Follow-up study on impacts on resource efficiency of future EU demand for bioenergy (ReceBio follow-up)

Final report

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The material produced under the original ReceBio project is found at:
http://ec.europa.eu/environment/integration/energy/studies_en.htm

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1. FOREWORD

The aim of this study is to complement the work earlier set out within the framework of the "Study on impacts on resource efficiency of future EU demand for bioenergy" (ReceBio) project[1]. In this follow-up study, we perform further modelling work and analyses to help understand the potential interactions and impacts resulting from increased EU demand for bioenergy, focusing specifically on the implications for resource efficiency. The assessment described in this report builds on the work earlier done in the ReceBio project and use the same modeling framework for the assessment, the GLOBIOM[2] and G4M[3] models.

1 Forsell, N. et al. 2016: Study on impacts on resource efficiency of future EU demand for bioenergy (ReceBio). Final report. Project: ENV.F.1/ETU/2013/0033. Luxembourg: Publications Office of the European Union, 2016. 43 p. All ReceBio study reports are found at: http://ec.europa.eu/environment/enveco/studies.htm#4

2 See: www.iiasa.ac.at./GLOBIOM

3 See: www.iiasa.ac.at/G4M

2. SUMMARY OF KEY FINDINGS AND MAIN ASSUMPTIONS

In this study, we developed and analysed three additional scenarios, building on the work done in the ReceBio project[1]. The updated EU emission reduction scenario (REDU2) forms the basis of this analysis, depicting increased EU bioenergy targets and hence also an increased use of woody biomass for energy. In the Scenario with land criteria on high biodiversity and high carbon stock areas (LAND), we added global constraints on the areas available for biomass harvests. The third scenario, RWCAP, analysed the effects of also capping the amount of roundwood used directly for energy in EU, on top of the restrictions already in place in LAND. For each of the three scenarios, also additional sensitivity analyses were done. Here, we give an overview of the main findings and assumptions of the analysis.

Updated EU emission reduction scenario (REDU2)

The REDU2 scenario of this study depicts the development of biomass use to fulfill bioenergy demand as estimated by PRIMES for the EUCO 27 scenario. The scenario is based on the EU emission reduction scenario (REDU) analysed in the ReceBio project, and aims for an 80% reduction in greenhouse gas emissions within the EU by 2030. The main differences between REDU and REDU2 are the updated projections for bioenergy demand taken from PRIMES 2016 EUCO 27, and some changes in the assumptions for specific feedstocks. Most importantly, in REDU2 the demand for SRC and lignocellulosic crops is fixed at the same levels as in PRIMES 2016 EUCO 27 development (instead of being price-elastic as in REDU), and the share of roundwood in wood pellets is assumed to be 75% (instead of 0% in REDU – this initial assumption was due to the lack of reliable data to base any estimate on; on the contrary, in REDU2, new data was used to base this new assumption on[4]).

The REDU2 results show a clear increase of wood used for both material and energy production between 2010 and 2050. On the bioenergy side, the results show a **considerable increase over time in the use of imported pellets** (from 10 Mm^3 in 2010 to 70 Mm^3 in 2050) and EU domestic production of **SRC** (from negligible amounts in 2010 to 280 Mm^3 in 2050, following the PRIMES estimates). Additionally, **the rapid increase of bioenergy demand is seen to also lead to large quantities of domestic roundwood combusted directly for bioenergy production (in the form of logs, chips, or pellets)** (25 Mm^3 in 2050). In other words, the bioenergy demand increases to an extent where stemwood that is of industrial roundwood quality (mainly pulpwood quality) and could be used for material purposes by the forest-based sector, is instead being used directly for energy production. The increased use of biomass for energy and material is expected to lead to a large **intensification in the use of EU forests**. The forest harvest level in the REDU2 scenario is seen to reach a level of 660 Mm^3 by 2050 (12% higher than in 2010).

Land use in the scenario is also characterized by the increase of SRC: the land area used for SRC expands from almost zero to 15 Mha in 2050. We detect also an increase of the total forest area within the EU by almost 14 Mha in 2050 compared to 2010. Both of these land use changes are found to mostly result from a change from other natural land (abandoned cropland, unused grassland, etc.).

Scenario with land criteria (LAND)

LAND investigates the effect of applying land conservation criteria which **restricts biomass harvests for both energy and material purpose** globally in areas with high biodiversity value and/or high carbon stocks (HBVCS areas) – hence representing a scenario more restrictive than applying purely to energy feedstocks. This is modelled by

4 Strange Olesen, A. et al. 2016: Environmental Implications of Increased Reliance of the EU on Biomass from the South East US. Final report. Project: ENV.B.1/ETU/2014/0043.

prohibiting conversion of HBVCS areas on the global level, and constraining the collection of woody biomass feedstocks from HBVCS areas within the EU. The biomass harvest restrictions lead to a reduction of the global availability of wood for energy and material purpose. In the EU, this is shown by a **reduced amount of EU pellet imports** from the rest of the world (mainly Central and South America), by an **increase in the use of EU domestic biomass feedstocks** (the amount of roundwood combusted directly for bioenergy is 6 Mm^3 (23%) higher and the use of EU industrial by-products for energy 9 Mm^3 (7%) higher in 2050 than in REDU2). In the meantime, the EU sawnwood production is 4% higher in 2050 than in REDU2, responding to an enhanced profitability through a higher EU demand for by-products, together with a higher demand for EU sawnwood exports to accommodate lower availability of woody biomass in the rest of the world, resulting from the constraint on the collection of woody biomass from HBVSC areas.

In the LAND scenario, the increased demand for wood in the EU increases the EU forest harvest level by 4% in 2050, compared to REDU2. As a result of the increase in forest harvest, the area of used forest in EU will increase about 2 Mha in 2050 in comparison to REDU2. The used forest area increases at the expense of unused forest area and only a small area of additional new forest is established on other natural land as compared to REDU2.

On the global level, the scenario is expected to lead to **net GHG emissions saving in the range of 10 Mt CO_2** in 2050 as compared to REDU2 (Figure 1). At the same time, **net GHG emissions from LULUCF increase for the EU** compared to REDU2 (about 4 Mt CO_2 higher in 2050). This net balance is dominated by a reduction of the forest management carbon sink (about 13 Mt CO_2 compared to REDU2) and an **increased storage of carbon in wood products** (about 10 Mt CO_2 compared to REDU2). It should be noted that these global net emission savings in this scenario only refer to the savings related to the LULUCF sector as the energy demand is fixed; these estimates should therefore be seen in consideration to the underlying assumptions of the study.

Scenario with land criteria and a cap on the use of roundwood for energy (RWCAP)

RWCAP investigates the effect of a **cap on the EU28 use of roundwood for bioenergy** (either directly in the form of roundwood or indirectly in the form of imported wood pellets made of roundwood). In this scenario, the same restrictions for harvestable areas apply as in LAND, and in addition, the roundwood used directly for energy production was allowed to develop freely only until 2020, and remain constant thereafter. According to the model results, this option leads to a situation where **roundwood is no longer combusted directly for bioenergy production and reduced import of wood pellets** to the EU from the rest of the world, as 75% of the pellet feedstock is assumed to be roundwood. The resulting gap in the feedstocks for bioenergy in the EU is, in this scenario, fulfilled by industrial by-products, mostly through a change in the feedstock composition within the pulp and board industries towards use of roundwood instead of by-products, and an increase in sawnwood production (11% increase compared to REDU2 in 2050), since sawmills become more profitable as the by-products are in high demand for bioenergy and achieve high market prices.

The changes in demand for wood are expected to result in an intensification of forest management and lead to an increase in the area of used forest within the EU by 8.5% in 2050 compared to REDU2. The used forest area increases at the expense of unused forest area and only a small area of additional new forest is established on other natural land.

Globally, the RWCAP scenario is expected to lead to **net emission saving in the range of 15 Mt CO_2** in 2050 as compared to REDU2 (see Figure 1). At the same time, **net GHG emissions from LULUCF increases in the EU** compared to REDU2 (about 9 Mt CO_2 higher as of 2050). Similar to LAND, this net balance is dominated by a reduction of the forest management carbon sink (about 30 Mt CO_2 compared to REDU2) and an increased storage of carbon in wood products (about 22 Mt CO_2 compared to REDU2). These net emissions reduction of the scenario only refer to the savings related to the LULUCF sector as the energy demand is fixed and the estimates should be reviewed in consideration to the underlying assumptions of the study. In particular, it should be kept in mind that potential additional GHG emissions reduction related to material substitution effects are not considered within this study. As both LAND and RWCAP lead to an increase in the EU consumption of wood products, additional reduction of GHG emissions from material substitution could be expected in LAND and even more so in RWCAP compared to REDU2.

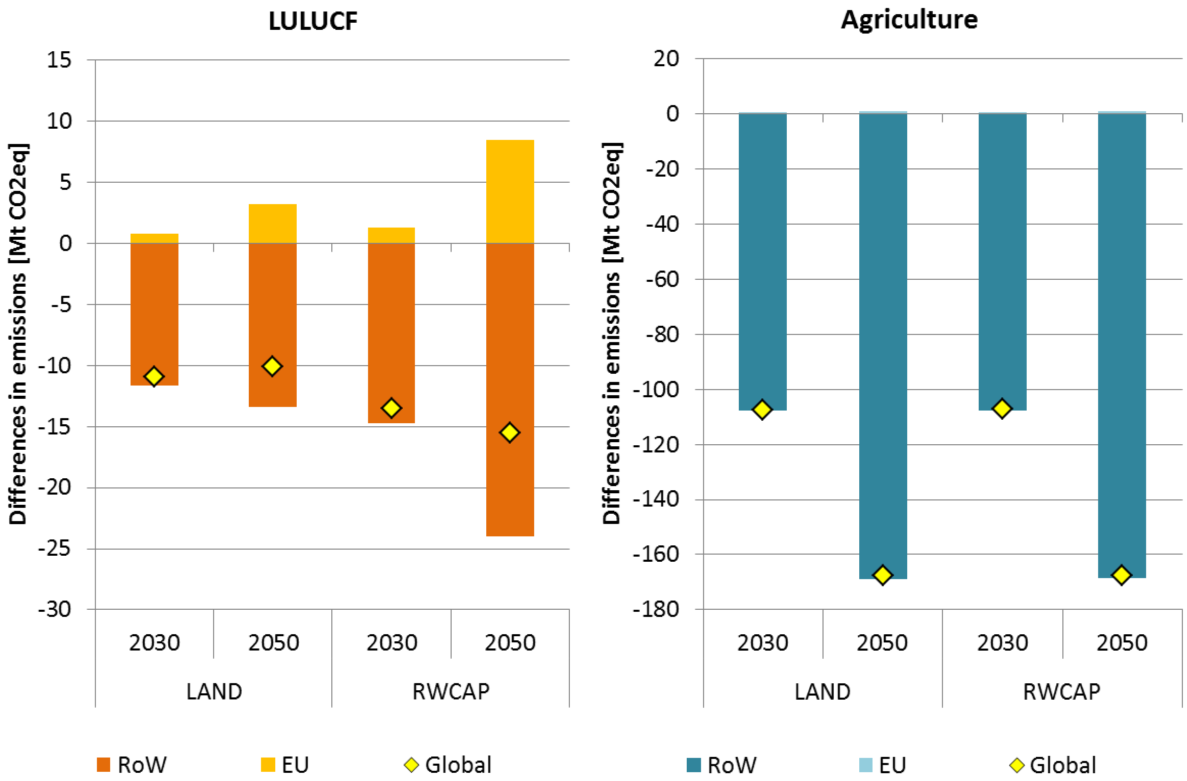


Figure 1: Differences in global LULUCF (left) and agriculture (right) net emissions for LAND and RWCAP in comparison to REDU2.

Key assumptions

- The scenarios only represent cases where the bioenergy demand for heat, electricity and transport is exogenously defined and is not sensitive to changes in feedstock prices. At the same time, the demand of food, feed, and wood products is price elastic and thereby adjusts depending on consumers' willingness to pay. This implies that, for each scenario, we assess the changes in consumption of woody products but not the total bioenergy demand.
- The analysis accounts for the impact of GHG emissions from land use, land use change and forestry (LULUCF). However, no feedback from LULUCF emissions to policy targets is considered within the study.
- Global and EU net emission saving in the energy sector is not assessed within this study; the net emissions savings as assessed for each scenario only relate to changes in LULUCF emissions and removals related to assumed changes in feedstock supply.
- Potential GHG savings related to material substitution effects are not considered within this study. The emissions and removals as reported cover the Harvested Wood Products (HWP) carbon pool development, but do not cover changes in emissions and removals related to a decrease or increase of production and consumption of materials substituted by woody products.
- The EU sourcing of SRC and perennial lignocellulosic crop for bioenergy is exogenously defined according to the PRIMES 2016 EUCO 27 scenario development and is not sensitive to price development. In the ReceBio study, the sourcing of SRC for bioenergy production was modelled to be in competition with the sourcing of woody biomass.
- The availability of recovered wood for the production of wood based panels and/or energy production is exogenously defined and not sensitive to changes in consumption patterns. Therefore, no feedback from changes in consumption of wood products to future availability of recovered wood for material and/or energy purposes is considered within the study.

3. METHODOLOGY

Overview of the integrated modelling framework used in this study

At the center of the analysis of this study are two modeling tools that are developed and run by IIASA: an economic land use model GLOBIOM[5] that is utilized together with a detailed forestry sector model G4M[6]. GLOBIOM is an economic partial equilibrium model that jointly covers the forest, agricultural, livestock, and bioenergy sectors, allowing it to consider a range of direct and indirect causes of biomass use. The wood demand estimated by GLOBIOM is used as input in G4M, a detailed agent-based forestry model that models the impact of wood demand in terms of forestry activities (afforestation, deforestation, and forest management) and the resulting biomass and carbon stocks. In essence, G4M is a geographically explicit model which in combination with GLOBIOM helps to evaluate changes in national silvicultural forest practices related to changing demand and price information.

GLOBIOM is a global model of the forest and agricultural sectors, where the supply side of the model is built-up from the bottom (land cover, land use, management systems) to the top (production/markets). The GLOBIOM model has a long history of publication[7] and has previously been used in several European assessments[8]. The model computes market equilibrium for agricultural and forest products by allocating land use among production activities to maximise the sum of producer and consumer surplus, subject to resource, technological and policy constraints. See Annex II for details concerning the land categories being considered in the model framework. The level of production in a given area is determined by the agricultural or forestry productivity in that area (dependent on suitability and management), by market prices (reflecting the level of supply and demand), and by the conditions and cost associated to conversion of the land, to expansion of the production and, when relevant, to international market access. Trade flows are computed endogenously in GLOBIOM, following a spatial equilibrium approach so that bilateral trade flows between individual regions can be traced for the whole range of the traded commodities. This also allows the tracking of direct and indirect changes in the global trade of commodities with regards to changes in production or availability of commodities in a single targeted region.

The following modelling features are reflected in the GLOBIOM integrated framework used for this assessment:

- As the focus of the study is to assess the potential impact of increasing bioenergy demand, the study makes no attempt to estimate future bioenergy demand levels and all bioenergy demand projections are exogenously defined. The basis for the modelling lies in previous adaptation of the PRIMES and POLES modelling results developed for previous Commission work[8]; for this study, the PRIMES and POLES scenarios are updated to more recent ones. GLOBIOM uses these bioenergy demand projections as exogenous inputs, they always have to be fulfilled, even if it reduces the availability of biomass resources for other purposes.
- There is no feedback from price signals of feedstocks on the total bioenergy demand. That is, increases in bioenergy use may well push up prices for feedstocks, but this will not feed back to reduce the demand for bioenergy (compared to other energy technologies). The demand for food and feed

5 See also: www.iiasa.ac.at./GLOBIOM
6 See also: www.iiasa.ac.at/G4M
7 See Havlík, P., Valin, H., Herrero, M., Obersteiner, M., Schmid, E., Rufino, M.C., Mosnier, A., Thornton, P.K., Böttcher, H., Conant, R.T., Frank, S., Fritz, S., Fuss, S., Kraxner, F., Notenbaert, A., 2014. Climate change mitigation through livestock system transitions. Proc. Natl. Acad. Sci. 111, 3709–3714.
8 See EC, (2013). EU Energy, Transport and GHG Emissions Trends to 2050: Reference Scenario 2013. European Commission Directorate-General for Energy, DG Climate Action and DG Mobility and Transport., Brussels, p. 168. and EC, (2014). A policy framework for climate and energy in the period from 2020 to 2030. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. European Commission, Brussels, p. 18.

commodities is on the other hand price elastic and therefore may change depending on consumers' willingness to pay. The same applies to material production, which is also price elastic and hence varies depending on the changes in the total demand. Indeed, in this exercise, we are interested in the consequences of delivering a given bioenergy level and this is, therefore, fixed at a certain level. It is subsequently up to policy makers to design policies that will lead to the level of demand deemed necessary to meet renewable targets and acceptable in terms of its impacts.

- During the modelling, changes in GHG emissions and removals due to increased or reduced biomass demand linked to land use and land use change (LULUCF) is not accounted for in the efforts needed for reaching an overall EU GHG emission reduction target for each scenario. Therefore, there is no feedback loop back to bioenergy demand from increasing or decreasing forest carbon stocks through forest management levels. GHG consequences are, however, analysed as outputs of the study.
- The starting year of the modelling is the year 2000, and the potential impact of bioenergy demand is being assessed for years 2010–2050. Bioenergy demand and model outcome are presented on a ten-year basis.
- Material and energy substitution effects are not assessed in this work. The emissions and removals from the LULUCF sector that are reported cover the Harvest Wood Products (HWP) carbon pool development, but do not cover changes in emissions and removals related to a decrease or increase in the production and consumption of materials substituted by woody products.
- The availability of recovered wood for the production of wood based panels and/or energy production is fixed over time and a change in availability of recovered wood from an increase or decrease in consumption of woody products is not accounted for in the framework. Therefore, there is no feedback loop from a change in the consumption of HWP commodities and the future availability of recovered wood for material and/or energy purposes.
- In terms of Common Agriculture Policies (CAP) within the EU, it is assumed that direct payments under the CAP stay constant throughout the modelling timeframe. The Ecological Focus Areas (EFA) policy is assumed to have no further impacts on EU agricultural production and the level of set-aside land is here considered to remain constant.
- As compared to EU LULUCF and Agriculture GHG projections, it should be noted that a number of project specific updates of the GLOBIOM and G4M models has been done for this project and not the same input data is being used as for the earlier projection published within the European Commission Trends to 2050 Report[8] that describes the EU Reference scenario projection 2013. For an elaboration of the scenario specifications see the ReceBio Task 3 and 4 reports.

For the forestry sector, emissions and removals as well as biomass supply are projected by the Global Forestry Model (G4M), a geographically explicit model that assesses afforestation-deforestation-forest management decisions. Given an increasing demand of wood, the G4M model estimates the conversion of unused forests to used forests, as well as the intensification in management options in already managed forest areas (thinning of forests, change in rotation periods, etc.). The forest area change and associated emissions and removals from afforestation, deforestation and forest management are reported based on estimates by the G4M model. In the model, the decision of afforestation or deforestation is made by comparing the income of managed forest (difference of wood price and harvesting costs plus income by storing carbon in forests) with income by alternative land use on the same place. The increased value of forests, driven by an increase in wood prices, thereby reduces deforestation activities and increases afforestation activitites. An increase in value of agriculture activites acts in the opposite direction and induces land use change through increased deforestation activities and reduced afforestation activitites. The G4M model receives information from GLOBIOM on the development of land use, wood demand, wood prices and land prices, and is initially calibrated to historic data reported by Member States on afforestation and deforestation rates and therefore includes policies on these activities.

The following modelling features of the G4M are used for this assessment:

- The afforestation and deforestation rates in G4M have been calibrated to forest area changes for the period of 2000 to 2010 based on data provided by FAO FRA 2010. Historical harvest removals from 1960 onwards taken from FAOSTAT data have been considered in the calculation of the harvested wood sink and the forest area was set to match the reported forest area in 2000 according to FAO FRA 2010.
- Afforestation and the development of new forest areas is assumed to only be established on other natural land (please see Annex II - Definitions of land categories) and directly converts an area to the used forest land category.

Definitions

The feedstocks and the terminology used to describe them in this report are in line with the reporting of ReceBio (please see Annex III - Glossary). The key bioenergy feedstocks that are in full competition with each other in this current report are: roundwood used directly for energy, imported pellets, and industrial by-products. Roundwood used directly for energy refers to industrial quality stemwood that could be used for material purposes (pulpwood) but is instead combusted for energy. Imported pellets refers to wood pellets that are produced outside of the EU. All domestic production of wood pellets within the EU is reported under the feedstocks used to produce the pellets, i.e. roundwood used directly for energy or industrial by-products.

Indicators

To analyse economic and environmental impacts of different scenarios, a list of potential indicators has been defined. These indicators relate to land use, GHG emissions and removals, and impacts on biodiversity, and are directly linked to GLOBIOM model variables. The main indicators for assessing environmental impacts of biomass use in EU28 in different policy scenarios are derived from the following model output variables (as in ReceBio):

- Land use (addressing the model variables Forest area (including the categories Afforestation, Used Forest, Unused Forest); Area of Deforestation; Area of Cropland (including the category Short Rotation Coppice [SRC]); Area of Grazing land; Area of other natural land). The indicators 'used' and 'unused' forest area and the conversion between them are among those indicators that show significant differences between scenarios both for EU28 and for the Rest of the World (RoW) as earlier research within the ReceBio revealed. This indicator is a good proxy for assessing changes in the intensity of forest management due to increased biomass demand. ‘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).
- Greenhouse Gases (addressing the model variables Emissions from agriculture and livestock; Emissions from forest activities and Harvested Wood Products; Total net land use emissions)
- Biodiversity (addressing the model variables ‘Unused forest area’ or ‘Unused forest’ converted to other land use; Areas with high biodiversity value and/or high carbon stocks (HBVCS areas)). Areas with HBVCS are defined according to the

WCMC[9] map. Most of the HBVCS areas as defined in this study are located outside EU28, where also most of the conversion is expected.

Indicators looked at in the constrained scenarios (LAND and RWCAP) are:

- Production of biomass in the EU by biomass type (i.e. roundwood, 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.
- 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 and the development of the HWP pool.
- Biodiversity.

9 http://www.unep.org/pdf/carbon_biodiversity.pdf

4. DESCRIPTION OF THE SCENARIOS

The following is a specification of how the various policy scenarios have been implemented in GLOBIOM for this assessment. Note that the input data from PRIMES is different from what was used for the ReceBio study, but is below not marked as a changed assumption as PRIMES data is only used as input to GLOBIOM. In this study, all PRIMES data is derived from the PRIMES 2016 EUCO 27 scenario, whereas in ReceBio the corresponding data stemmed from the GHG40/EE scenario published in 2014.

