Study on impacts on resource efficiency of future EU demand for bioenergy (ReceBio)

Final report

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EXECUTIVE SUMMARY

This project was commissioned to examine the resource efficiency implications of increased EU use of bioenergy for electricity and heat until 2050. Methods of analysis include an extensive literature and statistical review, detailed GLOBIOM modelling of cross-sectorial wood biomass production and use, and in-depth analysis of the implications on a multitude of sustainability indicators. The results for biomass use for material and energy are reported for EU28, while the sustainability indicators are assessed both for the EU and globally. In addition, country specific assessments were carried out for three case countries (Finland, Germany, and Italy) to examine the results against country-specific policies and resources.

The detailed results of the project are published as five separate task reports that can be found at http://ec.europa.eu/environment/integration/energy/studies_en.htm.

Biomass use for material and energy production

To analyse the implications of increasing bioenergy consumption, five prospective scenarios were constructed and analysed within the project. The **Baseline scenario** was specified as close as possible to that of the EU Reference Scenario 2013 published by the Commission. The Baseline scenario depicts the development of biomass use under bioenergy policies that aim at a 20% reduction of greenhouse gas (GHG) emissions in the EU28 by 2020, whereas the EU proposed climate-energy targets for 2030 are not considered. The results show that increased demand for bioenergy will already by 2030 lead to a considerable increase in the EU domestic production of woody biomass (an increase by as much as 10% by 2030 in comparison to 2010 levels) and increased EU reliance on imported biomass feedstock, in particular import of wood pellets (an increase by 90% by 2030 in comparison to 2010 levels). From 2030 to 2050, the EU domestic production of biomass stabilizes as a result of slower development of EU bioenergy demand. The largest changes in the EU28 production of biomass feedstocks for bioenergy are seen in the development of short rotation coppice (SRC) which together with EU import of wood pellets are foreseen to increase considerably in the future. In addition, the project results show clear intensification in the use of EU forests, as well as an increase in the EU net import of roundwood. The increase in EU forest harvest is both driven by the increasing demand for bioenergy and the foreseen increasing demand of woody materials. Another important source of bioenergy feedstock are by-products of wood-processing industries: half of the total biomass for heat and power production in 2010 was retrieved from industrial by-products of wood material industries (sawdust, wood chips, bark and black liquor). The high share of by-products as bioenergy feedstocks is foreseen to remain also in the future. This development highlights the future importance of sawmills as a provider of by-products both for the bioenergy and material sector through the downstream wood flows.

The four other policy scenarios each focus on a particular issue in bioenergy demand and trade of biomass. The development seen in the Baseline scenario is found to be accentuated in the **EU Emission Reduction scenario**, which builds on the policy target of decreasing the GHG emissions by 80% by 2050 in the EU. In this scenario, the development of biomass use follows that of the Baseline scenario until 2030. Thereafter, the results show a considerable increase in the EU import of wood pellets and domestic production of SRC. The increasing production of SRC in the EU after 2030 is seen to lead to some reductions in cropland and grazing land areas as compared to the Baseline scenario, which in turn affect food and feed production. Additionally, we see also large quantities of roundwood directly used for bioenergy production in small and large-scale conversion facilities, especially by 2050. In other words, the bioenergy demand increases to an extent where stemwood that is of industrial roundwood 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 has a direct impact on forest harvests, which are almost 9% higher than in the Baseline results in 2050.

Constant EU Bioenergy Demand scenario investigates the effects of policies that increase the EU bioenergy demand similarly until 2020, but stay constant thereafter. There are only small differences between this scenario and the Baseline on the overall aggregate material production sector. However, compared to the Baseline scenario, there is more particleboard production and less sawnwood production in this scenario, driven by decreased demand for industrial by-products from sawmills (wood chips and sawdust) for bioenergy production. A clear difference is also seen in the composition of feedstocks used for energy production. Most importantly, the sourcing of domestically produced SRC and import of pellets is smaller than in the Baseline scenario. Pellet imports increase until 2020, but remain almost constant thereafter.

The third policy scenario, **Increased Rest of the World (RoW) Bioenergy Demand scenario**, investigates a future increase in the bioenergy demand in the RoW, together with an increase in the EU as in the EU Emission Reduction scenario. Most importantly, countries outside of EU are more reliant on their own biomass sources to fulfil their own increasing bioenergy demand. Consequently, this scenario depicts a situation where EU may not be able to import as much of the biomass feedstocks as in the previous scenarios. Indeed, the results show that with an increased RoW bioenergy demand, net EU imports of wood pellets are 25% lower than in the EU Emission Reduction scenario in 2050. In addition, also EU roundwood imports decrease by more than 20% in 2050. This requires EU to source more biomass from domestic SRC production: in this scenario, the production of SRC in the EU28 is the highest of all scenarios. Material production levels stay at almost the same level as in the EU Emission Reduction scenario. However, as EU roundwood imports decrease, the domestic EU forest harvest level increases slightly more than in the EU Emission reduction scenario.

The fourth scenario, **Increased EU Biomass Import scenario**, investigates the impact of increasing EU reliance on imported biomass resources and domestic production triggered by decreased trade costs. Consequently, EU net import of roundwood grows 22% more by 2050 compared to the EU Emission Reduction scenario, and EU net import of wood pellets grows to more than four times the amount foreseen in the EU Emission Reduction scenario. Here, Latin America and South-East Asia grow into important pellet suppliers, alongside with Canada and the former Soviet Union. Following the increased dependency of imported feedstocks for bioenergy, domestic harvests in the EU will only increase modestly over time in this scenario. The harvest level in 2050 is 11% lower than in the EU Emission Reduction scenario and 3.7% lower than in the Baseline scenario. The decreased competition for woody biomass feedstocks also leads to a slight increase in the EU material production level (especially particleboard and chemical pulp production).

