expensive biomass resources etc.).

[5] The term "used forests" refers to all forest areas where harvesting operations take place, while "unused forests" refers to undisturbed or primary forests. There are other three land cover types represented in the model to cover the total land area: other agricultural land, wetlands, and not relevant (bare areas, water bodies, snow and ice, and artificial surfaces). These three categories are currently kept constant at their initial level.