Updated EU emission reduction scenario (REDU2)

Assumptions that are consistent with what was assumed for the ReceBio study

- Global population growth and GDP projections until 2050 are exogenously set according to the PRIMES 2016 EUCO 27 scenario.
- Demand for food and fibre is driven by human population growth and changing GDP. Demand for commodities is price elastic and therefore changes depending on consumers' willingness to pay. Demand is modelled through the use of constant elasticity functions which are parameterized by consumption quantities from EUROSTAT and FAOSTAT data on price and quantities.
- Total bioenergy demand (including heat, electricity, and biofuels) evolves over time according to the PRIMES 2016 EUCO 27 scenario development and always has to be fulfilled (i.e. is not price elastic to feedstock prices). The demand of each PRIMES feedstock category is specified on the level of each EU28 Member State. Demands for all countries, regions, and years are implemented in the model as minimum constraints, meaning that a country can produce more but not less biomass for energy use than prescribed (e.g. not price elastic). By doing this it is assured that the production of biomass in the EU is achieved, but also allowing for flexibility to produce more if demanded, e.g. through international trade. Other (non-energy) wood products are competing for the wood resource.
- The use of food and feed crops for the production of first and second generation biofuels follows the feedstock specific demand projections set out in the PRIMES 2016 EUCO 27 scenario.
- Trade of biofuels between EU28 and RoW is fixed according to the PRIMES 2016 EUCO 27 scenario development and always has to be fulfilled.
- The use of forest residues for the production of heat and electricity is fixed according to the PRIMES 2016 EUCO 27 scenario development and always has to be fulfilled.
- Bioenergy demand projection for the Rest of the World and separation of the total demand into feedstock categories is consistent with the assumptions for the ReceBio study, based on the baseline demand projections as presented in the latest 2015 GECO POLES report.[10]
- Availability and consumption of recovered wood (e.g. wood from used packaging material, scrap timber from building sites, wood from demolition projects) used for production of wood based panels and/or energy purposes is based on data collected in Task 1 of the ReceBio project. The same data sources as in the ReceBio study are being used for this work.
- For clear reporting of feedstock use for energy purposes, each feedstock category is reported separately for the EU. Production of wood pellets within the EU is reported upon as a separate category for this study. That is, a share of the EU reported energy use of wood chips, sawdust, and roundwood combusted directly

10 Labat, A., Kitous, A., Perry, M., Saveyn, B., Vandyck, T., and Vrontisi, Z. (2015). GECO2015. Global Energy and Climate Outlook. Road to Paris. JRC Scientific and Policy Reports, EUR 27239 EN.

for energy could potentially be used within the EU for domestic production of wood pellets and traded between Member States before being consumed for energy purposes. However, such uses of EU feedstocks are not reported as a separate category; instead, only EU imported sources of wood pellets are reported.

- Forests protected according to the WDPA Consortium 2004[11] definitions are excluded from the analysis and no conversion or use of protected forest is allowed. This implies that no biomass is allowed to be harvested from protected forest areas.
- Agricultural and forestry production does not expand into protected areas; however, land conversion can occur on unprotected areas.

Assumptions differing from the ReceBio study

- Free competition between woody biomass feedstocks is allowed within the EU for fulfilling the 'Harvestable Stemwood' demand category from PRIMES. Different to ReceBio, the set of the feedstock categories that are in competition now excludes SRC and lignocellulosic crops. In this study, the feedstocks allowed to compete within 'Harvestable Stemwood' are:
    - Import of wood pellets from the RoW.
    - The use of woody by-products from forest based industries (sawdust, wood chips, etc.).
    - Roundwood combusted for energy.
- SRC and perennial lignocellulosic crop development is for the EU exogenously fixed according to the PRIMES 2016 EUCO 27 scenario development and always has to be fulfilled. In the ReceBio study, SRC was in competition with the woody biomass category as mentioned above.
- In terms of production of wood pellets in RoW, it is for this study assumed that roundwood is used to supply 75% of the total feedstock use for pellets production based on data emerging from South East of US[4]. This share is applied for all countries in the RoW and kept constant over time due to lack of reliable data for individual countries and the fast development of the wood pellets market. The remaining 25% of feedstock for pellets production is endogenously selected based on the cost competitiveness of using any combination of forest based industrial by-products, and SRC. It is acknowledged that there is high uncertainty concerning the current and future feedstock use for pellets production, and sensitivity analysis concerning these assumptions has been performed (see Section 6).

Scenario with land criteria for high biodiversity and high carbon stock areas (LAND)

- Same assumptions as in REDU2 (e.g. total bioenergy demand, fixed demand for SRC and perennials). Additional assumptions for LAND are stated below:
    - Areas of high biodiversity and/or high carbon stocks (HBVCS area) are defined globally according to the WCMC[12] map. It should be noted that this map both covers areas of high biodiversity and areas of high carbon stocks.
    - **Within EU28,** two issues concerning the HBVCS areas are constrained: the harvest of wood; and the conversion of land.

11 WDPA Consortium, 2004: World Database on Protected Areas. Copyright World Conservation Union (IUCN) and UNEP-World Conservation Monitoring Centre (UNEP-WCMC)
12 http://www.unep.org/pdf/carbon_biodiversity.pdf

  - For HBVCS forest areas, a constraint is placed on the amount of feedstocks that can be collected from the HBVCS areas to represent the maintenance of existing provisions in these areas. It is assumed that no woody biomass is allowed to be harvested from HBVCS forest areas independent of the final downstream use of the wood (i.e. used for material or energy purposes). In reality, however, some wood collection may be possible within HBVCS areas without affecting the biodiversity and/or carbon stock, or sometimes even preferable to enhance the biodiversity of certain ecosystems. The modelled constraint therefore limits the wood availability more strongly than the probable outcome of protecting HBVCS areas would be in reality (therefore, a sensitivity analysis is done on this issue and presented in Section 6). Note that this constraint only focuses on forest areas and not on any other land category (e.g. SRC, agriculture land, grazing land). This implies that cropland or grazing land classified as HBVCS can continue to be managed in the future with the same assumptions as in REDU2 and that no constraint is placed on these land categories relating to food and feed production.
  - For all HBVCS areas, specific types of land use conversion are also forbidden in order to protect areas from conversion in relation to direct and indirect effects of biomass production for energy and material purposes. The scenario represents a stronger constraint on land conversion than the probable outcome of the restriction only on energy use, as the protection from conversion of HBVCS areas is done independently of the final downstream use of the wood (i.e. used for material or energy purpose). The constraint on conversion applies for all HBVCS land classes (forest, cropland land, grazing land, other natural land, etc.) but only applied to specific categories of land use conversions. See Table 1 for the land use conversions that are forbidden in LAND.
  - Land classified as highly biodiverse grassland within EU28 is not allowed to be converted to Short Rotation Plantations.
- **For the RoW**, only the conversions of HBVCS areas is constrained:
  - For all HBVCS areas, land use conversion is forbidden in order to protect areas from conversion in relation to direct and indirect effects of biomass production for energy and material purposes. The constraint is modelled in the same way as for EU28. As for EU28, the constraint is specified on specific categories of conversions from one land use category to another. See Table 1 for the land use conversions that are constrained. It should be noted that a number of land use conversions are already forbidden in REDU2 (See Table 1 and conversions noted as 'Forbidden as of REDU2').
  - For HBVCS forest areas specifically, no constraint is placed on the amount of feedstocks that can be collected from the areas and exported to the EU. In reality, however, the policy option would forbid wood harvested from HBVCS to be exported to the EU. Therefore, the projected trade of wood from the RoW to EU for LAND could be overestimated as a share of the wood that is traded between RoW and EU could have been sourced in HBVCS areas would no longer be available – or only available at a higher price (therefore, a sensitivity analysis is done on this issue and presented in Section 6). No additional constraint is placed on cropland or grazing land classified as HBVCS and they can continue to be managed in the future with the same assumptions as in REDU2.
  - For all HBVCS areas, the protection from land conversion has not been explicitly linked to conversion of peat land and related emissions and removals. The reason for this is that an overlay between the WCMC map of Areas of high biodiversity and/or high carbon stocks and detailed maps of peatland soils is deemed at this stage to be associated with too high uncertainties. This is particularly the case for countries with current high

level of peatland emissions such as Indonesia where the location of peatland as well as soil depth is still highly uncertain. The modelling of the constraint is therefore likely to provide a smaller reduction of land use emissions from areas with large amounts of peat land, as such conversion is not limited in the modelling framework but would probably be limited in reality.

Table 1: Land use conversions for HBVCS areas that are constrained in the LAND scenario (for all biomass uses, not only for energy use), based on the WCMC map of high biodiversity spots. Clarification of land categories can be found in Annex I

Conversion from	Conversion to	Allowed / Forbidden
Unused forest	Used forest	Forbidden
Unused forest	Cropland	Forbidden
Unused forest	Grazing land	Forbidden
Unused forest	Short Rotation Plantation	Forbidden as of REDU2*
Used forest	Unused forest	Allowed
Used forest	Short Rotation Plantation	Forbidden as of REDU2*
Cropland	Short Rotation Plantation	Allowed
Cropland	Grazing land	Allowed
Cropland	Other Natural Land	Allowed
Grazing land	Cropland	Forbidden
Grazing land	Other Natural Land	Allowed
Grazing land	Short Rotation Plantation	Forbidden
Other Natural Land	Cropland	Forbidden
Other Natural Land	Grazing land	Forbidden
Other Natural Land	Short Rotation Plantation	Forbidden
Short Rotation Plantation	Other Natural Land	Allowed

* This land use cover change is forbidden already in the REDU2 scenario and remains forbidden in the LAND scenario.

Scenario with land criteria and a cap on the use of roundwood for energy (RWCAP)

- Same assumptions as in LAND (e.g. total bioenergy demand and restrictions concerning HBVCS area). Additional assumptions for the scenario are stated below.
- For RWCAP, the total use of "roundwood for energy" and wood pellets produced from roundwood is capped on the aggregate EU28 level, modelling it to remain on the 2020 level. The cap to constrain the maximum quantity of "roundwood for energy" and wood pellets that can be used within EU is set on the aggregate EU28 level and not on the level of each individual EU Member State to allow for flexibility between Member States. The cap is set according to the total use of "roundwood for energy" and wood pellets as estimated for 2020 in GLOBIOM within LAND. In other words, we check the GLOBIOM data for 2020 in runs for LAND and then cap the value according to the model results. As the RWCAP scenario builds on the land criteria for high biodiversity and high carbon stock areas (the LAND scenario), the cap on total use of "roundwood for energy" and wood pellets produced from roundwood is set on the 2020 estimates for the LAND scenario and not on the 2020 estimates for the REDU2 scenario.
- The cap on the use of roundwood is set on the direct use of "roundwood for energy" plus the use of wood pellets produced from roundwood. In other words, the cap is implemented in terms of the total use of the two feedstocks and the model endogenously selected the final mix of the use of the two feedstocks based on availability and costs. The cap considers imported roundwood, domestically harvested roundwood, as well as domestically produced and imported wood pellets that have been produced from roundwood. However, the cap does not apply to the share of the wood pellets that have not been produced from roundwood. As a result, the share of wood pellets produced from other sources

than roundwood (e.g. sawdust, wood chips, SRC) are not accounted for in the cap. Changes in the share of roundwood used for pellets production within the RoW are further assessed in a sensitivity analysis.

- No additional constraint is imposed for the RoW. As a result, wood pellets produced from roundwood in the RoW can still be traded and consumed for bioenergy production by countries within the RoW.

5. SCENARIO RESULTS

Impact on material and energy balance

A **comparison between the results of REDU2 and the EU emission reduction scenario (REDU) of the ReceBio project** is shown in Table 2. In both scenarios, the total bioenergy demand was fixed to development given by PRIMES: in REDU to GHG40/EE, and in REDU2 to EUCO27. In contrast, demand for woody materials, food, and feed was price-elastic in all scenarios. The largest difference between the scenarios is the amount of short rotation coppice (SRC) domestically produced within the EU: in REDU, the SRC production was modelled endogenously and was in competition with other feedstocks. In REDU2, SRC was fixed to the PRIMES 2016 EUCO 27 scenario development. As a result, SRC production in REDU2 increases much more slowly until 2030 than in REDU. However, thereafter SRC increases very rapidly in REDU2, reaching 280 Mm^3 by 2050 – more than 70% increase compared to REDU in 2050.

Because the development of SRC **between 2010 and 2030** is projected to be slower in REDU2 than in REDU, the amount of forest biomass demanded for energy use is conversely 22% higher in 2030 in REDU2 than in REDU. This higher demand for non-SRC woody biomass for energy affects the EU import of wood pellets from RoW, which doubles in REDU2 from the level of REDU, and roundwood combusted directly for energy, which is almost doubled in REDU2 as compared to REDU in 2030.

Table 2: Comparison of the results in EU emission reduction scenario (REDU) of the ReceBio project, and the REDU2 scenario.

Study		REDU		REDU2	
Reference year	2010	2030	2050	2030	2050
	Million m³				
Total Wood Consumption	841	987	1304	982	1375
Total Material Use	535	613	679	619	694
Wood products industry**	367	435	499	433	496
Pulp	162	172	174	187	199
Total Energy Use, excl. SRC	306	327	464	351	400
Wood products industry side streams***	155	187	222	180	202
Wood used primarily for energy****	151	140	242	171	198
Roundwood used for energy	0	5	78	9	25
Energy biomass from SRC	0	47	161	13	280
Imported pellets	10	19	52	39	70
Energy use, %	*36%*	*38%*	*48%*	*37%*	*49%*
Material use, %	*64%*	*62%*	*52%*	*63%*	*51%*

Note that this table describes the input volumes for wood-using industries. This means that some of the wood biomass is counted both within “Total Material Use” and “Total Energy Use”, because by-products of the material industries can be used in the production of other materials (pulp and/or particleboards), or for energy. This is a common way of accounting for wood use found in the literature, but partial double-counting makes it impossible to compare these numbers with actual harvest volumes.
*Here: Sawmill and board industries, pulp production, and recovered wood used for material
**Here: Sawmill and board industries
***Here: Sawdust, wood chips, bark and black liquor used for energy, and recovered wood
****Here: firewood, forest residues, industrial-quality roundwood used directly for energy, imported pellets.

However, the rapid increase of SRC in REDU2 **after 2030** decreases the demand for wood for energy purposes as well as the competition for woody biomass resources between the energy and material sectors. This affects especially the amount of roundwood burnt directly for energy in 2050: the amount of roundwood for energy is only one-third of the amount in REDU (25 Mm^3 in REDU2 compared to 78 Mm^3 in EU emission reduction scenario). Import of pellets is on a higher level in REDU2 than in REDU also in 2050, explained by the higher demand for bioenergy in the new PRIMES scenario. Moreover, the higher level of pellet imports in 2030 leads to more investments in infrastructure and trade which makes trade of pellets more profitable in 2050 than in the REDU scenario.

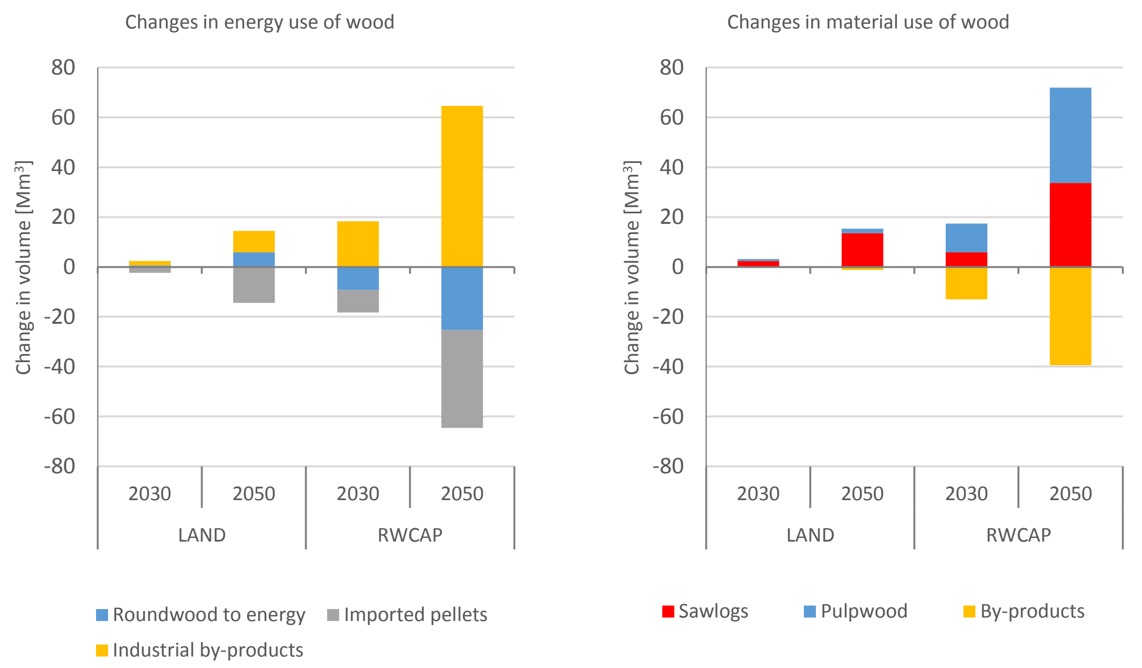
The material use of wood develops relatively similarly in REDU and the REDU2, with a slight increase in EU pulp production over time in REDU2. This is explained mainly by the rapid increase of SRC in REDU2 that decreases the competition for pulpwood, which is the major feedstock in the pulp producing industry alongside with wood chips.

When moving from REDU2 to LAND and RWCAP scenarios, we see **changes in the composition of both energy and material feedstocks** (Figure 2). The changes are more prominent towards the end of the analysis period (2050), albeit the same trends can be detected already in 2030.

In LAND, the restriction on the HBVCS areas will decrease the amount of woody biomass available from the RoW, including also woody biomass that in REDU2 was used to produce pellets. That is, land criteria on HBVCS areas reduces the availability of wood within certain regions (mainly central and south America) as it prohibits forest management intensification (the conversion of an unused HBVCS forest area to a used forest). The land criteria is less restrictive within the EU28 than in RoW, because the share of HBVCS areas of the total forest area is relatively small in the EU28. This means that the wood harvest and conversion of HBVCS areas projected in REDU2 can relatively easily and for a relatively low cost be displaced to non-HBVCS areas. This is not always the case for all countries within the RoW, where the HBVCS areas may constitute a major share of the total forest area. It should though be taken into account that the protection from conversion of HBVCS areas is done independently of the final downstream use of the wood (i.e. used for material or energy purpose). Land criteria on HBVCS areas makes pellet imports less competitive compared to the use of EU28 domestic biomass resources. As a consequence, EU pellet imports in LAND are 7% lower in 2030, and 22% lower in 2050 than in REDU2. Furthermore, the demand for EU sawnwood exports is higher in LAND than in REDU2, shown both as an increase in the amount of sawlogs used for material production, as well as industrial by-products that will as a consequence become available for energy production. In addition, the decreased availability of pellet imports in LAND increases the EU use of roundwood combusted directly to energy, especially towards 2050. However, it should be noted that the land use constraints in place in LAND affect all uses of forests; if the constraint would only be put on the wood used for energy purposes, it can be expected that the results would be closer to those in REDU2.

In RWCAP, roundwood use for energy was capped, leading to a decrease in the amount of roundwood used for energy production and, consequently, to a clear increase in the use of industrial by-products for energy production. In 2030, roundwood used for energy is 4.2 Mm^3 lower in RWCAP compared to REDU2, and in 2050 it is 20 Mm^3 lower. The increased demand for by-products increases the use of sawlogs for material purposes, as sawnwood production increases its profitability through higher demand for its by-products. This leads in turn to a substantial change in the feedstocks used in material production. Industrial by-products formed previously a high share of pulp and fibreboard production – while in the RWCAP scenario they are instead increasingly used for bioenergy, and the share of pulpwood in material production is, in 2050, 23% higher than in REDU2. In other words, pulp mills that previously used a high share of wood chips as a feedstock, now increase the share of pulpwood (i.e. roundwood of smaller diameter) in the production. In addition, like in the LAND scenario, EU pellet imports decrease also in this scenario due to the constraint on the HBVCS land globally. However, unlike in LAND, here in RWCAP there is also the additional constraint for roundwood use for energy in the EU. This cap on the roundwood for energy increases the demand for other feedstocks in RWCAP compared to LAND, and hence also the pellet imports are about 6 Mm^3 higher in 2050 in RWCAP than in LAND (while still almost 9 Mm^3 lower than in REDU2). The effect of the cap on the roundwood modelled in RWCAP is illustrated in

Figure 3. As shown clearly in the figure, the cap to constrain the total use of roundwood for bioenergy within the EU (either directly in the form of roundwood or indirectly in the form of imported wood pellets) to remain on the level of 2020 is expected to lead to no roundwood being used directly for energy purposes. The amount of roundwood that is allowed to be used for energy within the cap is expected to be fulfilled fully through imported pellets as it allows for a higher energy quantity per unit of biomass accounted for in the cap.



		ENERGY USE OF WOOD			MATERIAL USE OF WOOD		
		Rw to energy	**Imported pellets**	**By-products**	**Sawlogs**	**Pulpwood**	**By-products**
LAND	2030	6%	-6%	2%	1%	0%	0%
	2050	23%	-21%	7%	4%	1%	-1%
RWCAP	2030	-100%	-23%	18%	2%	7%	-13%
	2050	-100%	-57%	51%	10%	23%	-36%

Figure 2: Changes in the energy and material use of wood in LAND and RWCAP, compared to REDU2.

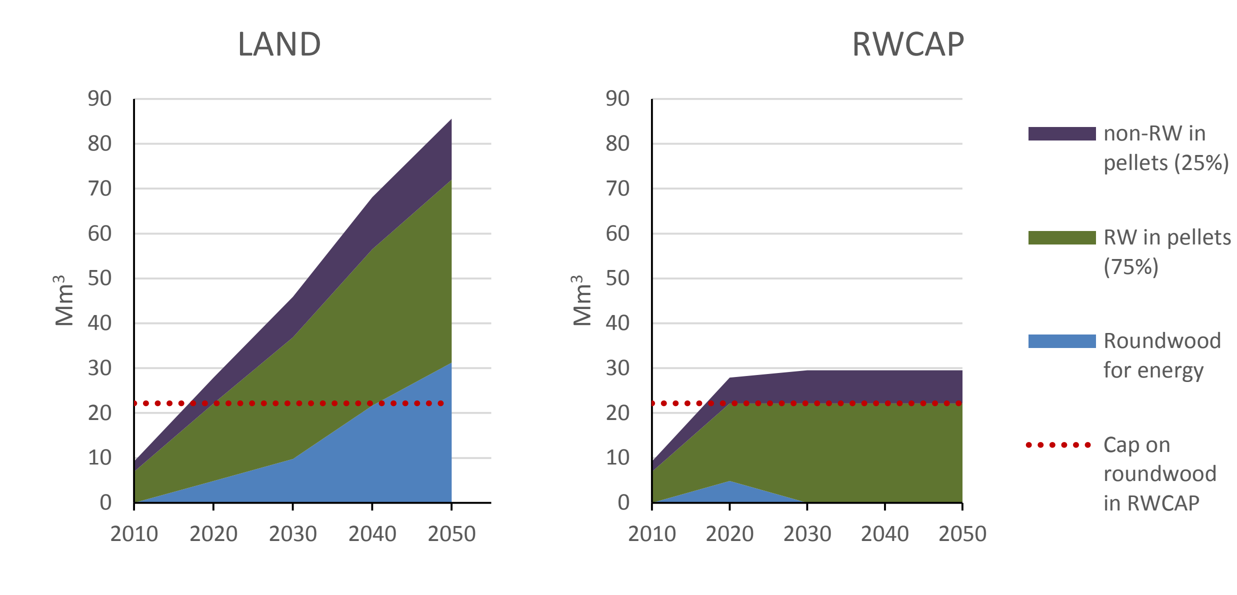


Figure 3: Volume of roundwood used for energy (either directly or through pellets) in LAND and RWCAP (volume of non-roundwood made pellets also shown for completeness)

In terms of **total harvest volumes when moving from REDU2 to LAND and RWCAP scenarios**, the model shows that both LAND and RWCAP scenarios result in an **increased harvest level *within the EU*** as compared to REDU2 (Figure 4), while the total global forest harvest level remains unchanged. The higher harvest level in the EU is explained by the land criteria restricting the harvest of woody biomass more outside of the EU, hence decreasing the possibilities of sourcing biomass from the RoW. That is, EU will import less pellets from the RoW, and in the meantime the RoW demand for sawnwood will increase EU sawnwood exports, as the possibilities for forest management intensification in the RoW will be limited compared to REDU2 due to constraints on HBVCS forest areas. Land criteria on HBVCS forest area restrict the possibility for intensification in forest management as it limits the conversion of forests available for wood production (see Table 1). In REDU2, the total annual harvests within EU are projected to increase by 34 Mm^3 between 2010 and 2030, and further by 40 Mm^3 between 2030 and 2050, corresponding to an 18% increase by 2050 compared to year 2010. In LAND and RWCAP, the harvests increase already between 2010 and 2030 more than in REDU2; in LAND, EU harvest level is 6 Mm^3, and in RWCAP, 12 Mm^3 higher than in REDU2, and higher than in 2010. The differences between the scenarios are accentuated between 2030 and 2050, and in 2050, the harvests in LAND and RWCAP are projected to be 687 Mm^3 and 717 Mm^3, respectively. This corresponds to an increase of 23% in the total EU harvests between 2010 and 2050 in LAND, and 28% in RWCAP.

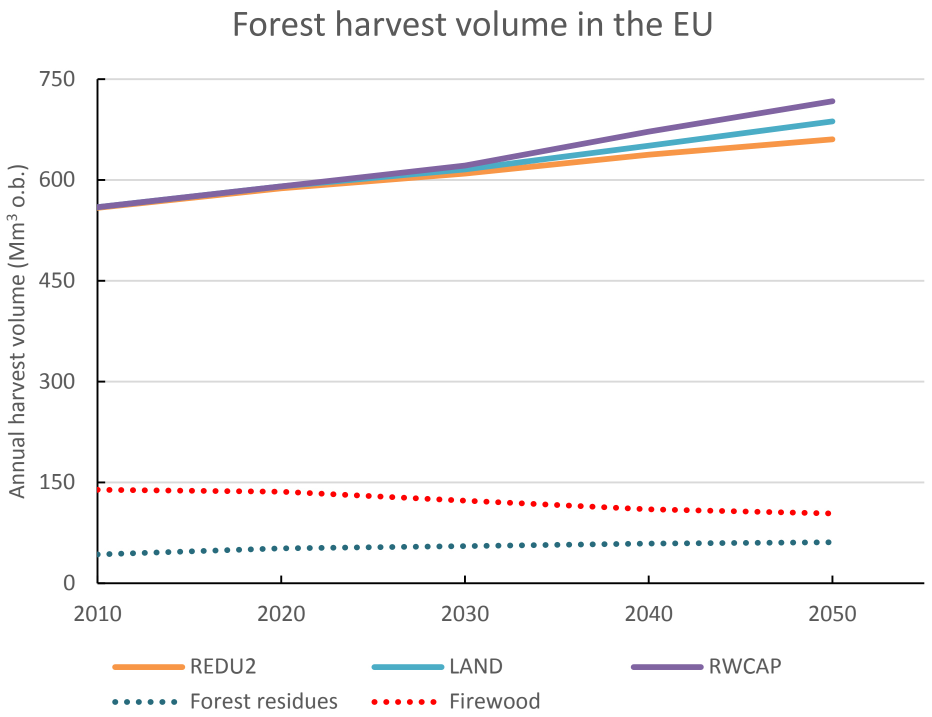
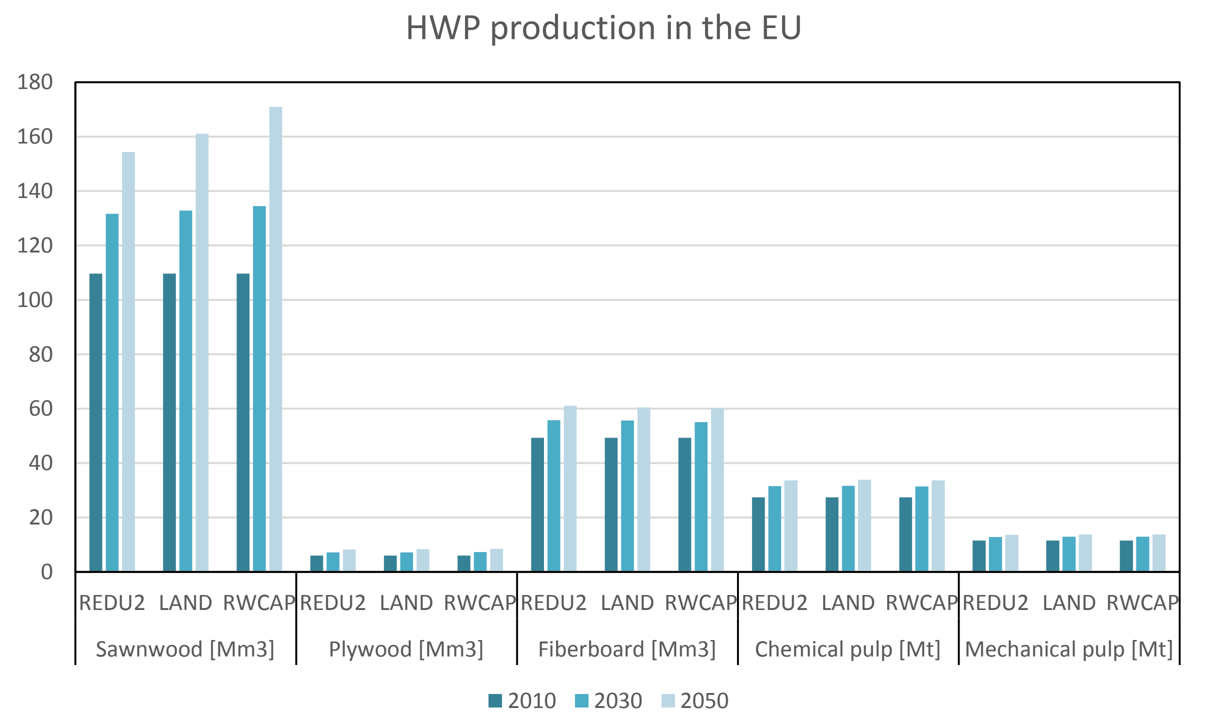


Figure 4: Development of forest harvest volume within the EU in the different scenarios. Total harvest volume is here reported over bark, and includes roundwood and firewood harvests, as well as the collection of forest residues. The shares of firewood and forest residues are shown with dotted lines – their harvest volumes were fixed to follow PRIMES development and hence do not differ between the scenarios.

The EU production of semi-finished harvested wood products (HWP) in the different scenarios is shown in Figure 5 below. Unlike bioenergy demand, which was fixed in all scenarios, material production was modelled to be price elastic and hence the production of HWP differs between the different scenarios. In all scenarios, the production of HWP increases over time in the EU. Between the scenarios, there are only subtle changes in all but the production of sawnwood. There, the increased use of sawlogs for material production seen already previously in Figure 2 for LAND, and especially RWCAP, is reflected as a clear increase in the production of sawnwood compared to REDU2 in 2050. In 2050, the production of sawnwood is 4% higher in LAND than in REDU2, while in RWCAP it is 11%. This development stems from the combination of two effects: I) a reduction in the import of wood pellets from RoW to the EU, and II) an increased competitiveness of EU export of sawnwood to the RoW. In terms of wood pellets trade, the RoW constraints implemented in LAND restricts the use of HVBCS areas for wood harvests (and hence overall biomass availability), and in RWCAP the additional constraint limits the use of roundwood for energy (and hence, pellets production). These constraints decrease the import of wood pellets from RoW to the EU (see Figure 2) in LAND and RWCAP. The constraints furthermore decrease the production of sawnwood in RoW due to the limitations for intensification in forest management and harvest of wood from HBVCS areas for material purposes. This overall leads to an increase in thedemand for sawnwood from the EU – that is, EU sawnwood exports, and hence also EU sawnwood production, increase as a result of the constraints for wood harvested in the RoW. Here, it is notable that the land use constraints in place in LAND affect all uses of forests; if the constraint would only be put on the wood used for energy purposes, the impacts on EU sawnwood exports can be expected to have been somewhat smaller as more wood would domestically be available for material production in RoW. However, the issue is not straightforward, as is seen when looking at RWCAP: in that scenario, sawnwood production in the EU increases even more strongly than in LAND. This development is explained by the large increase in the demand for sawmill by-products within the EU, which increases the profitability of sawmills, increases their competitiveness and in turn enhances sawnwood exports.

For other HWP, the differences between the scenarios are only in the order of one or few percent: plywood production increases slightly from REDU2 to LAND and RWCAP and pulp production increases even more subtly, while particleboard production decreases slightly when moving from REDU2 to LAND or RWPCAP.



%-CHANGE IN THE PRODUCTION, COMPARED TO REDU2

		Sawnwood	Plywood	Fiberboard	Chemical pulp	Mechanical pulp
LAND	**2030**	1%	0%	0%	0%	1%
	2050	4%	1%	-1%	1%	1%
RWCAP	**2030**	2%	1%	-1%	0%	1%
	2050	11%	3%	-1%	0%	0%

Figure 5: The production of semi-finished harvested wood products (HWP) in the EU in the different scenarios, and the %-change production in LAND and RWCAP compared to REDU2.

Figure 6 shows the price development in the EU for sawlogs and pulpwood as well as some of the semi-finished woody products. It should be noted that the fluctuations seen in the graph reflect model reaction of prices to demand on the previous time step, rather than a change in the policy situation or actual demand shift; the price development should be assessed in terms of trends, rather than prices at a given point in time.

It is notable that the prices of woody materials increase only little between 2010 and 2050, whereas the price of the harvested wood (sawlogs and pulpwood) increases up to 50%, and the price of pellets up to 40% by year 2050. Price development is the strongest in LAND and RWCAP, while especially the prices of sawlogs and imported pellets increase less in REDU2. Moreover, it is notable that the prices are quite similar in all scenarios during the first part of the projection period, and differences start to arise only close to year 2050. An exception is the price of sawlogs, which increases at a faster rate in LAND and RWCAP than in REDU2 already from year 2010.

The strong increase in sawlog prices compared to sawnwood prices is explained by the increased demand for industrial by-products (here shown for wood chips), which increases the profitability of sawnwood production and their capacity to pay for sawlogs without putting pressure to increase sawnwood prices. The price development of the other key industrial by-product, sawdust, follows the same pattern as wood chip prices shown in Figure 6. A similar phenomenon is seen also with the smaller diameter roundwood (pulpwood): while the price of the harvested feedstock increases as more wood is being harvested from areas associated with higher costs, the prices of the products stay relatively constant, the demand for the feedstock being driven by the increased demand for energy. For wood pellets, the price increases only little between 2010 and 2030, but after that turns into a steep increase. The increase is accentuated in LAND and RWCAP, where the availability of pellets is restricted through the land criteria applied to HBV areas; in REDU2, the price increase ceases after 2040 and even shows a slight decrease between 2040 and 2050.

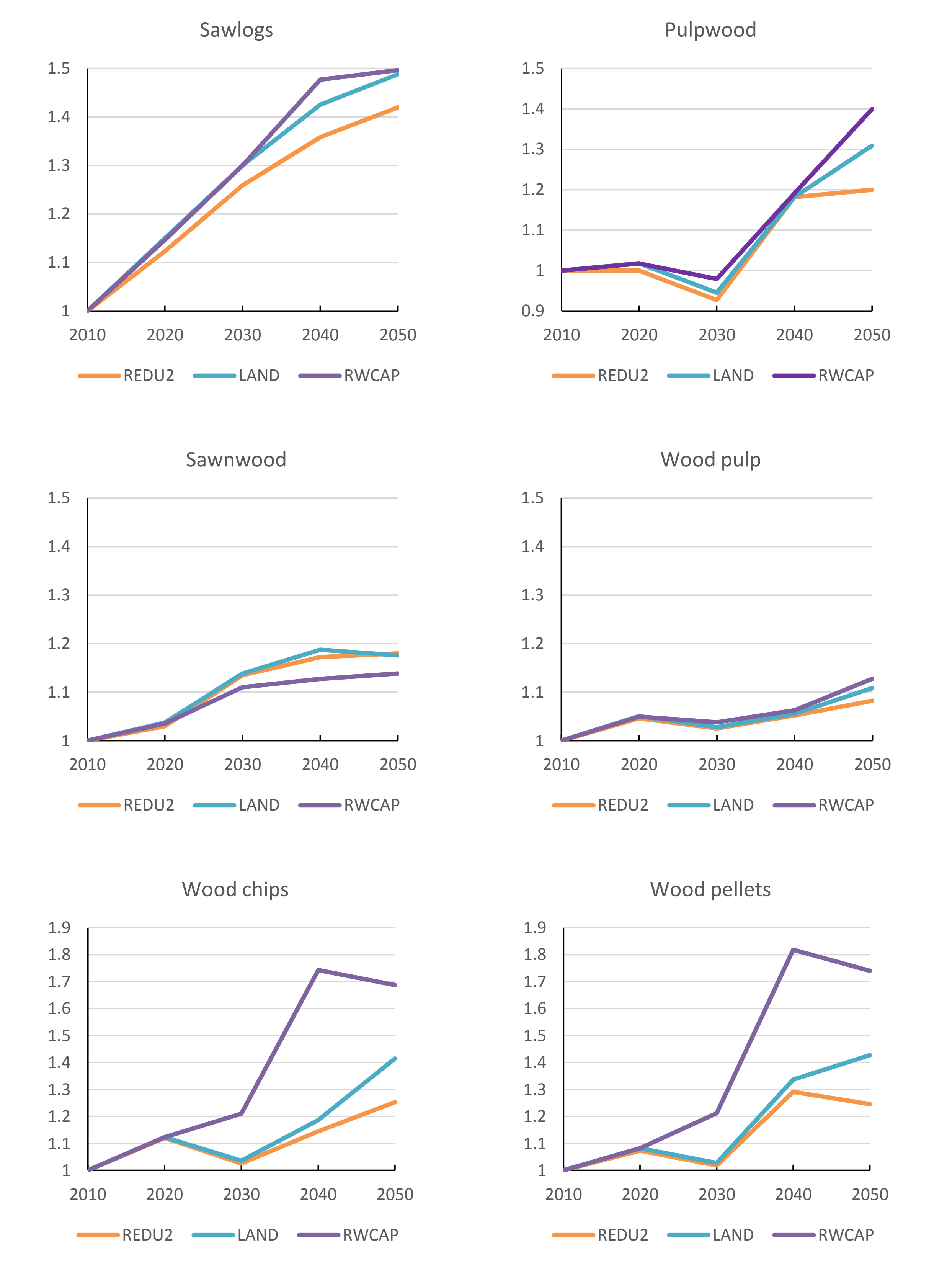


Figure 6: Price development of various woody feedstocks and semi-finished wood products, relative to price in year 2010.

Environmental impacts

Impacts on land use

The scenario underlying REDU2 leads to a significant change of land use in EU (Figure 7). While cropland (excluding SRC) and grazing land remain relatively stable at 107-112 Mha and 53-56 Mha without a clear trend over the course of the 40 years of simulation, there is a large increase of SRC area from zero to almost 15 Mha in 2050. Similarly, unused forest area remains stable at around 40-45 Mha until 2050 but used forest area increases from 105 in 2010 to 130 Mha in 2050. Both forest and SRC area expansion comes at the expense of other natural land. Between 2010 and 2050, 35 Mha of this land category is converted to forest and SRC, cutting this land category by more than 50%.

Figure 8 describes land use development under the REDU2 scenario for RoW. Total forest area is decreasing to a minimum of 3,158 Mha in 2020 but increasing thereafter due to increased afforestation. On the contrary, unused forest area decreases constantly. Between 2010 and 2050, more than 250 Mha of unused forest are either converted to used forest or converted to other land uses. Also other natural land is shrinking – more than 450 Mha are converted between 2010 and 2050, representing 18% of the area in 2010. Cropland and grazing land are two categories that continuously increase until 2050 by 150 Mha and 250 Mha, respectively. In addition, SRC areas increase by more than 100 Mha.

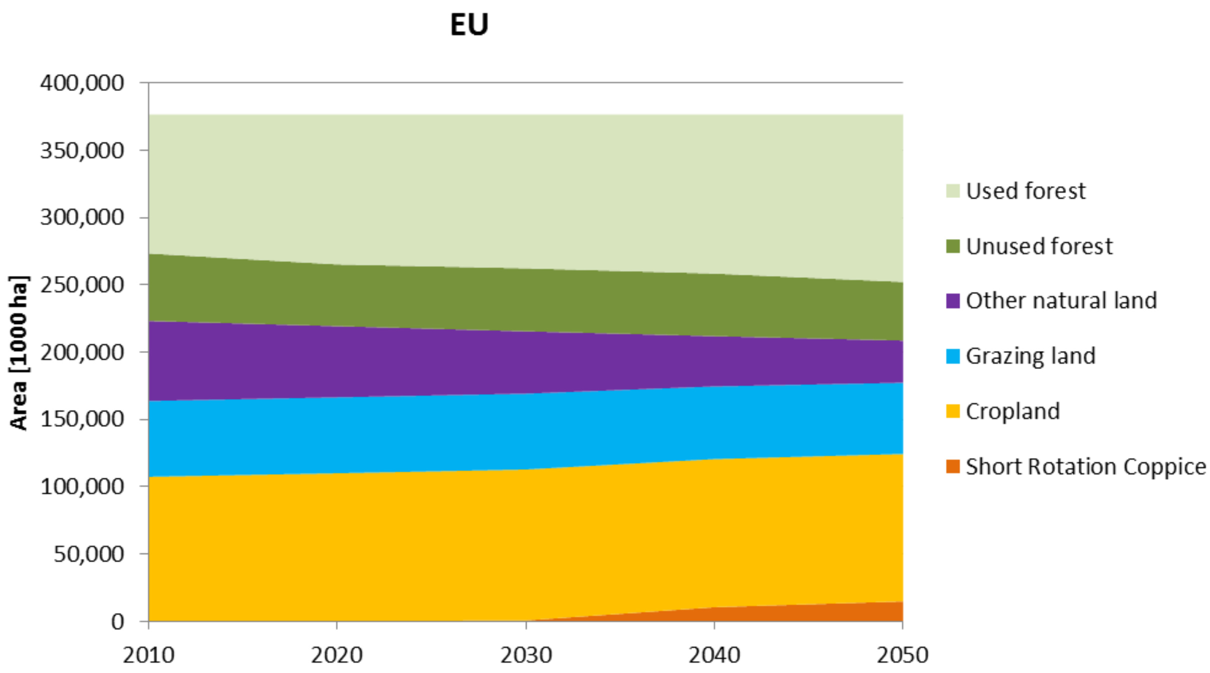


Figure 7: Development of land use under REDU2 in EU28.

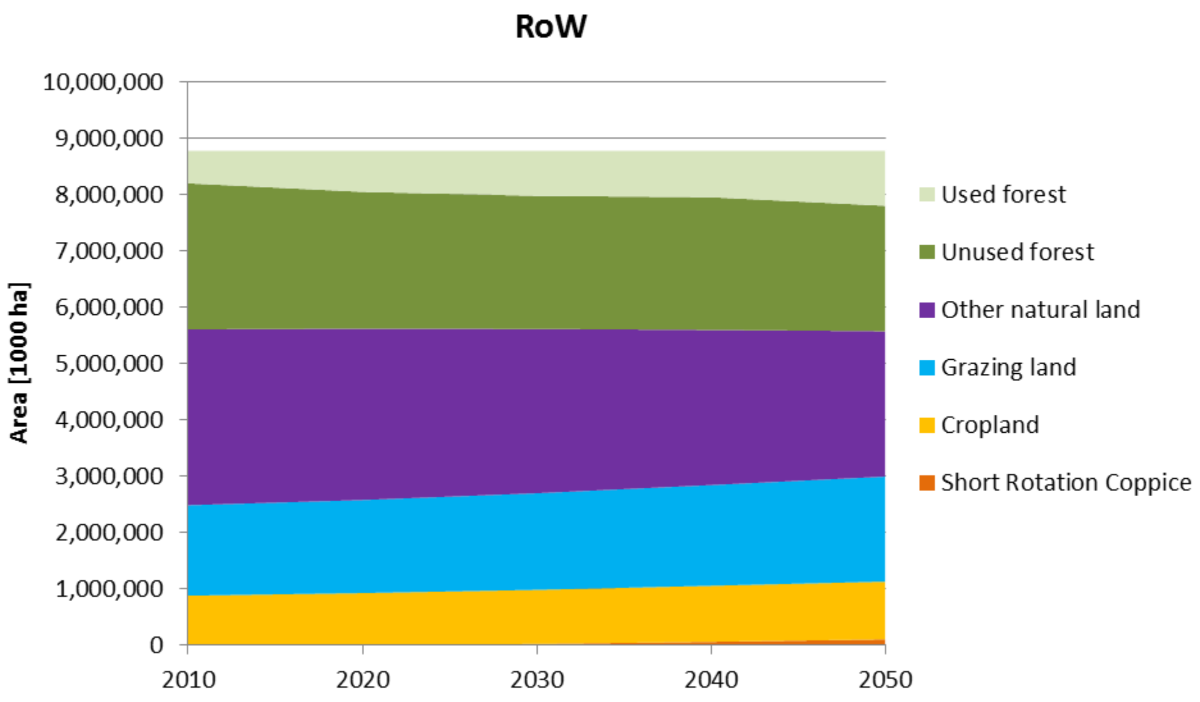


Figure 8: Development of land use under REDU2 in RoW.

Differences between LAND and RWCAP compared to REDU2 are documented in Figure 9. Deviations from REDU2 are similar in their type of change but differ significantly regarding in magnitude. **In EU28** over time the effects get stronger. LAND leads to an increase in used forest area in EU28 of about 2 Mha in 2050 in direct relation to the increasing domestic demand of wood for material and energy purposes. Under RWCAP in 2030 about 0.8 Mha more used forest area is recorded, climbing up to about 4.5 Mha in 2050. In both LAND and RWCAP, used forest area increases at the expense of unused forest area (as a result of forest management intensification). The increase in demand for wood and higher sawlog and pulpwood prices in LAND and RWCAP also leads to an increase of the afforestation rate, however, only a slight increase is observed and a rather small area of new forests is established on other natural land. In 2050 about 0.2 Mha of other natural land is converted to forests compared to REDU2. Grazing land areas decrease because they are converted to cropland, but area turnover for these categories remains below 0.5 Mha.

In RoW, both scenarios let grazing land area and area of other natural land increase by 30 Mha and 12-15 Mha, respectively, relative to REDU2. Also SRC area increases to 3 Mha in 2050. These increases are associated with a decrease in cropland of about 45 Mha in 2050. The implications for existing forests in RoW are not consistent over time for both scenarios. In the medium term (2030) both scenarios tend to leave forest unused compared to REDU2. This trend is reverted in 2050 when slightly more forest is converted from unused to used.

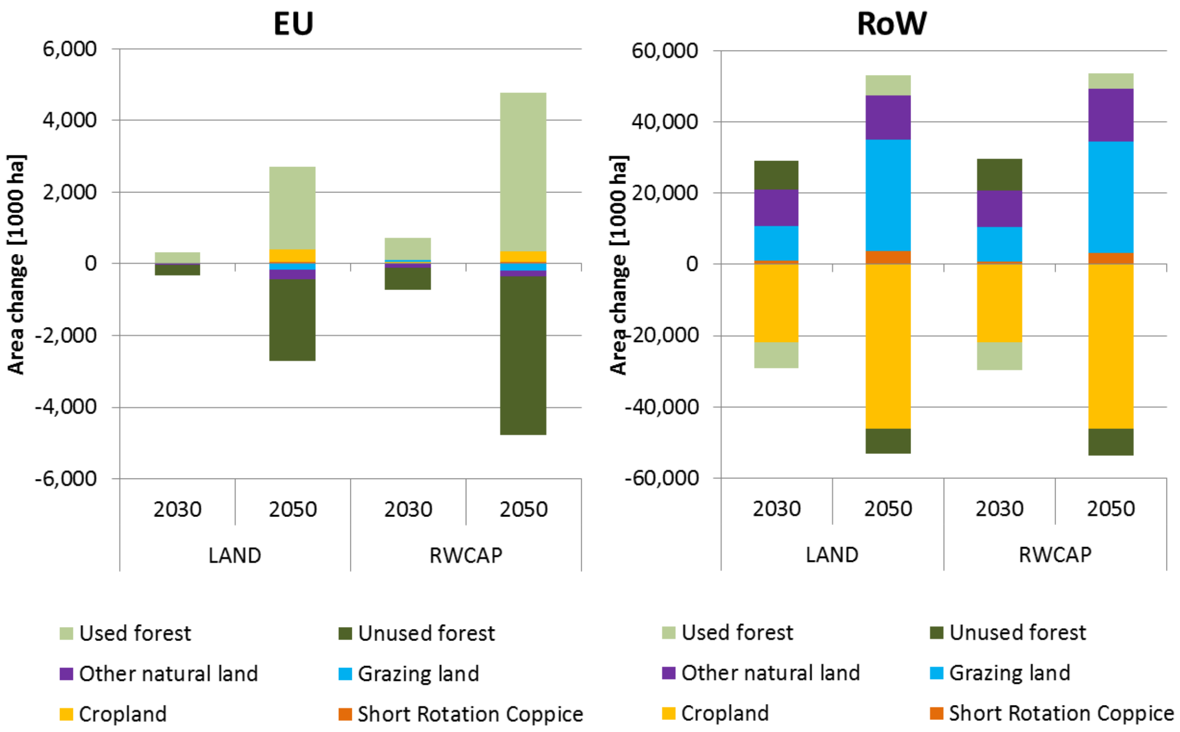


Figure 9: Differences in land use for LAND and RWCAP in comparison to REDU2 for EU28 (left) and RoW (right).

Impacts on biodiversity

Under LAND and RWCAP in EU28 the conversion to cropland from any land use category that is considered of high biodiversity value and/or high carbon stock is not allowed (HBVCS). This is reflected in Figure 12 where annually about 8,000 ha less are converted from other natural land to cropland compared to REDU2. This is the amount of area that is converted under REDU2 (Figure 10).

In RoW differences between the scenarios are more complex. Consistently across LAND and RWCAP more other natural land of high biodiversity is converted to grazing land and less area of that land use and status is converted to cropland. In all cases also the conversion of HBVCS cropland to grazing land is reduced. This is despite the fact that in total grazing land area is increasing (see Figure 9).

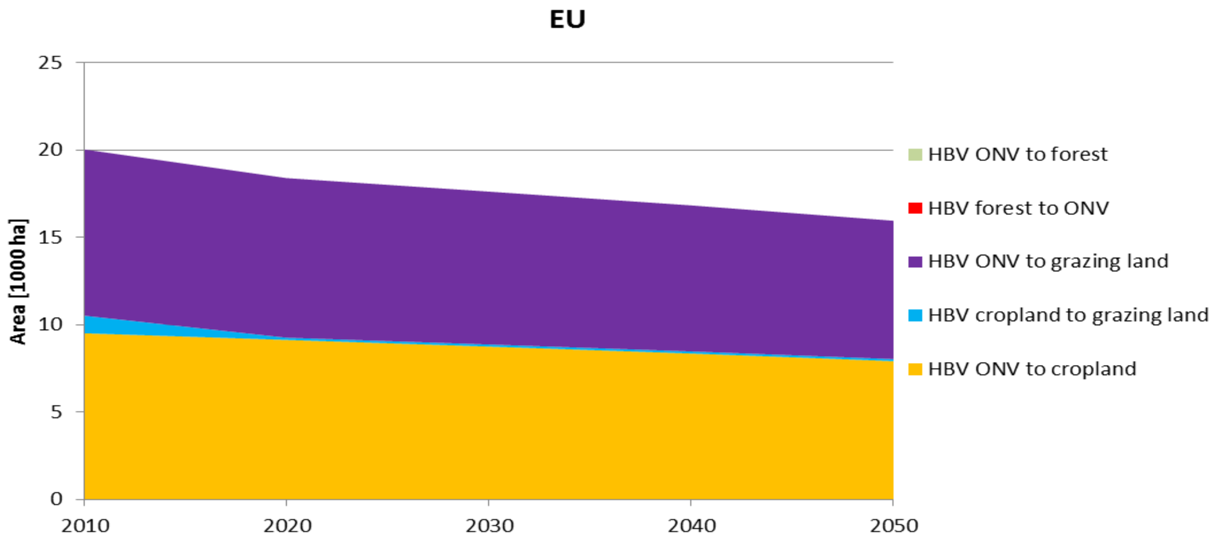


Figure 10: Development of area of HBVCS areas converted in REDU2 scenario in for EU28 for different land use categories.

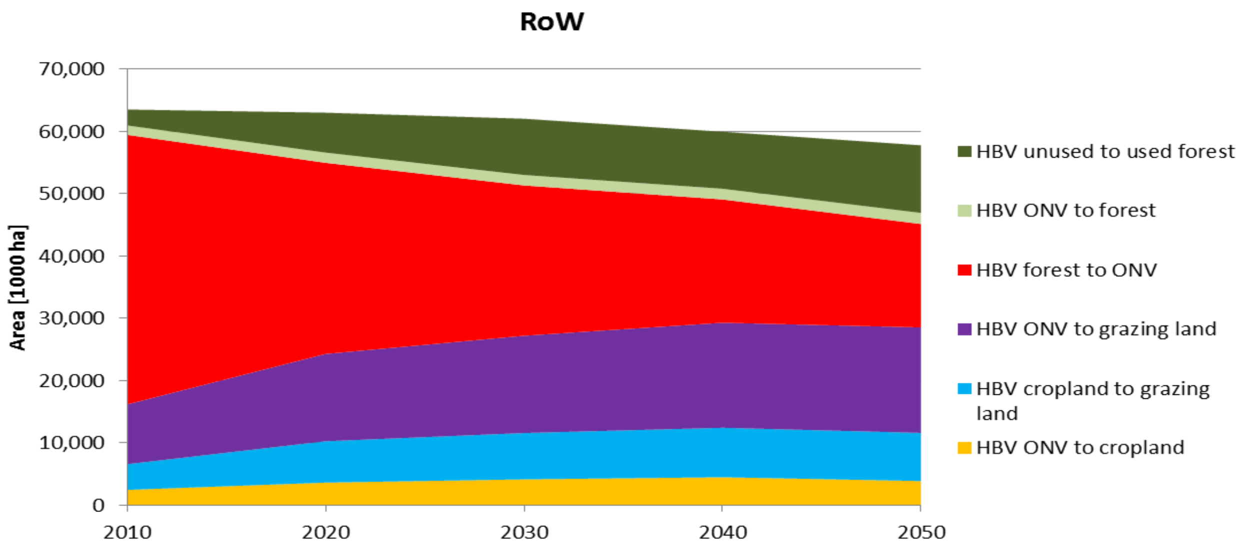


Figure 11: Development of area of HBVCS areas converted in REDU2 scenario in for RoW for different land use categories.

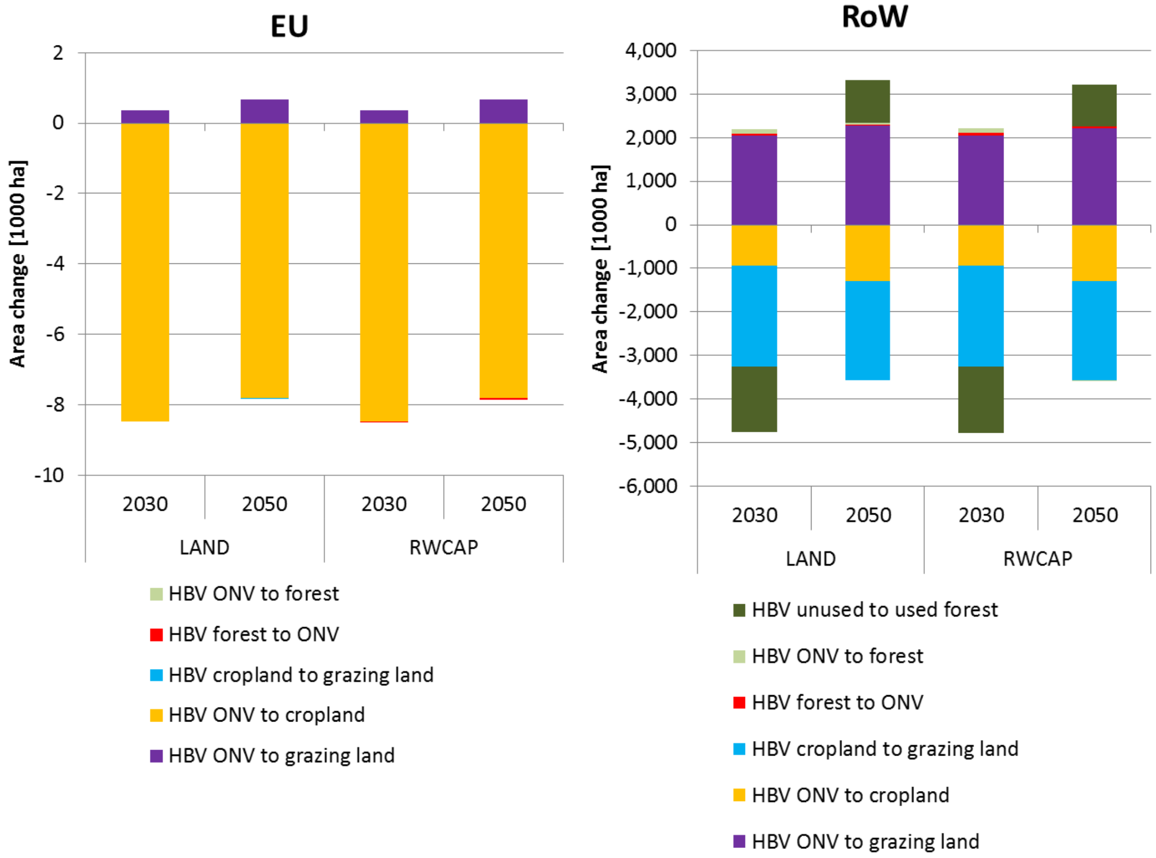


Figure 12: Differences in HBVCS areas converted for LAND and RWCAP in comparison to REDU2 for EU28 (left) and RoW (right).

Impacts on land use GHG emissions

Under REDU2, the LULUCF sector forms an increasing net sink in EU28 (Figure 13). Deforestation emissions are constantly decreasing from currently about 50 Mt to 12 Mt CO_2 in 2050, harvested wood products and afforestation are increasing sinks amounting to 50 and 130 Mt CO_2, respectively. Existing forests in EU28 (forest management) continue to be a net sink for CO_2, however, the sink will decline significantly from currently more than 200 Mt CO_2 to about 50 Mt CO_2 in 2050. The decrease of the forest management sink is both driven by an increase in the harvest of wood within the EU (see Figure 4 on p. 23) for material and energy purposes, as well as the decrease of the forest increment driven by the aging of the EU forests. This development is in-line with earlier projections of the EU forest management sink development[8,13]. It should be noted that the forest management sink is increasing when the forest increment (the accumulation of carbon in forest through tree growth) is higher than the harvest rate. Also, as forests grow older, generally, the rate of increment reduces. While other land use changes remain stable of the simulation period, cropland emissions change from a net source in 2010 to a net sink in 2040 and 2050, which is closely related to the expansion of SRC on cropland (see Figure 7).

The LULUCF emissions in the EU28 for REDU2 are found to be of similar magnitude as that of the REDU scenario for the ReceBio project. Emissions from deforestation within the EU were roughly 13 Mt CO_2 in the REDU scenario for 2050 as compared to 12 Mt CO_2

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13 Böttcher, H. et al. Projection of the future EU forest CO2 sink as affected by recent bioenergy policies using two advanced forest management models GCB Bioenergy (2012) 4, 773–783, doi: 10.1111/j.1757-1707.2011.01152.

in REDU2. However, the decrease in deforestation emissions from the 2010 are faster in REDU2 than for the REDU scenario, driven particularly by the weaker increase in land use prices during 2020 and 2030. The REDU2 development of the harvested wood product pool is until 2030 similar to the REDU scenario, however, the sink increases faster from 2030 onwards in the REDU scenario driven in partly by the higher consumption of plywood products. The trend of the decline of the forest management sink is consistent in both scenarios with a resulting sink of about 40 Mt CO_2 in 2050 in the REDU scenario as compared to about 50 Mt CO_2 in 2050 for REDU2. That the decline of the forest management sink is stronger in the REDU scenario is consistent with the higher forest harvest level (roughly 720 Mm^3 in the REDU scenario and 660 Mm^3 in REDU2), driven partly by slower development of the SRC in the REDU scenario than in REDU2.

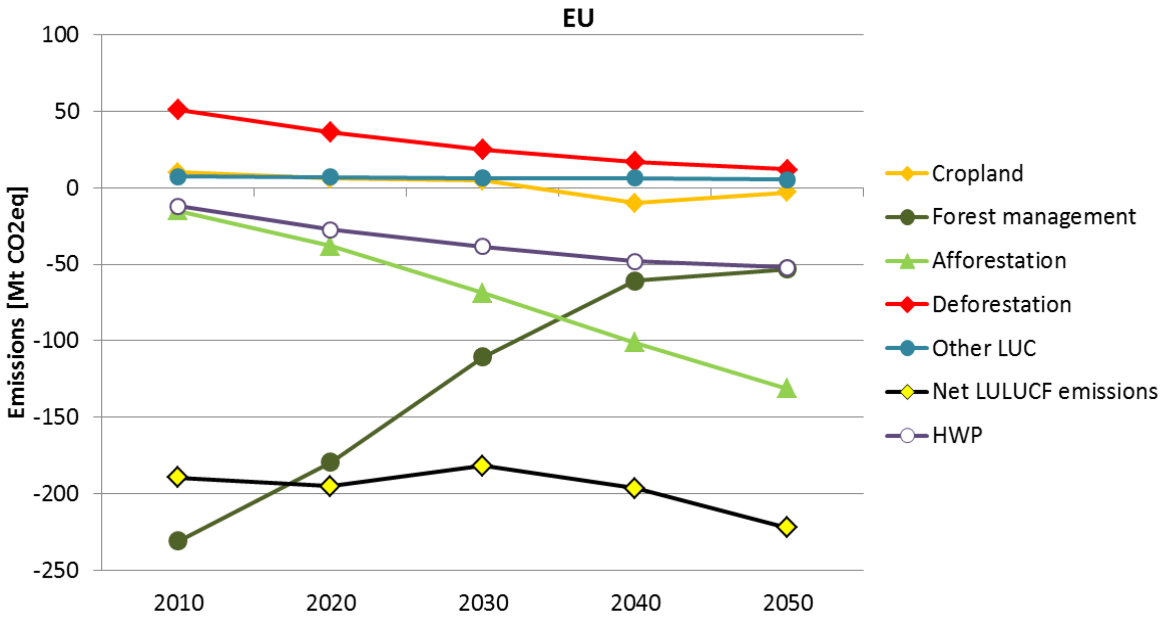


Figure 13: Development of LULUCF emissions under REDU2 in EU28.

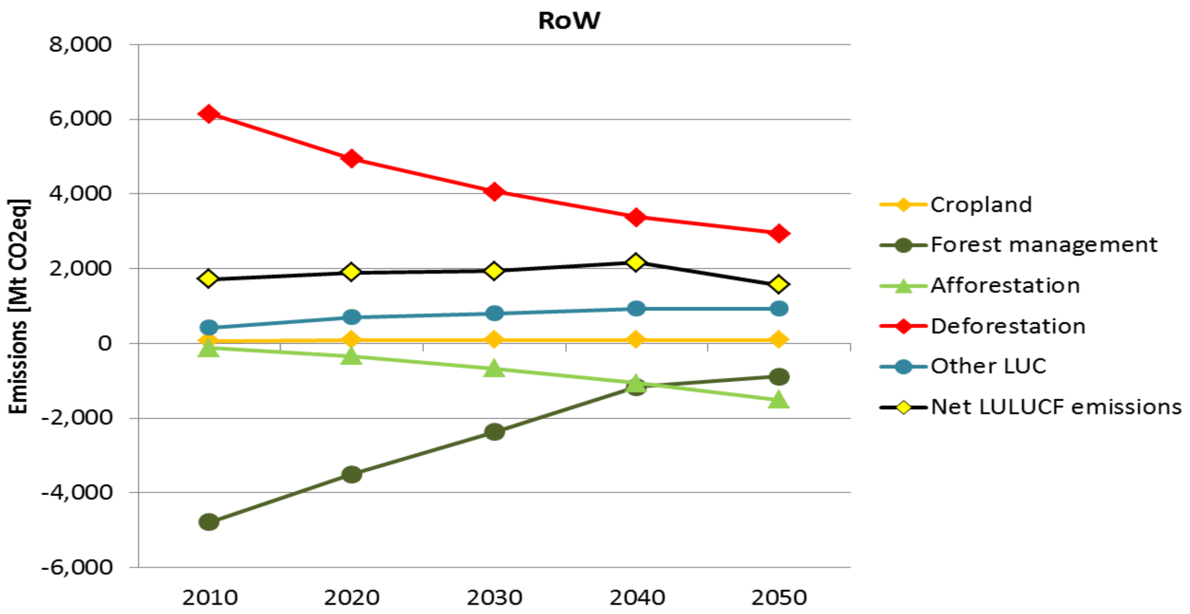


Figure 14: Development of LULUCF emissions under REDU2 in RoW.

Also RoW faces a decreasing sink in the existing forests (Figure 14). The absorption of CO_2 through forest management will be less than a quarter of the rate in 2050 (900 Mt) of what it was in 2010 (4,800 Mt). An only moderate increase in afforestation removals and only slowly decreasing deforestation emissions (from 6 Gt in 2010 to3 Gt in 2050) let net LULUCF emissions stabilize at about 2 Gt CO_2.

Figure 15 describes differences in LULUCF emissions between LAND and RWCAP compared to REDU2. In the long run, for EU28 both scenarios slightly increase net GHG emissions from LULUCF compared to REDU2. This net balance is dominated by the reduction of the forest management sink (showing up as relatively higher emissions) and an increased storage of carbon in wood products. The sink strength of forest management is reduced in all scenarios and at all time compared to REDU2, more strongly in 2050 than in 2030 and more strongly in RWCAP than LAND. This reflects the intensified domestic harvest of wood to compensate for reduced import potentials from abroad (see Figure 4). Since the harvested material is used mostly for additional wood products there is a build-up of the HWP carbon stock. However, due to losses during harvest and along the processing chain, parts of the additionally harvested carbon are released to the atmosphere. This development is in line with other studies assessing the EU forest management sink development vs. the HWP sink development of mitigation strategies[14]. Effects on afforestation removals and deforestation emissions are negligible as the change in wood prices between the LAND and RWCAP scenarios compared to REDU2 are of the same magnitude as the change in land prices. That the land prices are reacting strongly to the relatively small change in land use between LAND and RWCAP compared to REDU2 (see Figure 9), is connected to the strong increase in SRC during 2040 and 2050 already in REDU2. When comparing the results of the LAND and RWCAP scenario to REDU2, it should be noted that the land use constraints affect all uses of forests. If the constraint would only be put on the wood used for energy purposes, the impacts on EU LULUCF emissions could be expected to have been somewhat closer to those in REDU2.

It should be kept in mind that additional mitigations related to material substitution effects are not considered within this study. As both LAND and RWCAP lead to an increase in the EU consumption of wood products (see Figure 5), additional reduction of GHG emissions from material substitution could be expected in LAND and even more so in RWCAP compared to REDU2.

14 Rüter S, Werner F, Forsell N, Prins C, Vial E, Levet A-L (2016) ClimWood2030, Climate benefits of material substitution by forest biomass and harvested wood products: Perspective 2030 – Final Report. Braunschweig: Johann Heinrich von Thünen-Institut, 141 p,

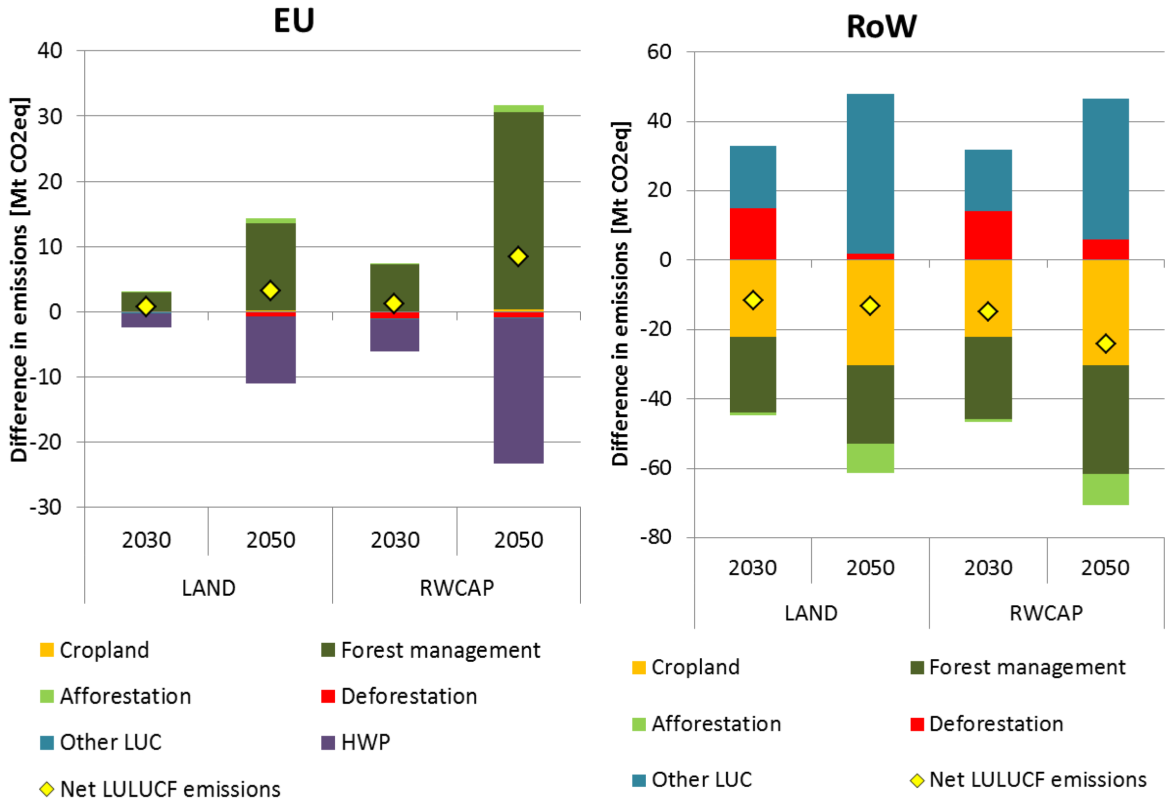


Figure 15: Differences in LULUCF emissions for LAND and RWCAP in comparison to REDU2 for EU28 (left) and RoW (right).

In RoW, net LULUCF emissions show a reduction of about 10-20 Mt CO_2 throughout the scenarios and time slices, larger in RWCAP in 2050. This is due to reduced cropland emissions but also net forest management emissions are reduced (the sink increased) as the production of pellets made out of roundwood decreases (see Figure 2 on p. 21). These improvements on the sink strength that amount together 40-60 Mt CO_2 are partly compensated by increased emissions from deforestation (up to 17 Mt CO_2) and other and use change emissions (up to 45 Mt CO_2).

When combined with emissions of non-CO_2 GHGs from agriculture (Figure 16) EU28 and RoW show two contrasting pictures. The net LULUCF emissions observed under both scenarios in EU28 are associated with increased emissions from agriculture. However, agriculture emissions do not dominate and do not change the overall magnitude or sign. In contrast, in RoW emission reductions in agriculture in the two scenarios are dominating. About 170 Mt CO_2 less are emitted in RoW under LAND and RWCAP in 2050. This is about ten times the emission reductions expected from LULUCF in the two scenarios compared to REDU2 related to a reduction in the production of certain food and feed commodities, in particular the production of bovine and poultry meat.

Globally, net emission savings for LAND and RWCAP compared to REDU2 can be observed for both sectors. Figure 17 presents differences between the three scenarios for the sum of EU and RoW countries. In both sectors RoW GHG implications dominate. This is why net emissions from LULUCF in EU28 are more than compensated by RoW removals, summing up to net emission reductions of 10 Mt CO_2 for LAND and 15 Mt CO_2 for RWCAP compared to REDU2 in 2050. In addition there are strong reductions in emissions in the livestock sector, not directly related to the bioenergy options described in the scenarios but through indirect effects caused by the environmental policy constraints applied in LAND and RWCAP.

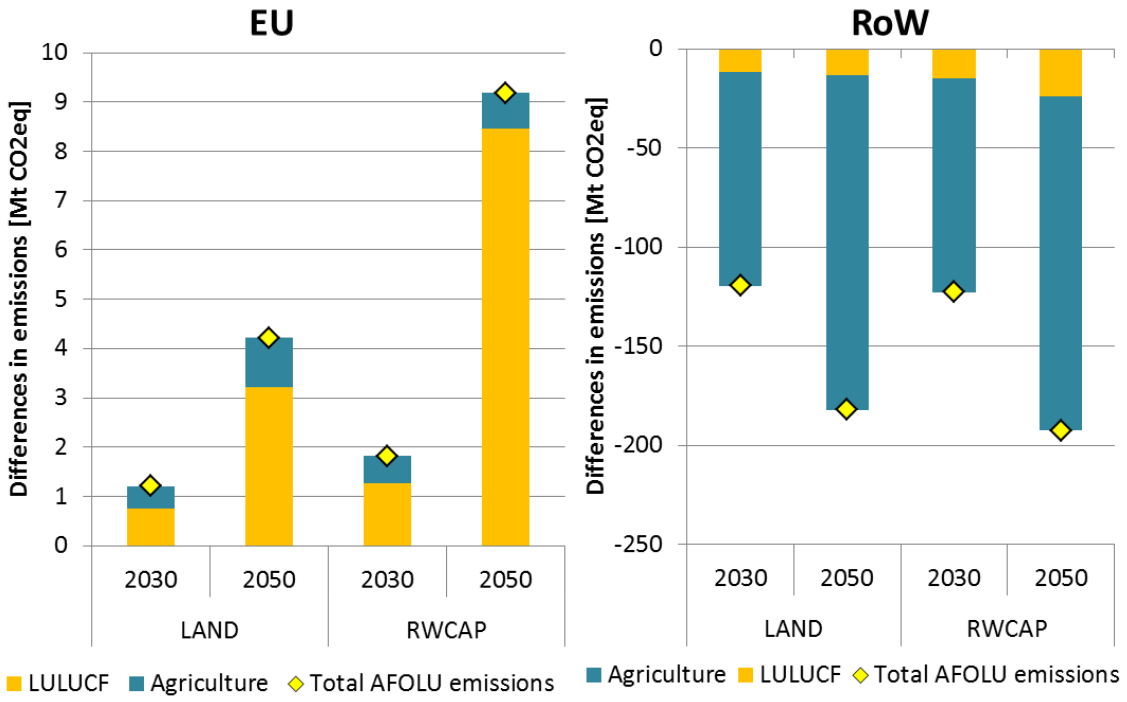


Figure 16: Differences in total LULUCF and Agriculture emissions for LAND and RWCAP in comparison to REDU2 for EU28 (left) and RoW (right).

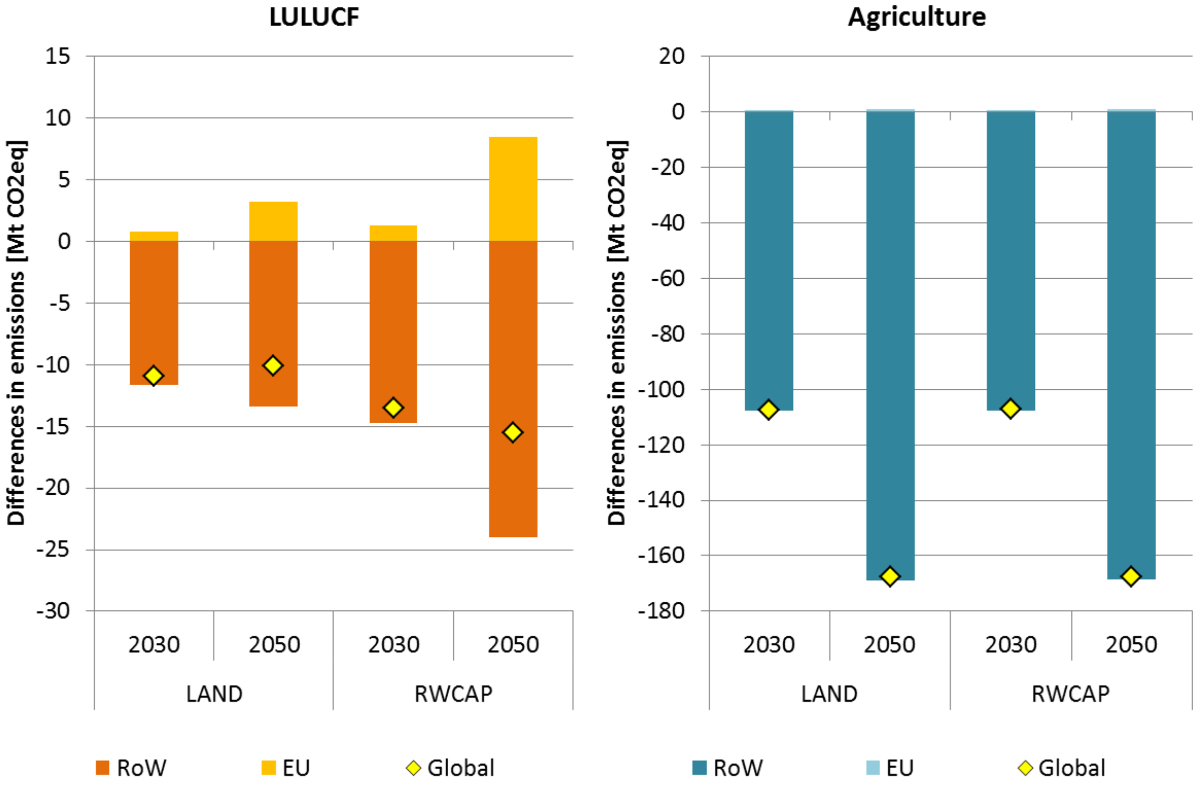


Figure 17: Differences in global LULUCF (left) and Agriculture (right) net emissions for LAND and RWCAP in comparison to REDU2.

6. RESULTS CONCERNING SENSITIVITY ANALYSES

A number of sensitivity analyses have been performed for the various policy scenarios described above. The underlying assumptions and key outcomes of these sensitivity analyses will be described here while supporting figures of the key outcome of the sensitivity analysis can be found in Annex I - Outcome of sensitivity analysis.

Sensitivity analyses for REDU2

Key assumptions

A sensitivity analysis was performed for this scenario focusing on the use of roundwood for wood pellets production in RoW countries. As both the current and future use of roundwood for pellets production are uncertain in a number of RoW countries, the aim of this sensitivity analysis is to assess the impact of a wide range of possible future shares of roundwood for pellets production. Two versions of this sensitivity analysis are analyzed:

REDU2a: *<u>Key assumption</u>: The share of roundwood being used for wood pellets is decreased to 50%, compared to 75% in REDU2.*

REDU2b: *<u>Key assumption</u>: The share of roundwood being used for wood pellets is increased to 100%, compared to 75% in REDU2.*

Key outcomes

An assumed decrease in the use of roundwood for production of pellets in the RoW (REDU2a) is expected to lead to a 9% increase in EU pellets imports in 2030, and a 28% increase by 2050, compared to REDU2 (Figure 18). The increase in import of wood pellets to the EU is due to an increased future competitiveness of using SRC for wood pellets production in regions with high SRC potentials and low production costs (e.g. Latin America, Sub-Saharan Africa) instead of using roundwood for pellets production. As the potential share of using SRC is increased, pellets production in regions with high SRC potentials becomes more cost competitive and decreases the global cost of pellet imports to the EU. As an effect of increasing pellets import to the EU, the use of domestic roundwood for energy decreases by 14% by 2030, and 37% by 2050. The increased pellet imports substitute also industrial by-products for energy use, albeit compared to the total use of this feedstock for energy, the effect of the change in pellet assumptions has only a marginal effect on the use of industrial by-products to energy (-2% by 2030 and -8% by 2050). The decreased demand for by-products on the energy sector discourages the material use of sawlogs somewhat, although the changes in the material sector are in general relatively low.

When the share of roundwood used for pellet production is instead increased to 100% (REDU2b), the effects are the opposite: production of pellets becomes more expensive and hence the import of wood pellets to the EU become less cost-competitive with domestic feedstocks (Figure 18). As a result, EU pellet imports decrease by 10% in 2030, and by 18% in 2050. More roundwood will instead be combusted directly for bioenergy production already by 2030 (17% increase compared to REDU2), and, especially by 2050, also the amount of by-products for energy increases (+5% compared to REDU2).

Changes in the share of roundwood used for pellets have also implications for land use (Figure 19) and GHG emissions from land use (Figure 20 and Figure 21) in EU and RoW. A decrease in the share of roundwood used for pellets reduces the intensity of forestry in EU but has limited impact on other land uses. A decrease of the share of roundwood used for pellets from 75% to 50% leaves almost 2 Mha of forest unused in EU in 2050. An increase from 75% to 100%, instead, increases the area of used forest in the EU by 1 Mha in 2050. Similar effects can be reported for RoW.

These land use changes have implications for GHG emissions from land use. However, Figure 20 shows that in EU net emission changes are rather small. This is due to opposing effects on the forest carbon sink (forest management) and carbon stored in harvested wood products. A decrease in roundwood share for pellets increases the forest sink (reduced emissions) but also decreases the sink in HWP of a similar magnitude in 2050. An increase in the share of roundwood in pellets, however, results in a net emission increase because the negative impact on the sink is slightly stronger than the positive effect on HWP. There are limited impacts of changes in the share of roundwood used for pellets also for deforestation emissions in EU and RoW. This is due to changes in the economic valuation of forests. If the share of roundwood for pellets is lowered, existing forests in EU are less utilized, leading to a lower value of forests. This in turn leads to slightly more conversion of forests to other land uses (agriculture) as they get relatively more competitive in terms of value for a land owner. The same applies to RoW, where at least for 2050 a similar behavior can be observed: the reduction in roundwood share for pellets takes pressure from forests leading to decreased emissions from forest management (an increased sink) but increased emissions from deforestation. In contrary to this, it is observed that in 2030 the reduction of roundwood used for pellets causes a decrease of deforestation emissions in RoW for REDU2a, instead of an increase as of 2050. The reason for this is that as of 2030, the harvest of wood within the Sub-Saharan Africa region increases in REDU2a as compared to REDU2, as the increase in pellets production is larger than the offsetting of roundwood related to the change in share of roundwood for pellets. This leads to an increased value of the forests and a reduction of deforestation. However, by 2050, the harvest of wood within the Sub-Saharan Africa region is decreased as the increase is pellets production is smaller than the offsetting of roundwood related to the change in the share of roundwood use.

Total LULUCF emissions for EU presented in Figure 21 show the net results. The net balance depends on the size of the opposing trends. As discussed above, in RoW both alternative Scenarios REDU2a and REDU2b lead to reduced emissions in the long run through an increased forest sink and despite increased deforestation emissions in case of REDU2a, and a reduced forest sink but also reduced deforestation emissions in case of REDU2b.

Sensitivity analyses for LAND

Key assumptions

Three different types of sensitivity analysis were performed for this scenario: one sensitivity analysis focusing on EU assumptions, and two sets of analyses focusing on assumptions concerning the RoW.

Sensitivity analysis focusing on the EU28 (LANDa)

This sensitivity analysis focuses on the assumptions concerning the restriction of collection of feedstock from HBVCS forest areas within the EU. It should be noted that, in the model, the wood that is harvested from an HBVCS area is assumed to be available for both material and energy purposes as the downstream use of the wood from these geographical areas currently cannot be constrained within the model framework being applied.

The constraint put on LAND in the model impedes the harvest of wood from HBVCS within EU for all purposes, while the actual policy scenario would only forbid harvests directed to energy uses; modeling results for LAND are therefore too strong and do not fully reflect the aim of the policy scenario.

The sensitivity aims at correcting this limitation, by testing the impact of an increased potential to harvest woody biomass from HBVCS areas. The share of available woody biomass feedstocks that is allowed to be harvested is specified for each MS according to the 2010 share of wood biomass being harvested for material purposes over the total amount of wood being harvested (based on EUROSTAT). For the RoW, the same assumptions as in LAND apply to HBVCS areas.

Sensitivity analysis focusing on the RoW (LANDb to LANDg)

This sensitivity analysis focuses on the assumptions concerning trade of wood from the RoW to EU. The constraint put on LAND for the RoW impedes land use conversion but not the harvest of wood from HBVCS areas, this while the actual policy scenario would forbid harvests to energy uses from HBVCS areas. Projected trade of wood from the RoW to EU for LAND could thereby be overestimated as a share of the wood that is traded between RoW and EU could have been sourced in HBVCS areas would no longer be available – or only available at a higher price.

The aim of this sensitivity analysis is to assess this shortcoming by analyzing the impacts of a reduced trade of wood from RoW to the EU. As the constraint on HBVCS areas could both impact the trade of roundwood as well as processed woody commodities used for energy purposes, two sets of sensitivity analysis have been performed, one set focusing on the trade of roundwood (LANDb-d), and one set focusing on the trade of pellets (LANDe-g).

Opposed to the sensitivity analysis for REDU2, this sensitivity analysis for LAND does not focus on how the pellets are being produced, but on the total amount of trade. For this analysis, the trade of wood pellets or the trade of roundwood from the RoW to the EU is reduced by a fixed exogenously defined amount, while all other trade flows are still endogenously estimated by the model. A total of six versions of this sensitivity analysis are analyzed:

LANDb: *Key Assumption: Trade of wood pellets from the RoW to the EU28 is reduced by 5%, compared to levels in LAND.*

LANDc: *Key Assumption: Trade of wood pellets from the RoW to the EU28 is reduced by 10%, compared to levels in LAND.*

LANDd: *Key Assumption: Trade of wood pellets from the RoW to the EU28 is reduced by 20%, compared to levels in LAND.*

LANDe: *Key Assumption: Trade of roundwood from the RoW to the EU28 is reduced by 5%, compared to levels in LAND.*

LANDf: *Key Assumption: Trade of roundwood from the RoW to the EU28 is reduced by 10%, compared to levels in LAND.*

LANDg: *Key Assumption: Trade of roundwood from the RoW to the EU28 is reduced by 20%, compared to levels in LAND.*

Key outcomes

The results show that allowing, in the EU, for a collection of a share of the woody biomass available at HBVCS areas for markets instead of a total restriction (LANDa) has virtually no impacts on the use of biomass for material and energy purposes (Figure 22). That is, at least half of all HBVCS will not be economically profitable to harvest even in the presence of a more lenient constraint.

LANDb-d show almost a linear trend in the changes for energy and material of wood: if EU pellet imports were reduced, the EU domestic harvest of wood increases as the bioenergy demand would instead be fulfilled roughly half-and-half through roundwood combusted directly for energy and forest industry by-products (Figure 22). Comparing to the total amount of each feedstock used, however, the changes are more notable: as the total amount of roundwood combusted directly for energy is much smaller than the use of industrial by-products, a similar volume increase in roundwood directly combusted for energy represents an increase of up to 32% (year 2030 in LANDd), while an increase of a similar magnitude in industrial by-products is only about 4% increase to the total amount used for energy. As a general trend, we see similar development of the feedstocks as in the sensitivity analyses for REDU2: the direct combustion of roundwood for energy responds faster to the changes in the bioenergy feedstocks, but in the longer term, other feedstocks (here, industrial by-products) will increase their share of the total biomass used for energy production.

In the sensitivity analyses for LANDe-g, the amount of EU imports of roundwood were restricted. This affects first and foremost the sawnwood industry, as it is the larger user of imported roundwood in the EU (Figure 22). As a consequence of the restriction, sawlog use for material production decreases, reducing the amount of industrial by-products available to be used for energy production, and as a consequence, increases the import of pellets. However, in total terms the impacts are quite small, as the volumes of EU roundwood imports are relatively small compared to the total wood use within the region.

All trade sensitivities have implications for land use in EU and RoW and almost all variants calculated by the model lead to an increase in forest management intensity in EU and therefore a shift from unused to used forest (Figure 23). These changes are of different magnitude. In general, it can be observed that constraints on trade of wood pellets have a stronger impact on forest management intensity than trade of roundwood. This as the percentage reduction of the import of wood pellets leads to a stronger increase in the domestic EU forest harvest level than the reduction of import of roundwood. Furthermore, it can be observed that stronger constraints on trade result in stronger increase of forest management intensity. An example are LANDc and d, where net pellet imports to EU28 are reduced by 10% and 20%, respectively, resulting in 0.35 Mha and 0.9 Mha increase of used forest at the expense of unused forest in 2050. But there are non-linear effects, as it can be noticed the LANDb with a 5% reduction in trade has a stronger effect than LANDc with a 10% reduction in trade. However, it should be noticed that the 0.16 Mha difference in used forest between LANDb and LANDc only amounts to a 0.12% change in the EU total forest area.

For RoW a less consistent pattern can be observed. Striking is LANDb, a reduction of net pellet imports by 5%, that leads to an increase in grazing land in RoW. Almost all scenarios lead to increases in other natural land at the expense of forests. This is because reduced EU imports of both pellets and roundwood lower the value of forests outside EU, leading to an increased reduction in forest area in the RoW, due to relatively more competitive agriculture options for land owners. This becomes more evident when looking at LULUCF emissions in detail (Figure 24) or at an aggregate level and in comparison to agriculture (Figure 25). For almost all variants of LAND, deforestation emissions increase in RoW. The same applies to other land use changes. Overall, in the long run, net LULUCF emissions are higher compared to LAND. This is even true for variants e, f, g that foresees a decrease in EU imports. There is a change in the net balance over time for these three scenarios: in 2030, a net reduction can be achieved before net emission changes are increased in 2050. This patter is mirrored by net emissions from LULUCF in EU: in 2030, net emissions increase as imports are reduced and more domestic biomass resources are used, while in 2050 net emissions are lower than the reference.

Sensitivity analyses for RWCAP

Key assumptions

A sensitivity analysis has been performed for this scenario focusing on the share of roundwood used for wood pellets production in RoW countries. As the REDU2a and REDU2b, the aim of this sensitivity analysis is to assess the impact of a changes in the future shares of roundwood for pellets production. Two versions of this sensitivity analysis are presented:

RWCAPa: *<u>Key assumption</u>: The share of roundwood being used for wood pellets is decreased to 50%, compared to 75% in RWCAP.*

RWCAPb: *<u>Key assumption</u>: The share of roundwood being used for wood pellets is increased to 100%, compared to 75% in RWCAP.*

Key outcomes

An assumed decrease in the use of roundwood for production of pellets in the RoW (RWCAPa) is expected to lead to an 11% increase in EU pellets imports by 2030 and 2050, compared to RWCAP (Figure 26). This is the same trend as seen in REDU2a, that a reduction in the use of roundwood for pellets production in RoW leads to an increased import of wood pellets to the EU. The reason for this outcome is twofold. Firstly, a decrease in the share of roundwood being used for pellets production directly implies that the EU cap on the use of roundwood can be fulfilled with a higher quantity of imported wood pellet as one unit of imported wood pellets is now associated with a lower unit of roundwood in the cap. Secondly, a decrease in the share of roundwood use for pellets production decreases the global cost of wood pellets imports to the EU as more SRC can be used for the pellets production. That no difference is seen between the energy use of wood in 2030 and 2050 is due to the fact that the cap is expected to be fulfilled fully through imported pellets already in RWCAP (see Figure 3 on p. 22). The effect of the change in pellet assumptions has only a marginal effect on the use of industrial by-products for energy (-3% by 2030 and 2050 compared to RWCAP). The decreased demand for by-products in the energy sector somewhat discourages the material use of sawlogs and pulpwood as well as the total EU harvest level of wood, although the changes in the material sector are in general relatively low. That the decrease in sawlogs in 2050 is larger than in 2030 relates to a reduction in the export of sawnwood. The decreased export of sawnwood relates to the reduced use of industrial by-products for energy, which reduced the profitability of sawmills.

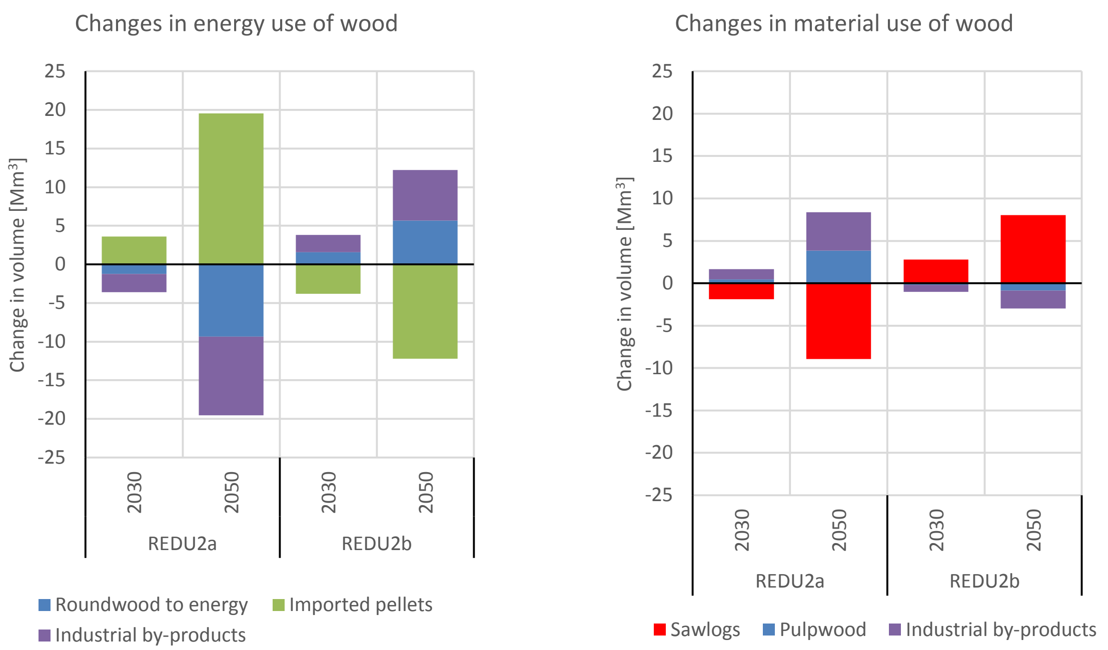
When the share of roundwood used for pellet production is instead increased to 100% (RWCAPb), the effects are the opposite: imports of wood pellets to the EU are decreased as 1 unit of imported wood pellets is now associated with a higher unit of roundwood in the cap on the total roundwood use for bioenergy (Figure 26). As a results, EU pellet imports decrease by 6% in 2030 and 2050. More by-products will instead be used for bioenergy production (1% increase compared to RWCAP) and the overall EU forest harvest level is slightly increased as compared to RWCAP.

Changes in the share of roundwood for pellet production in RoW affect land use in EU and RoW (Figure 27), and LULUCF emissions (Figure 28 and Figure 29). A reduction of this share to 50% (RWCAPa) leaves more forest unused in EU of about 0.25 Mha, but also leads to increased deforestation. This is because, similarly to the sensitivity runs on REDU2 above, the economic valuation of the forest is changed. As the EU forest harvest level decreased, the value of forests decreases slightly, leading to more forests being converted to other land uses. RWCAPb on the contrary leads to smaller change in harvest level as compared to RWCAPa. The relative small increase in forest harvest leads to small displacement in harvests between countries which results in an overall decrease in the economic value of the forest. The effects on deforestation emissions are stronger in the short run for EU where the deforestation rate in the reference scenario is dropping rather quickly. In RoW the effect becomes stronger from 2030 to 2050 and both scenarios leads to a reduction in the deforestation emissions as of 2050. The reduction in the share of roundwood for pellets production leads to a slightly overall increased forest harvest in within RoW regions with where wood is the dominating feedstock for pellets production instead of SRC (e.g. USA, Canada) and the change in pellet production leads to an increasing demand of industrial by-products. This increase in forest harvest leads to decreased deforestation rate in RoW by 2050 for RWCAPa as compared to RWCAP.

Regarding GHG emissions, only RWCAPa achieves emission reductions in 2050 and only in EU. This is due to an increased forest sink as domestic production shrinks while imports are increased.

ANNEX I – SUPPORTING FIGURES FOR THE SENSITIVITY ANALYSIS

REDU2



%-CHANGE TO REDU2		ENERGY USE OF WOOD			MATERIAL USE OF WOOD		
		Rw to energy	Imported pellets	By-products	Sawlogs	Pulpwood	By-products
REDU2a	2030	-14%	9%	-2%	-1%	0%	1%
	2050	-37%	28%	-8%	-2%	2%	4%
REDU2b	2030	17%	-10%	2%	1%	0%	-1%
	2050	23%	-18%	5%	2%	0%	-2%

Figure 18. Changes in the energy and material use of wood in REDU2a and REDU2b, compared to REDU2.

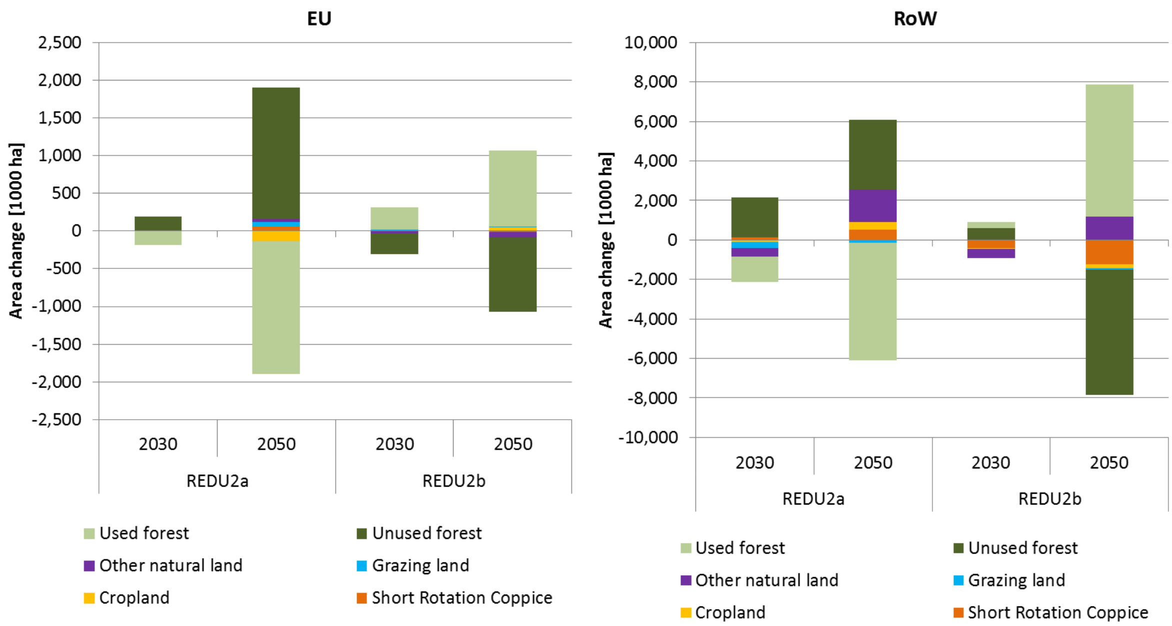


Figure 19: Changes in land use in EU (left) and RoW (right) in REDU2a and REDU2b, compared to REDU2.

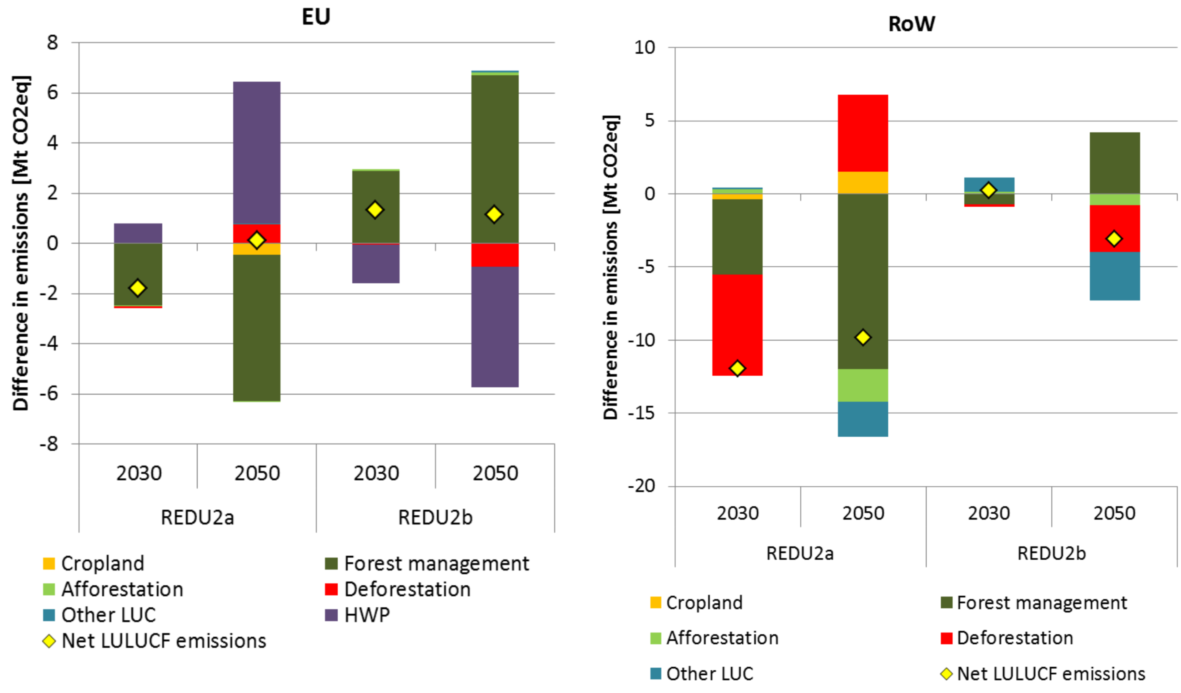


Figure 20: Changes in LULUCF emissions in EU (left) and RoW (right) in REDU2a and REDU2b, compared to REDU2.

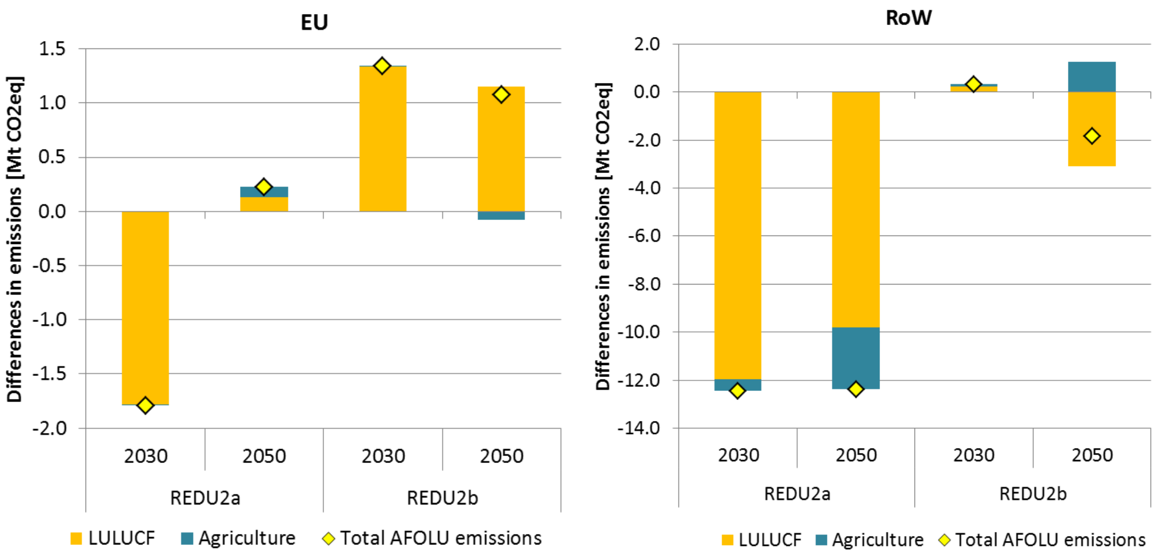
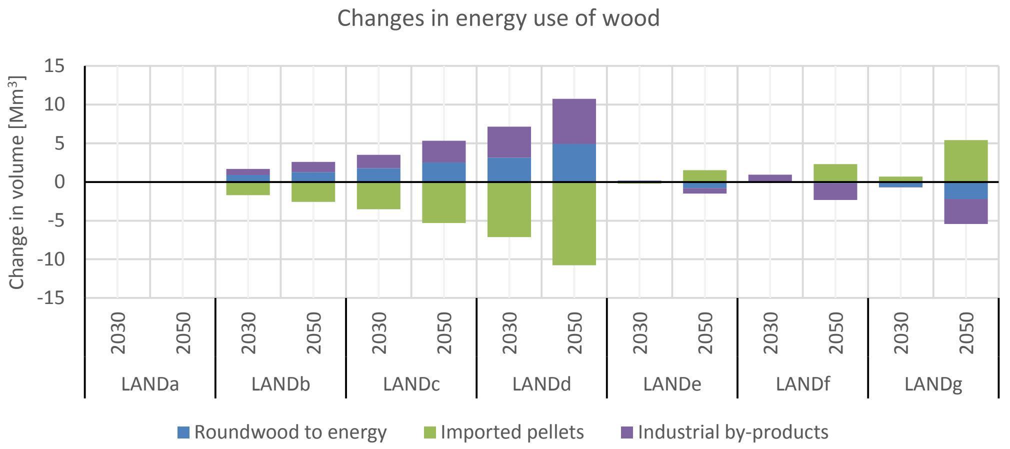
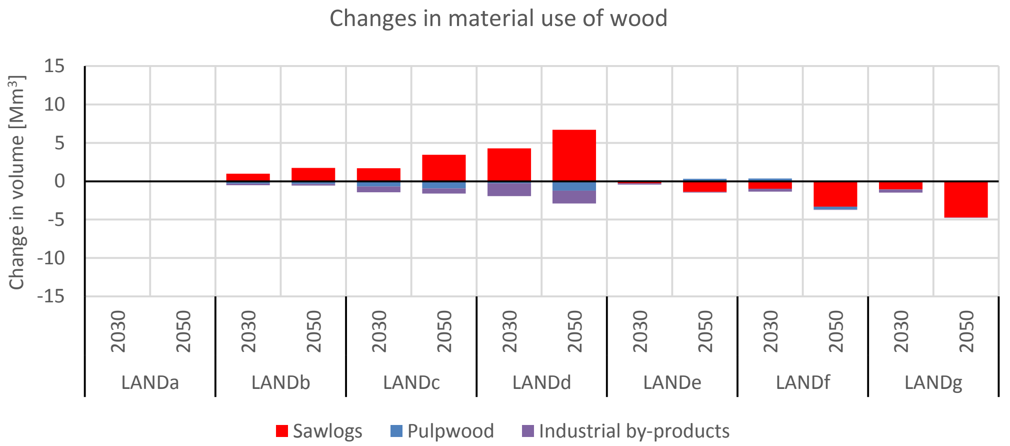


Figure 21: Changes in total net LULUCF and agriculture emissions in EU (left) and RoW (right) in REDU2a and REDU2b, compared to REDU2.

LAND





%-CHANGE TO LAND		**ENERGY USE OF WOOD**			**MATERIAL USE OF WOOD**		
		Rw to energy	Imported pellets	By-products	Sawlogs	Pulpwood	By-products
LANDa	**2030**	0%	0%	0%	0%	0%	0%
	2050	0%	0%	0%	0%	0%	0%
LANDb	**2030**	9%	-5%	1%	0%	0%	0%
	2050	4%	-5%	1%	1%	0%	0%
LANDc	**2030**	18%	-10%	2%	1%	0%	-1%
	2050	8%	-10%	2%	1%	-1%	-1%
LANDd	**2030**	32%	-20%	4%	2%	0%	-2%
	2050	16%	-20%	4%	2%	-1%	-2%
LANDe	**2030**	2%	-1%	0%	0%	0%	0%
	2050	-3%	3%	-1%	0%	0%	0%
LANDf	**2030**	1%	0%	1%	0%	0%	0%
	2050	-1%	4%	-2%	-1%	0%	0%
LANDg	**2030**	-7%	2%	0%	0%	0%	0%
	2050	-7%	10%	-2%	-1%	0%	0%

Figure 22. Changes in energy and material use of wood resulting from the sensitivity analyses on LAND, using LAND as the reference.

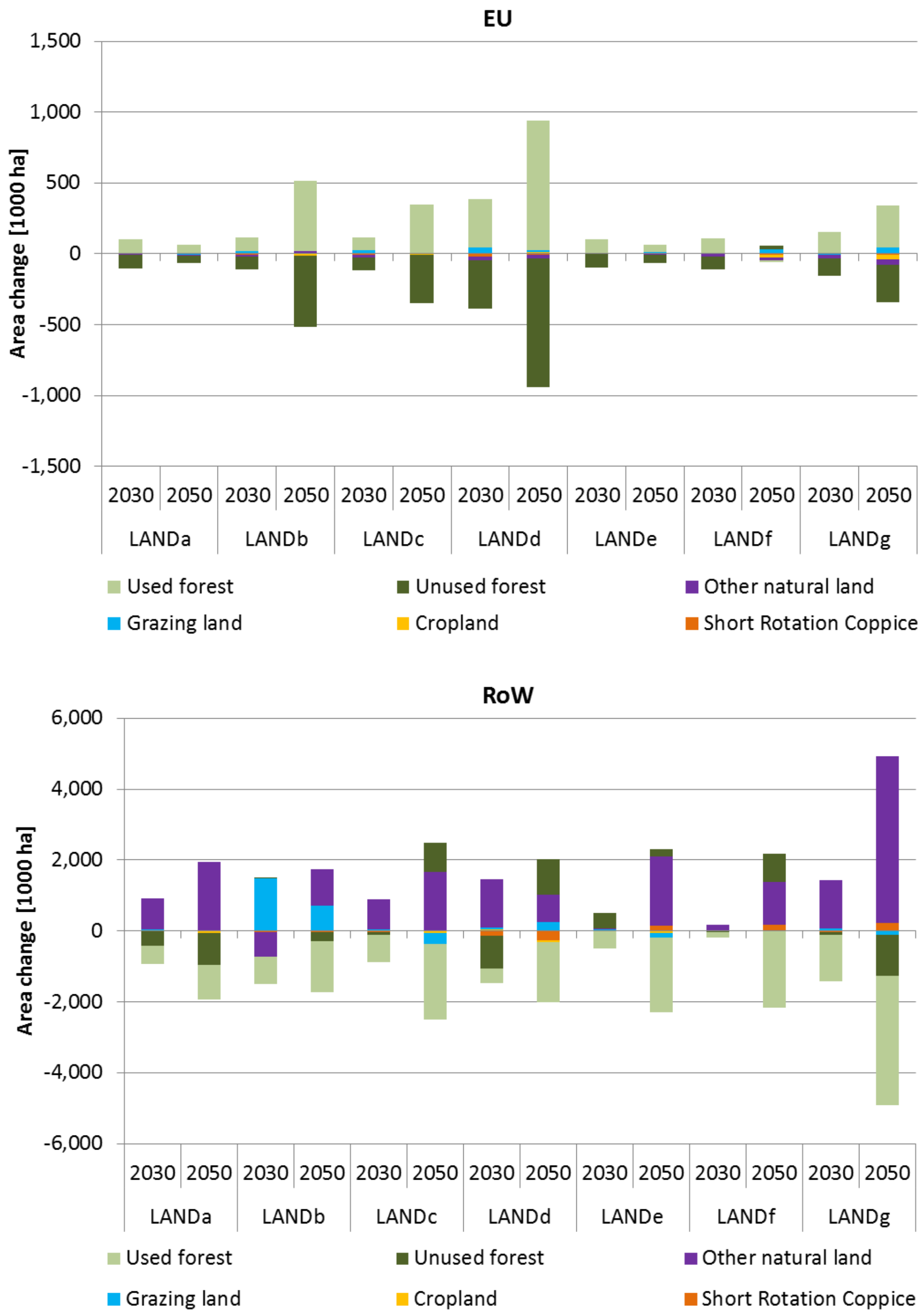


Figure 23: Changes in land use in EU (upper panel) and RoW (lower panel) resulting from the sensitivity analyses on LAND, using LAND as the reference.

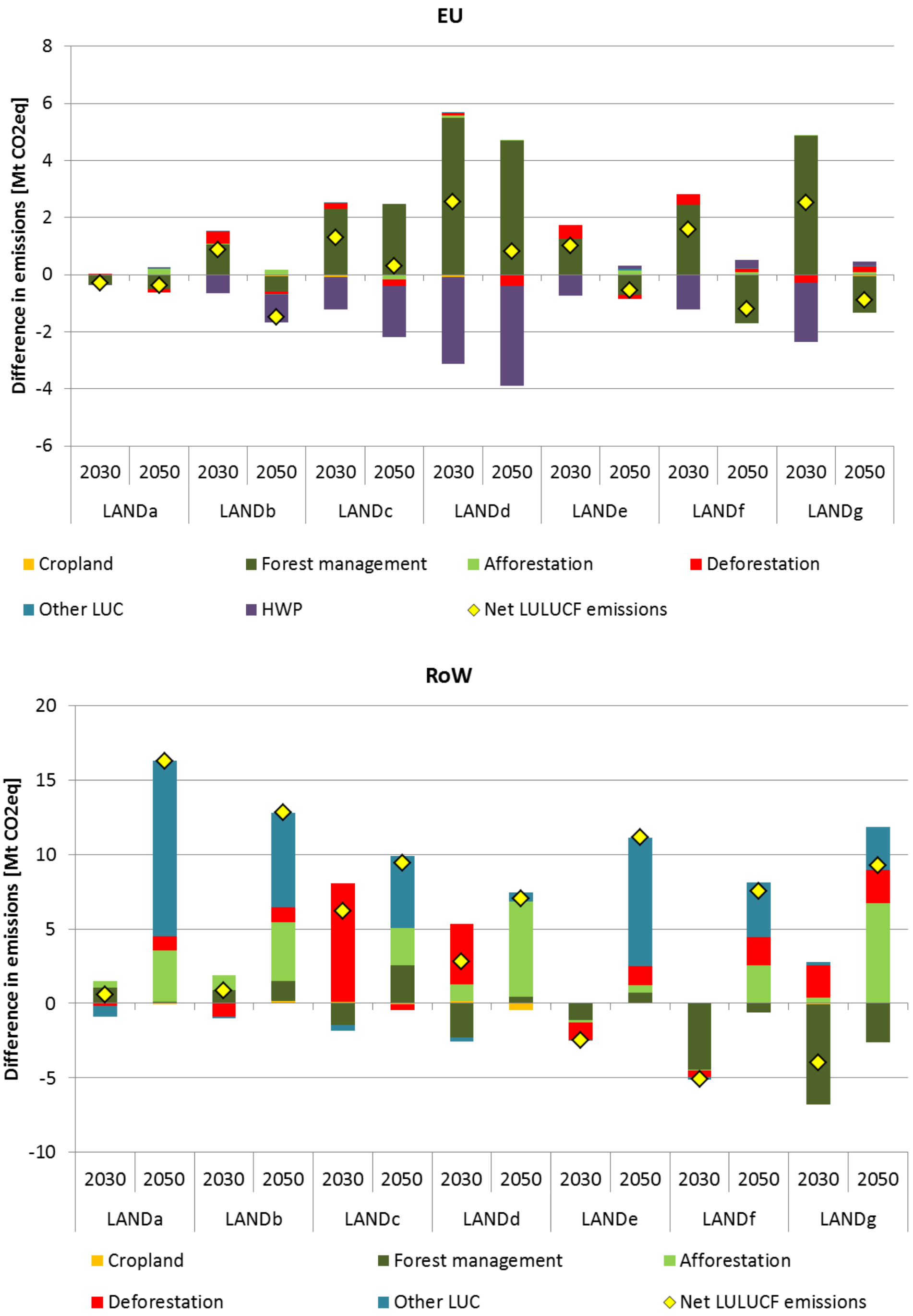


Figure 24: Changes in LULUCF emissions in EU (upper panel) and RoW (lower panel) resulting from the sensitivity analyses on LAND, using LAND as the reference.

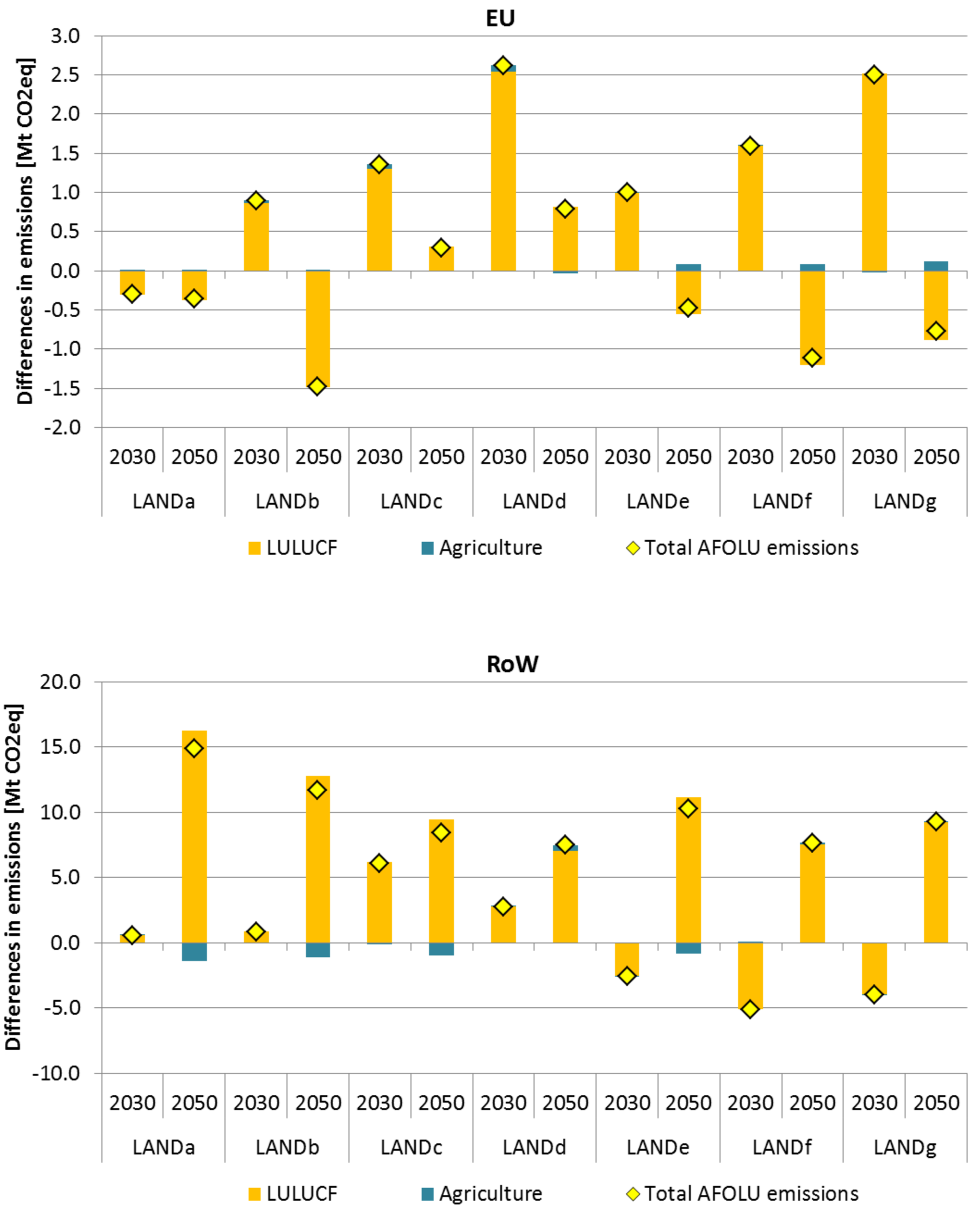
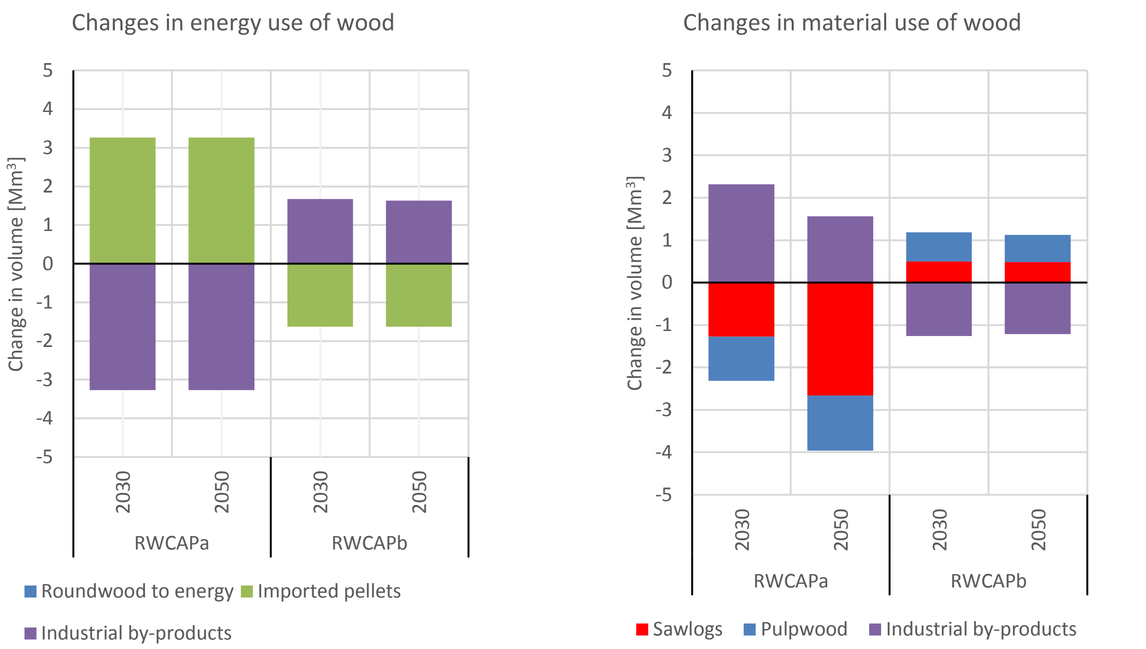


Figure 25: Changes in total net LULUCF and agriculture emissions in EU (upper panel) and RoW (lower panel) resulting from the sensitivity analyses on LAND, using LAND as the reference.

RWCAP



%-CHANGE TO RWCAP		ENERGY USE OF WOOD			MATERIAL USE OF WOOD		
		Rw to energy	Imported pellets	By-products	Sawlogs	Pulpwood	By-products
RWCAPa	2030	-	11%	-3%	0%	-1%	3%
	2050	-	11%	-3%	-1%	-1%	2%
RWCAPb	2030	-	-6%	1%	0%	0%	-1%
	2050		-6%	1%	0%	0%	-2%

Figure 26: Changes in the energy and material use of wood in RWCAPa and RWCAPb, compared to RWCAP.

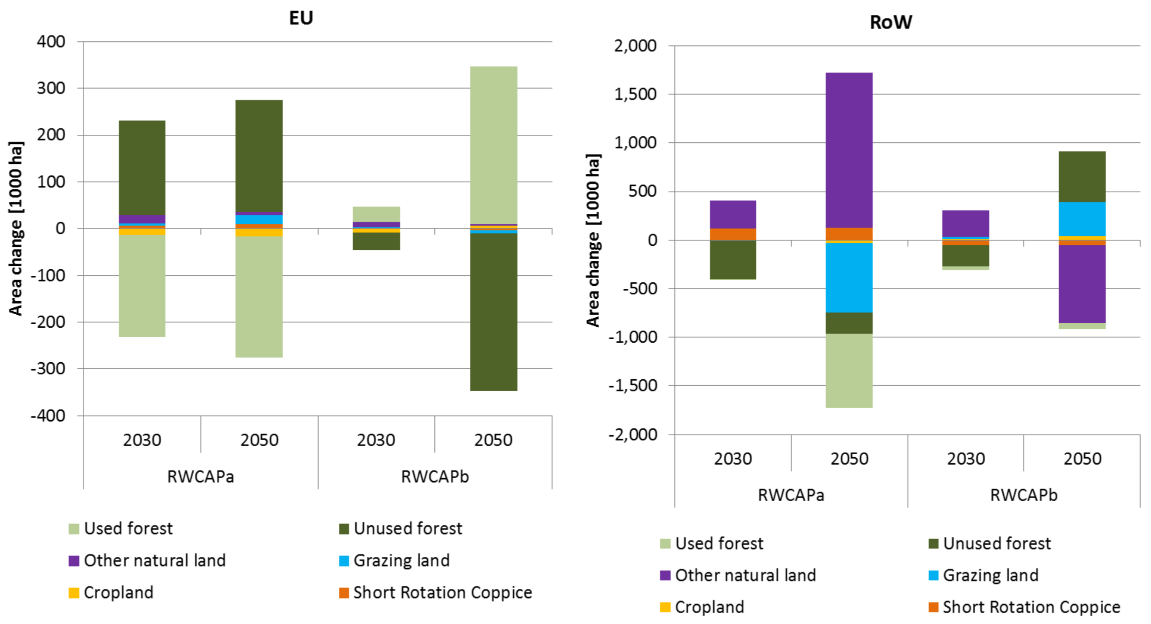


Figure 27: Changes in land use in EU (left) and RoW (right) in RWCAPa and RWCAPb, compared to RWCAP.

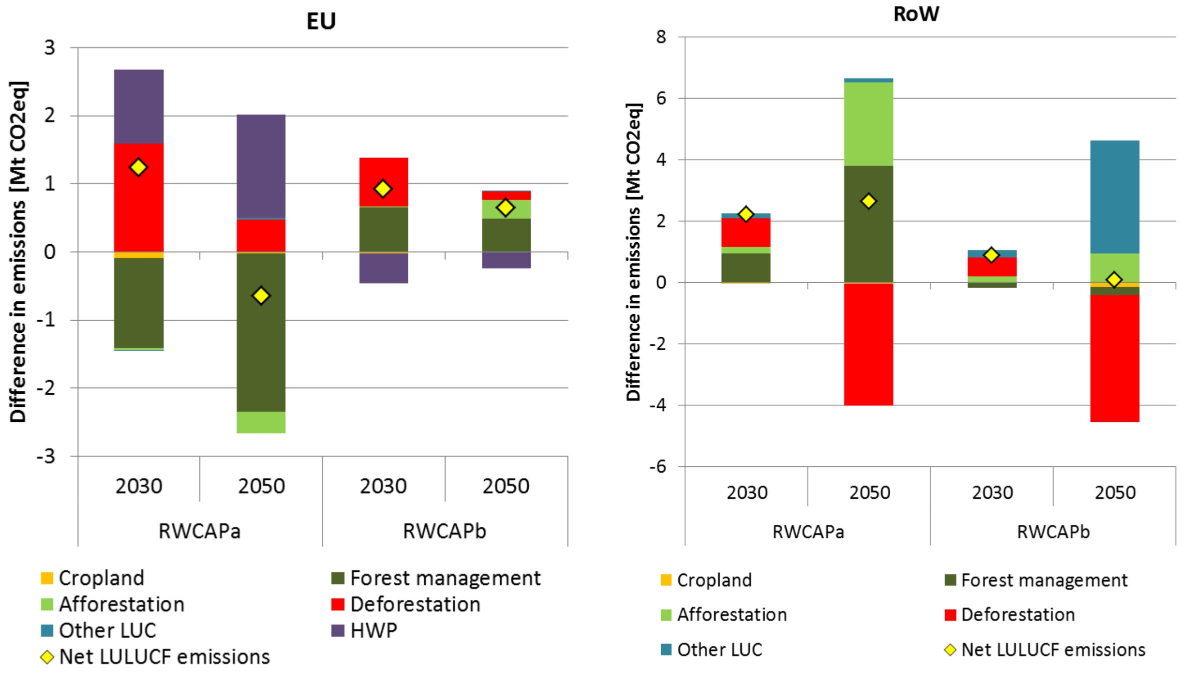


Figure 28: Changes in LULUCF emissions in EU (left) and RoW (right) in RWCAPa and RWCAPb, compared to RWCAP.

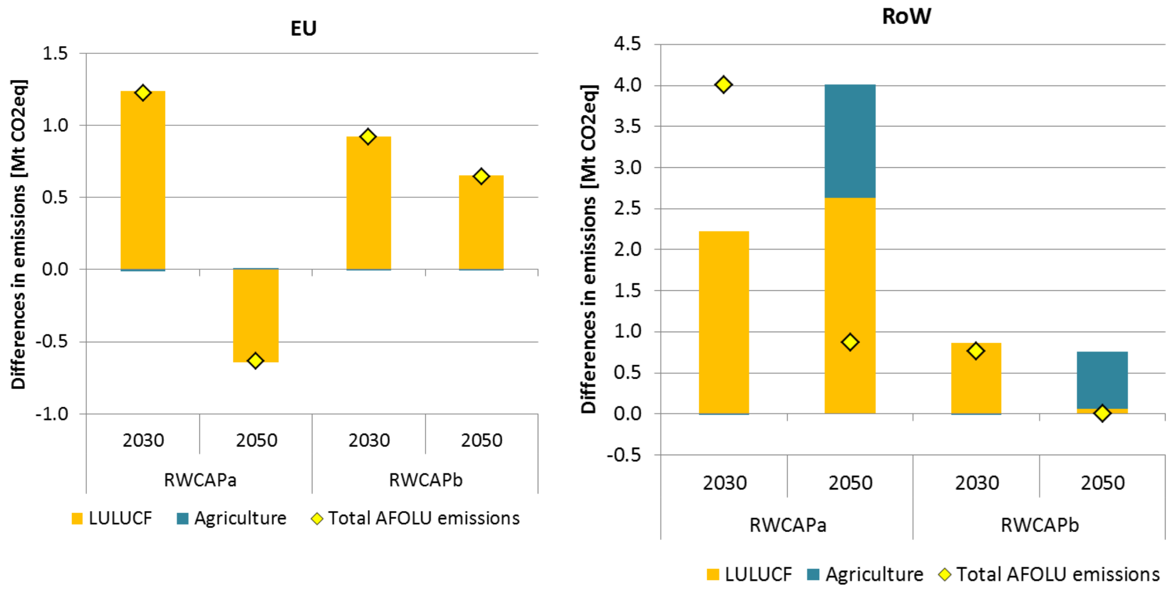


Figure 29: Changes in total net LULUCF and agriculture emissions in EU (left) and RoW (right) in RWCAPa and RWCAPb, compared to RWCAP.

ANNEX II - DEFINITIONS OF LAND CATEGORIES

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[15]). **Protected forests** (as defined by WDPA Consortium 2004[16]) are excluded from the analysis and no conversion or use of protected forest is allowed. Forest that is not protected is considered as forests available for wood supply. 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. In this project, we classify these forests as **unused** and **used forests**, depending on whether they contribute to the wood supply or not. **Unused forests** do currently not contribute to wood supply, based on economic decision rules in the model. However, they may still be a source for collection and production of non-wood goods (e.g. food, wild game, ornimental plants). 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.

Examples of used forests are:

- A forest that is actively managed (through thinning or clearcut activities etc.) on a regular basis and the wood is collected for subsistence use or to be sold on markets.
- A forest that has been regenerated (either by direct planting or natural re-growth) after harvesting and where the forest is intended to be actively managed in the future and the collected wood to be sold on market.
- A forest used on a regular basis for collection of firewood for subsistence use or to be sold on markets.
- A forest concession or community forest used for collection of wood for export and/or domestic markets.

The G4M model allows for conversion from used forests to unused, and unused to used forests. As the demand of wood increases, the G4M model selects a combination of two options to meet the increase in wood demand: Option 1, to increase the harvest of wood from "used forests" through a change in management intensification (thinning of forests, but mainly change in rotation periods); Option 2, to convert currently "unused forests" to "used forests" and directly harvest wood from the new area of "used forest". Generally, how much of these two options that is selected is mainly based on the associated costs and how much each option will increase the availability of wood. Initial selection of used and unused forest areas is done in G4M according to an approach described in Kindermann et al. 2008[17] and based on a global map of human influence (see CIESIN (2002)[18]). In its core, the map of human influence is created through overlaying global data layers. Data describing human population pressure (population density/population settlements), human land use and infrastructure (built up areas, night-time lights, land use/land cover), and human access (coastlines, roads, railroads, navigable rivers) are jointly combined to create the map of human influence.

15 FAO 2012. FRA 2015 – Terms and definitions. Forest Resources Assessment Working Paper 180.

16 WDPA Consortium, 2004: World Database on Protected Areas. Copyright World Conservation Union (IUCN) and UNEP-World Conservation Monitoring Centre (UNEP-WCMC)

17 Kindermann GE, McCallum I, Fritz S, Obersteiner M. A global forest growing stock, biomass and carbon map based on FAO statistics. Silva Fennica (2008) 42:387.

18 CIESIN. 2002. Last of the Wild Project, Version 1 (LWP-1): Global Human Footprint. Dataset (Geographic).Wildlife Conservation Society (WCS) and Center for International Earth Science Information Network (CIESIN), Palisades, NY.

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 may be used for bioenergy and biofuel production. **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. **Grazing land** contains of pasture lands used for ruminant grazing. It does not include natural grasslands. **Other natural land** or other natural vegetation is a category that includes a mixture of land that cannot be properly classified such as unused cropland (if not fallow) or grassland, including natural grasslands.

In addition to these classes, GLOBIOM also identifies other agricultural land (e.g. vegetable production, vineyards, orchards), settlements and wetlands. This land use class is for this project kept fixed over time in all scenarios.

ANNEX III - GLOSSARY

Black liquor
Black liquor is the spent cooking liquor produced from the kraft process when digesting pulpwood into paper pulp. Lignin, hemicelluloses and other substances are removed from the wood to free the cellulose fibres. The pulp industry derives a significant share its bioenergy in the form of black liquor.

Chemical pulp
Sulphate (kraft) and soda and sulphite wood pulp except dissolving grades, bleached, semi-bleached and unbleached. (FAOSTAT)

Forest-based industries
Industries using wood, paper or recovered paper and wood as their main raw material. These include manufacturers of sawnwood, wood-based panels and other wooden products, pulp and paper, as well as the packaging and printing industries.

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.

Forest residues
Forest residues are sometimes referred to separately from forest chips. Forest residues are typically leftover branches, stumps and stem tops from logging operations – thinning or final felling, chipped and mostly used for energy production. Forest residues are gathered from the logging site and forwarded to the roadside to be loaded on truck for long distance transport.

Fuelwood (firewood)
Fuelwood is roundwood being used as fuel for such purposes as cooking, heating or power production. It includes wood harvested from main stems, branches and other parts of trees (where these are harvested for fuel) and wood that is used for the production of charcoal (e.g. in pit kilns and portable ovens), wood pellets and other agglomerates. The volume of roundwood used in charcoal production is estimated by using a factor of 6.0 to convert from the weight (mt) of charcoal produced to the solid volume (m^3) of roundwood used in production. It also includes wood chips to be used for fuel that are made directly (i.e. in the forest) from roundwood. (FAOSTAT) In this project, the household and industrial uses of fuelwood are sometimes separated and referred to, respectively, as *firewood* and *roundwood for energy*.

Imported pellets
Wood pellets produced outside of the EU but consumed in the EU. Note that domestically produced wood pellets are not reported in this study as pellets, but instead in terms of the feedstocks used in their manufacturing.

Industrial by-products
Industrial by-products include 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.

Mechanical pulp
Wood pulp obtained by grinding or milling: coniferous or non-coniferous rounds, quarters, billets, etc. into fibres or through refining coniferous or non-coniferous chips. Also called groundwood pulp and refiner pulp. It may be bleached or unbleached. It excludes exploded and defibrated pulp, and includes chemi-mechanical and thermo-mechanical pulp. (FAOSTAT)

Particleboard
Particleboard is a panel manufactured from small pieces of wood or other ligno-cellulosic materials (e.g. chips, flakes, splinters, strands, shreds, shaves, etc.) bonded together by the use of an organic binder together with one or more of the following agents: heat, pressure, humidity, a catalyst, etc. The particle board category is an aggregate category, including for example oriented strandboard (OSB). (FAOSTAT)

Pulpwood (in ReceBio: pulplogs)
Roundwood (excluding tops and branches) not satisfying the diameter and/or quality constraints of sawmill and plywood industries. This type of stemwood is commonly used for pulp and particleboard production. Pulpwood is typically the main type of roundwood harvested in thinnings, where the mean diameter of the harvested trees is relatively small. In this report, we use the term *pulpwood* to refer to the harvested feedstock quality, and not to the final use of the stem. That is, pulpwood is assumed to be available for use in particleboard and pulp production, as well as for bioenergy purposes.

Recovered wood
Recovered wood includes all kinds of wood material which, at the end of its life cycle in wooden products, is made available for re-use or recycling. Re-use can be either for material purposes or energy production. This group mainly includes used packaging materials, wood from demolition projects, unused or scrap timber from building sites, and parts of wood from residential, industrial and commercial activities. Sometimes referred as "post-consumer" or "post-use" wood.

Recovery
According to Article 3(15) of the Waste Framework Directive (2008/98/EC) recovery means 'any operations the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil that function, in the plant or in the wider economy.'

Recycling
According to Article 3(17) of the Waste Framework Directive (2008/98/EC) recycling means 'any recovery operation by which waste materials are reprocesses into products, materials or substances whether for the original or other purposes. It includes reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels of for backfilling operations.'

Roundwood for energy
In this study, roundwood for energy is defined as stemwood that is directly used for energy production in small or large conversion facilities. This category does not include the wood biomass obtained from industrial by-products, nor firewood (household use of energy for fuel), nor forest residues. In this study, the category accounts for stemwood that is of industrial roundwood quality (usually pulpwood) and could be used for material purposes by the forest-based sector but that is instead being used for energy production.

Sawlogs
Roundwood of sawlog or veneer log quality (excluding tops and branches). In this study, sawlogs refer to roundwood that *could* be used for sawnwood or plywood production, satisfying the diameter and quality constraints of these industries. Sawlogs are typically the main type of roundwood harvested in final fellings, where the mean diameter of the harvested trees is relatively large.

Sawnwood
Wood that has been produced from both domestic and imported roundwood, either by sawing lengthways or by a profile-chipping process and that exceeds 6 mm in thickness. It includes planks, beams, joists, boards, rafters, scantlings, laths, boxboards and "lumber", etc., in the following forms: unplaned, planed, end-jointed, etc. It excludes sleepers, wooden flooring, mouldings (sawnwood continuously shaped along any of its edges or faces, like tongued, grooved, rebated, V-jointed, beaded, moulded, rounded or the like) and sawnwood produced by re-sawing previously sawn pieces. It is reported in cubic metres solid volume (FAOSTAT).

Short Rotation Coppice (SRC)
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.

Stemwood
Tree stems (excl. stumps, tops and branches). Stemwood can be used for energy or material purposes, see also Roundwood for energy.

Wood chips
Wood chips are wood that has been reduced to small pieces and can be used for material production or as a fuel. For pulping, particle board and/or fibreboard production, the chips need to be without bark, for fuel use the wood chips may contain bark.

Wood pellets
Wood pellets are refined wood fuels traditionally made of clean industrial by-products of the mechanical wood industry, mainly wood chips, sawdust and/or shavings. Wood pellets are cylinder shaped and their diameter varies between 6 - 8 mm and length between 10 - 30 mm. The heat value of one kilogram of pellets correspond almost half a litre of light fuel oil. Unlike other wood based commodities (sawnwood, wood based panels) the production, consumption or traded volumes of wood pellets are usually reported in tonnes. In trade of wood pellets price reference is commonly set per tonne of pellets. In this study, we report only imported wood pellets – the pellets produced in the EU are reported in terms of the feedstocks used to manufacture them (roundwood for energy or industrial by-products).

ANNEX IV - OVERVIEW OF POLICIES ON BIOENERGY FEEDSTOCKS ON SELECTED CASE AREAS

In this document, we assess specific policies on the use of biomass discussed and/or put in action in some case countries. The cases selected for the overview are Poland, Massachusetts (USA) and Flanders (Belgium). The policies are reviewed in terms of their overall coverage and the definitions used to describe the biomass feedstocks covered by the policies. When possible, also environmental and economic impacts observed or expected by the policies were assessed. In addition, we give a short overview of the risk based approaches for assessing the biomass sustainability that has been employed in the United Kingdom. The assessment, compiled as a collaboration between IIASA, IEEP and country experts, is based on the literature and information available in May 2016.

Poland

Overview of the new legislation for renewable energy in Poland

In Poland, the energy producers have been obliged to purchase or generate part of their electricity from renewable sources of energy since 2005[19]. The new Renewable Energy Law[20] from 2015, and amended in 2016, replaced the previous system of green certificates with two separate components: an auction scheme for new, large projects; and feed-in tariff (FiT) payments for small energy installations.

In the previous system, green certificates were granted for purchase of electricity and heat produced from renewable energy sources, including biomass. Biomass was defined as *liquid or solid substances of plant or animal origin, agricultural, food industry or timber production wastes, biodegradable wastes and low quality cereal grains not covered by the State intervention purchase[21].* Power plants using biomass were obligated to use certain amount of agricultural biomass in their overall fuel balance, as an attempt to limit and stabilize the use of wood resources in Poland at a certain level. This amount was dependent on biomass combustion technology (co–firing, hybrid combustion or biomass dedicated boilers).

IRENA[22] argues that the previous system of green certificates led to the development of centralized biomass co-firing, increasing biomass prices and delayed expansion of other bioenergy technologies. According to IRENA, with the new law, the government will get almost entire control over the technologies and volumes of each new renewable energy initiative, aiming to weigh cost-effective projects and technologies. Bacia (2014)[23] argues that the green certificate system mostly benefitted large facilities co-firing coal and biomass (which, according to Bacia, was often imported from South-East Asia), making it difficult for smaller renewable energy facilities to enter the markets, and indirectly supporting coal as an energy source – despite the ostensible focus on biomass.

The definition of the biomass feedstocks in the new legislation

In the legislation adopted in 2015 biomass is defined as: *liquid or solid biodegradable substances of plant or animal origin coming from products, waste or residues of agricultural and wood industries and industry processing their products, as well as low quality cereal grains not suitable for intervention according to the Regulation 1272/2009 as well as grains not covered by the State intervention purchase and biodegradable*

19 http://www.iea.org/policiesandmeasures/pams/poland/name-23916-en.php
20 IEA. http://www.iea.org/policiesandmeasures/renewableenergy/?country=Poland. Original policy text available in Polish at: http://dziennikustaw.gov.pl/du/2015/478/1
21 http://www.central2013.eu/fileadmin/user_upload/Downloads/outputlib/4biomass_Poland_trade_study_uploaded.pdf
22 http://www.irena.org/DocumentDownloads/Publications/IRENA_REmap_Poland_paper_2015_EN.pdf
23 Bacia, M. 2014. Poland's renewable energy story. Available online at: http://cleantechnica.com/2014/05/02/renewable-energy-legislation-poland-april-2014-proven-methods-killing-renewable-energy/

fraction of industrial and municipal waste, of plant or animal origin, including waste from waste processing installations and waste from water and waste water treatment, especially the sewage sludge, according to the provisions on qualification of energy recovered from thermal waste conversion. The amendment includes also a definition of “local biomass”, which is biomass that is sourced within the diameter of up to 300 km around the bioenergy generating installation[24].

The new Polish legislation does not recognise “full quality” wood as a renewable source of energy (Article 44 of the Act on Renewable Energy Sources of 2015, as a continuation of the original restrictive provision in the implementing act[25] of the Energy Law adopted in 2013).

24 http://www.cms-lawnow.com/ealerts/2016/05/draft-amendment-to-the-renewable-energy-sources-act, http://www.cire.pl/item,128409,1,0,0,0,0,0,nowelizacja-ustawy-o-oze---wsparcie-glownie-dla-stabilnych-zrodel.html

25 www.ure.gov.pl/download/1/6800/RozporzadzenieMG.pdf

Massachusetts

Overview of bioenergy policies in Massachusetts

Biomass is identified as a highly potential bioenergy feedstock in Massachusetts, where it is estimated to lie 3 000 000 acres (1.2 Mha) of underutilized forestland and other large sources of wood[26]. The government of Massachusetts made an extensive effort to investigate the potential of biomass resources and technologies that could be used to produce bioenergy, and to analyze their impacts on greenhouse gas emissions, initiating the Massachusetts Sustainable Forest Bioenergy Initiative. Related to this, a number of studies and technical reports have been prepared to investigate the potential to use forest biomass for energy, both to be used domestically but also as a possible export to e.g. the EU. Here, we focus especially on a study prepared by Manomet Center for Conservation Sciences[26] in 2010. In 2012, final regulation of the new Renewable Portfolio Standard describing the biomass policy regulatory process was filed[27].

Schemes in place to promote or restrict the use of biomass as an energy feedstock

The Manomet study[26] reviewed the federal bioenergy policy in the US, which is focused in supporting transportation fuels and electricity generation through a combination of tax programs and direct grants and loans. For transportation fuels, the federal support has mainly been directed to corn-based ethanol production through tax credits and direct grants. Biomass use for electricity production (open-loop facilities) has been eligible for tax credits and other funding, although the subsidies given to this sector are only a fraction compared to other renewables (in 2007, biomass-using facilities received $4 million in tax credits, compared to $600 million for wind facilities). The share of CHP or purely thermal energy-producing facilities has been negligible in the funding allocated for renewable energy.

In 2008, a federal Biomass Crop Assistance Program (BCAP) was created to support conversion of crops to bioenergy, and to assist the landowners in collecting, harvesting, storage and transportation of agricultural and forest biomass for energy purposes. The program pays up to 75% of the establishment costs of new energy crops, with additional support provided in the initial years of bioenergy feedstock production. This program resulted in a large number of existing facilities processing lumber, pellet and paper (and producing energy for their own use), to submit applications for qualifying for bioenergy subsidies. As an economic consequence of the BCAP program, fuel costs for the biomass power sector have been seen to decrease considerably; Manomet[26] notes that these savings tend to accrue to loggers and biomass consumers in the case of small landholdings, and more to the landowners when the landholdings are large. Moreover, according to the Manomet study, the subsidy has been criticized of distorting the markets by cutting costs for some users (biomass power plants), while increasing costs of competing industries (e.g. particleboard manufacturers).

In addition to these federal programs, the state of Massachusetts also has two regulatory programs in place to directly incentivize development of biomass-fueled electricity production: the Massachusetts Renewable Portfolio Standard, and the Regional Greenhouse Gas Initiative. Specific features of these two programs are covered in more detail below.

26 Manomet Center for Conservation Sciences. 2010. Biomass sustainability and carbon policy study. Available online at: http://www.mass.gov/eea/docs/doer/renewables/biomass/manomet-biomass-report-full-hirez.pdf. See also: http://www.mass.gov/eea/energy-utilities-clean-tech/renewable-energy/biomass/ma-sustainable-forest-bioenergy-initiative.html
27 http://www.mass.gov/eea/energy-utilities-clean-tech/renewable-energy/biomass/renewable-portfolio-standard-biomass-policy.html

The definition of the biomass feedstocks

In the Massachusetts Renewable Portfolio Standard, a minimum percentage of renewable feedstocks is required to be included in the electricity production. The definition of "eligible biomass fuel" under this program was: "*Fuel sources including brush, stumps, lumber ends and trimmings, wood pallets, bark, wood chips, shavings, slash and other clean wood that are not mixed with other unsorted solid wastes; by-products or waste from animals or agricultural crops; food or vegetative material; energy crops; algae; organic refuse-derived fuel; anaerobic digester gas and other biogases that are derived from such resources; and neat Eligible Biofuel that is derived from such fuel sources*." As pointed out by the Manomet study team, no requirement of sustainability was included in the definition. In the new Renewable Portfolio Standard from 2012, eligible biomass woody fuel was defined in more detail (see Box 1).

In the Renewable Portfolio Standard from 2012, eligible biomass fuel removal is not allowed from old growth forest stands, which are defined as "*forests that approximate the structure, composition, and functions of native forests prior to European settlement. They vary by forest type, but generally include more large trees, canopy layers, standing snags, native species, and dead organic matter than do young or intensively managed forests*." In addition, eligible biomass fuel removal is not permitted from harvest on steep slopes (a gradient of 30 percent or more for a slope distance of 200 feet or more).

In contrast, in the Regional Greenhouse Gas Initiative, where the goal is to cap carbon dioxide emissions from large fossil fuel-fired power plants, eligible biomass definition does contain requirement for sustainability: "*Eligible biomass includes sustainably harvested woody and herbaceous fuel sources that are available on a renewable or recurring basis (excluding old-growth timber), including dedicated energy crops and trees, agricultural food and feed crop residues, aquatic plants, unadulterated wood and wood residues, animal wastes, other clean organic wastes not mixed with other solid wastes, and biogas derived from such fuel sources. Liquid biofuels do not qualify as eligible biomass. Sustainably harvested shall be determined by the Department [of Environmental Protection].*" According to the initiative, in power plants where 95% or more of the fuel is biomass, emissions that result from the combustion of "eligible biomass" are not counted toward the compliance obligations.

Box 1. Eligible biomass definitions in Massachusetts according to the Renewable Portfolio Standard (2012).

Eligible Biomass. Woody Fuel. Woody fuels that are derived from the following sources, consistent with the requirements of 225 CMR 14.05(8):

Forest Derived Residues:

1. Tops, crooks and other portions of trees produced as a byproduct during the normal course of harvesting material, such as timber, pulpwood or cordwood. Minimum percent of tops and branches must be retained, reasonably well distributed, on the site (25% on good soils, 100% on poor soils). All naturally Down Woody Material must retain in the forest. In addition, in all harvests of Eligible Biomass Fuel, forest litter, forest floor, roots and stumps must be retained and protected. [28]

2. Other woody vegetation that interferes with regeneration or the natural growth of the forest, limited to locally invasive native species and non-native invasive woody vegetation.

Forest Derived Thinnings:

1. Unacceptable growing stock which is defined as trees considered structurally weak or have low vigor and do not have the potential to eventually yield a 12 foot sawlog or survive for at least the next 10 years.

2. Trees removed during thinning operations, the purpose of which is to reduce stand density and enhance diameter growth and volume of the residual stand.

Forest Salvage. Damaged, dying or dead trees removed due to injurious agents, such as wind or ice storms or the spread of invasive epidemic forest pathogens, insects and diseases or other epidemic biological risks to the forest, but not removed due to competition. Such eligible trees may be removed without limitation for biomass fuel, only if a major threat to forest health or risk to private or public resources, and if the USDA Animal Health and Plant Inspection Service (APHIS), the USDA Forest Service, or appropriate federal or state governmental agency has issued a declaration, rule, or order declaring a major threat to forest health or risk to private or public resources. Forest Salvage also includes trees removed to reduce fire hazard within Fire - adapted Forest Ecosystems, as certified by a letter to the Department from the state agency responsible for forestry in consultation with the appropriate environmental state agencies.

Non-Forest Derived Residues.

1. Primary forest products industry: Lumber mill residues or lumber processing residues consisting of the slabs, shavings, trimmings, sawdust, bark, end pieces of wood, and log cores that result from the various processing operations occurring in sawmills, pulp mills, and veneer and plywood plants.

2. Secondary forest products industry: Wood waste produced as a byproduct of the production of finished wood products, including but not limited to clean residues from woodworking shops, furniture factories, and truss and pallet manufacturing.

3. Land use change – non-agricultural: Trees cut or otherwise removed in the process of converting forest land to non-forest and non-agricultural uses provided that such development has already received all applicable state and local permits for the development.

4. Land use change – agricultural: Trees cut or otherwise removed in the process of converting forest land to agricultural usage, either for new or restored farm land.

5. Yard waste: Leaves, grass clippings, prunings, and other natural organic matter discarded from yards and gardens.

6. Wood waste: Non-treated pallets; pruned branches, stumps, and whole trees removed during the normal course of maintenance of public or private roads, highways, driveways, utility lines , rights of way, and parks.

Dedicated Energy Crops. Wood purposefully grown for the purpose of producing fuel, provided that such wood was not grown on land that sequestered significant amounts of carbon, such as a forest, and provided that such land does not have the economic potential to support production of any other agricultural crop grown for human consumption as food.

In addition, Manomet noted that the debate about biomass definitions continues on the federal level in the US, concerning which sources of biomass should be considered as carbon neutral, and how the safeguards for natural resources on public and private lands should be defined. The concern is that aggressive targets for increasing the use of biomass for bioenergy would exceed the economically and ecologically sustainable supply of wood from the US forests, with a debate of possible carbon caps based on full lifecycle accounting ongoing. Also, the authors of the Manomet study point out that there are

28 MA RPS Regulation – Biomass Eligibility and Certificate Guideline DOER. Available online at: http://www.mass.gov/eea/energy-utilities-clean-tech/renewable-energy/biomass/renewable-portfolio-standard-biomass-policy.html

issues in considering wood biomass acquired through land clearing (deforestation) as a renewable energy feedstock.

Environmental impacts

The study conducted by Manomet investigated also the carbon neutrality of burning wood biomass for energy, investigating the effects of different combustion technologies, the fossil fuel technologies replaced, and the characteristics of the forests from which the biomass was extracted. It was seen that the time needed to pay off GHG emissions from wood combustion through growth of forests was the shorter for thermal and combined heat and power (CHP) technologies compared to biomass electric plants, as thermal and CHP technologies achieve greater efficiencies in energy conversion. However, the forest management strategies adopted by the landowners were seen to have a large effect on the pay-off time. Moreover, conversion of lands with existing large carbon stocks in soil and vegetation into bioenergy plantations may be counteractive from the carbon sink perspective, as such conversion may negate the climate benefits of the bioenergy establishment.

On the stand level, the study identified maintenance of soil productivity and biodiversity as the most significant sustainability concerns associated with increased forest biomass harvests. As possible ways to counteract negative effects of biomass harvests, the study suggests leaving enough coarse woody debris on the ground, especially on nutrient-poor sites. Another important way to promote biodiversity would be to leave standing dead trees on the sites.

Flanders

Overview of the bioenergy policies

In July 2015, the Flemish Government approved the action plan Action Plan for Sustainable Management of biomass (waste) streams 2015-2020. The action plan provides a guiding framework for the sustainable and efficient use of biomass and residues (wood, organic waste, green waste, etc.), aiming *"to further stimulate the prevention, separate collection and recycling of (residual) biomass streams with a view to cost, (raw) material and energy savings"*[29]

In the Flemish part of Belgium, also a measure discouraging combustion of clean wood (wood that is not chemically treated, or mixed with other waste) is currently in effect. The measure was drafted and issued by the VREG, the Flemish regulator of the electricity and gas market, in 2008[29]. In this measure, combustion of wood that still has other industrial uses cannot be awarded renewable energy premiums. Companies that burn clean waste wood must prove their compliance with this measure via an audited report.

The definition of the biomass feedstocks

Biomass is defined as *"the biodegradable fraction of products, waste and residues of biological origin from agriculture (including plant and animal substances), forestry and related industries, including fisheries and aquaculture, as well as the biodegradable fraction of industrial and household waste"*[29].

Residual biomass streams are defined as *"waste and residual fractions of biomass which 1) are not used for the purpose for which the biomass was originally intended or produced, 2) are released and can be mobilized, and 3) for which recovery is desirable; e.g. unsold vegetables/fruit, residual waste streams from the food industry, animal by-products, VFG (Vegetable, Fruit and Garden) waste, wood waste, residual waste streams from the wood industry or streams generated by the management of gardens, parks, verges and banks, nature and landscapes"*[29].

According to the inventory of wood waste policies and markets carried out by the NL Agency[30], the specific wood streams available for use in renewable energy installations benefiting from green certificates are defined by exclusion rather than inclusion. That is to say that a list of prohibited fractions are set out, rather than those that can be included. This is linked to the categorisation of waste within the region (see below). Certain waste streams are not permitted for energy production, recognising the importance of recycling and material recovery over energy use. Importantly wood pellets are not considered to be a waste providing they meet the DIN standard[31] or the Önorm or the Belgian product standard.

It is forbidden to process the following wastes for incineration in an establishment that is located in a Flemish Region (OVAM, 2010):

1. Selectively collected streams that are eligible for material recycling. This prohibition is not valid for the burning of the following wastes, provided they have a caloric content > 11 500 kJ/kg, for the generation of renewable energy:

- Vegetable waste from agriculture and forestry;
- Vegetable waste from the food industries;

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29 VREG (2008) Mededeling van de Vlaamse Reguleringsinstantie voor de Elektriciteits- en Gasmarkt van 8 juli 2008 Gewijzigd op 2 juni 2009 met betrekking tot de toepassing van artikel 15 van het besluit van de Vlaamse regering van 5 maart 2004 inzake de bevordering van elektriciteitsopwekking uit hernieuwbare energiebronnen betreffende de aanvaardbaarheid voor de certificatenverplichting van groenestroomcertificaten voor elektriciteitsproductie uit houtstromen.

30 http://english.rvo.nl/sites/default/files/2013/12/Competition%20in%20wood%20waste%20June%202013.pdf

31 http://www.biomassenergy.gr/en/articles/technology/biomass/79-biomass-pellets-

- Fibrous vegetable waste from sorting, screening and washing the raw pulp and paper production;
- Wood;
- Waste cork.

2. Unsorted industrial waste; unsorted household waste.

The following wood waste streams are eligible for green certificates in the Flemish region (VREG, 2008):

- Short rotation wood: always entitled to green certificates;
- Wood / timber waste flows that are not used as industrial raw material, thus not eligible for material recycling;
- Wood fraction in organic residue waste: only entitled to green certificates when the installation has an energy recovery PEB (primary energy) of ≥ 35%;
- Any other timber flows: always entitled to green certificates.

The (residual) biomass streams released (waste and non-waste) must be used respecting the cascade as much as possible. Concretely, the cascade means:

- Use as feed (e.g. nature cuttings that are suitable as feed).
- Use as material: wood, paper and board material production, lignin or lignocellulose-based materials (e.g. platform chemicals), insulation materials, shock-absorbing materials, compost, digestate, growing substrates.
- Use as a source of energy: energy generation via incineration, use of e.g. biogas as fuel for transport.
- Disposal: incineration without energy recovery and landfilling are prohibited.

IEA (2016)[32] reports that in the Flemish legislation on the use of biomass for energy[33], wood-fuelled electricity generation is eligible for green electricity certificates only if the wood stream in question is not used as an industrial resource. According to IEA, the rationale behind excluding industrial resources for green electricity certificates is to maintain a cascading hierarchy of material over energy applications and avoid an uneven playing field between energy and material applications. The legal procedure on this topic has been amended over the past years. In the period 2008-2013 the practical implementation of the 'industrial resource' issue was regulated by a communication which stipulated that the wood and paper industry sector federations needed to declare that the wood resource in question did not serve as an industrial resource. The result of the declaration was binding and issued on plant level, giving the federations a virtual veto right on the matter. Since May 2014 it is the Public Waste Agency of Flanders (OVAM) and the wood and paper industry sector federations who are consulted for their advice by the Flemish Energy Agency to determine whether a specific wood resource can be used as industrial resource[34]. Invoking proximity or geography of the sourcing area as an argument in the advisory process was ruled as illegitimate. Moreover, in case of a negative advice, federations[35] needed to show that the envisioned wood resource **is** effectively used (and not **potentially to be used**) as a resource in industrial processes.

When implementing the cascade, the policy encourages to strive for social and economic added value. This means, among others, that the biomass is mobilized in accordance with approved management plans, the management and use of the biomass takes place

32 IEA Bioenergy Task 40. 2016. Cascading of woody biomass: definitions, policies and effects on international trade.

33 Flemish Energy Decree and its Decisions

34 OVAM (2015) Actieplan Duurzaam beheer van biomassa(rest)stromen 2015-2020. (Translated: Action Plan for Sustainable Management of biomass (waste) streams 2015-2020) Available online at: http://www.ovam.be/sites/default/files/atoms/files/Action%20Plan%20for%20the%20Sustainable%20Management%20of%20Biomass%20Streams%202015-2020.pdf

35 Fedustria represents the textile, woodworking and furniture industry's companies. Cobelpa is the association of the Belgian pulp, paper and board industries.

within the region of origin, and in accordance with the applicable environmental conditions.

Box 2. Economic impacts of the measures to discourage clean wood combustion in Flanders.[36]

As a side effect, discouraging combustion of clean wood has been seen to lead to increased export of wood pallets (wooden structures used to support goods e.g. for lifting with a forklift) to neighbouring countries like the Netherlands, which shows the transnational character of this issue. This is even clearer if we take into account the development towards intake of more contaminated wood by particleboard suppliers. Due to lower costs for contaminated wood and lower energy expenditure compared to virgin wood, particleboard manufacturers increasingly become competitors of energy generation plants. This – as well as regulation (for example the landfill tax in the UK) and additional waste-to-energy conversion capacity that is being implemented – leads to significant trade flows which are also subject to fluctuations. Post-consumer wood becomes increasingly a commodity subject to market forces

With respect to the Flemish measure to prohibit renewable energy subsidies for combustion of clean wood, the OVAM considers that this has resulted in stable prices of this type of wood, instead of the increase that is generally observed for other types of waste wood.

36 Source: IEEP compilation, see also Vis M., U. Mantau, B. Allen (Eds.) (2016) Study on the optimised cascading use of wood. No 394/PP/ENT/RCH/14/7689. Final report. Brussels 2016. 337 pages

United Kingdom

The risk based approach in the United Kingdom (UK) is one compliance pathway to demonstrate meeting of a certain set of sustainability parameters set out in the UK. The requirements for wood fuels also link to a wider system of compliance for wood products. In the UK, the risk based regional assessment is used to ensure compliance against the land criteria set out in the Timber Standard for Wood for Heat and Electricity. It is complemented by additional GHG criteria, based on the lifecycle GHG emissions associated with their fuel consignments, and is linked to a relatively stringent set of reporting and oversight requirements regarding engagement with the operator Ofgem.

The GHG criteria are determined based on the UK Solid and Gaseous Biomass Carbon Calculator[37]. Operators under the Renewables Obligation (RO) that are larger than 1MW and under the Renewable Heat Incentive (RHI) must provide consignment based reporting to Ofgem setting out the feedstock type, biomass form, origin, class of wood fuel, compliance with the wood fuel land criteria and compliance with the GHG criteria. For larger than 1MW RO operations they must report monthly to Ofgem on compliance, for the RHI reporting is quarterly. For all operations with operations larger than or equivalent to 1 MW there is also the requirement of an annual third party sustainability report[38].

The wood fuel land based criteria in the Timber Standard state that wood fuel utilised must be 'legal and sustainable'. The detailed definition of 'legal' focuses on criteria related to laws both on social (e.g. land tenure/right to harvest) and environmental (e.g. biodiversity protection/forest management) aspects and wider rules on due diligence/record keeping. The definition of 'sustainable' focuses on the management of the forest ecosystem in line with primarily environmental parameters. There are five sets of detailed multi-level criteria that have to be evidenced against to demonstrate compliance.

In order to demonstrate evidence against the wood fuel land based criteria specifically operators can undertake a regional based risk assessment. This is intended to enable a route to compliance that does not require the expense of applying for certification schemes (although this is also a route to partial compliance at least). This is because it is considered that the lower value often paid for wood for fuel, versus say material uses, means that wood producers may be unwilling to take up certification in order to demonstrate compliance. It also enables a route for small/local operators to demonstrate compliance.

The UK regional based risk assessment operates on the basis of determining the level of risk associated with breaching one of the wood fuel land based criteria, hence the risk of wood fuel being used that is not legal and sustainable. Department of Energy & Climate Change (DECC) has developed an extensive check list that demonstrates the nature of proof needed to demonstrate low risk of non-compliance for each of the wood fuel criteria. Operators using wood fuels have to complete a regional based risk assessment for each region (defined as the largest area in which reliable and independent information is available at which conditions are sufficiently homogenous to evaluate the risk of non-compliance with the wood fuel land criteria) relevant to the operations supply base (i.e. where it sources material from).

The UK operates a regional based risk assessment as an option for securing compliance against one subset of criteria required to be met in order for wood to be used as a fuel for heat or electricity generation. It is complemented by other systems for securing the compliance of wood products utilised in the UK. For such an approach to prove effective: appropriate and valid risk based approach parameters and areas of concern have to be

37 https://www.ofgem.gov.uk/publications-and-updates/uk-solid-and-gaseous-biomass-carbon-calculator
38 info based on the Woodfuel Advice Note, DECC, Dec 2014

identified; the risks inherent within each parameter defined; and the evidence required as proof against the risk parameters.

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