In addition to the analysis of the various scenarios, the effects of the **variation of central modelling assumptions** were assessed based on the EU Emission Reduction scenario. In particular, th sensitivity analysis highlighted the substitution potential between domestic SRC production and pellets import. In other words, it is expected that if the increase in SRC production does not materialize as expected in the EU Emission Reduction scenario, then a large share of the resulting gap of feedstock needed for energy purposes will be fulfilled by pellet imports, and vice versa. At the same time, it was seen that in the scenarios with increasing bioenergy demand, the cascading and multiple use of wood through the value chains of the forest-based industries and bioenergy sector will increase from 2010 until 2030, but decrease afterwards. The decrease in the cascading use of wood after 2030 results mainly from the large quantities of roundwood directly used for bioenergy production as seen in the Emission Reduction scenario. After 2030, demand for woody biomass in the bioenergy sector is projected to increase more than the intensification in the use of industrial by-products for material and energy purposes. Two potential policies for increase the cascading use of wood were evaluated. The analysis shows that an increasing use of recycled wood for material production has the additional benefit of decreasing the production of SRC in the EU28, as well as EU imports of wood pellets from RoW (see Box 3 for further information concerning the analysis). On the other hand, while an economic disincentive for the direct energy use of virgin wood would increase the cascading use of wood, it would also lead to an increasing amount of land dedicated to the production of SRC within the EU28 and an increasing import of pellets from the RoW.

Sustainability assessment

Sustainability implications of the scenarios were assessed using two approaches: comparing direct impacts of the policies on a number of environmental indicators across the scenarios, and through introducing constraints into the model that aim at reducing specific environmental impacts.

When comparing Baseline and policy scenarios for EU28 the chosen indicators for assessing environmental impacts related to biodiversity, GHG and land use tend to be affected the most. In general, for most environmental aspects deviations from the Baseline scenario are of similar percentage change or smaller for the RoW compared to impacts on EU28, except for the scenario simulating an increased demand for bioenergy in RoW.

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

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

In order to limit the most significant environmental impacts, **specific constraints are imposed** on key indicators: Forest area available for wood production can be used as a proxy for the **intensity of forest management**. If forests in EU are protected from further intensification (i.e. through constrained conversion of forests available for wood production), an increased production of SRC can be observed globally (comparably less SRC develops if constraints are put on the conversion of other natural land in EU). In addition, there is a significant intensification of forest management in forests of the RoW associated with such a constraint. This area is slightly exceeding the area being excluded by the constraint in EU28, so globally in total more forest area is converted if the constraint is applied to EU forests.

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

If land of HBV is protected from being converted in the model, more pressure for biomass production can be observed for the areas that are not protected, associated with more land conversion. Constraining the conversion of land with high biodiversity value worldwide has implications for biomass production in EU28, leading to more domestic wood harvest (used for the production of Harvested Wood Products (HWP) to be exported to the RoW) and decreased EU net-imports of sawlogs, pulpwood, and wood pellets in 2050.

The Baseline scenario describes overall net **GHG emissions from LULUCF** as a relatively stable net sink in the EU. The forest sink, however, is projected to decline **in the EU.** This is compensated by a decrease in deforestation emissions and an increase in afforestation removals. The decrease of the forest sink is found to be even stronger in the two policy scenarios with increased domestic biomass production, which is in-line with other reports and scientific publications. The effects on afforestation GHG removals between policy scenarios are comparatively small. The scenarios are also affecting non-CO_2 emissions. Looking at total net LULUCF and Agriculture sector emissions, it is striking that, compared to the Baseline, all scenarios reduce net emissions from LULUCF in the EU. Agriculture emissions are higher for the Constant EU bioenergy scenario but fully compensated by LULUCF CO_2 emission reductions. Looking at RoW, the net LULUCF and Agriculture emissions are projected to increase in the Increased RoW bioenergy demand scenario but also the EU emissions reduction scenario. This implies that some emissions are “exported” from EU to RoW when mitigation measures are applied within the EU.

When adding restrictions on resource use to the scenarios discussed above, all scenarios with constraints result in global net land use GHG emission reductions compared to the EU Emission reduction scenario. This means that there are clear **synergies between protecting biodiversity, avoiding the intensification of unused forests, the conversion of other natural land and global net GHG emissions from the land use sector**. However, the effects are different for EU and RoW as reduced production in EU is pushed abroad.

Case studies

Three case study countries, Finland, Germany and Italy, were analysed in more detail in terms of their current and projected biomass use and availability, as well as their existing national policies affecting the use of biomass resources. The three case study countries were found to vary considerably with respect to the resource availability, existing wood-based industries, and the scope of the use of biomass for material and energy purposes. In terms of future development in the Baseline scenario, intensification of forest use was seen especially in Finland, while the development of SRC was prominent in Germany and Italy. In addition, especially Finland and Italy were seen to increase their wood biomass imports in the future. Overall, the case study analysis supported the modelling approach, finding the projected biomass use over time to 2050 to be plausible with regards to the current resources and policies in place.

Conclusions

This project examined the resource efficiency implications of increased EU use of bioenergy for electricity and heat until 2050. The chosen approach of integrating the modelling of trade, biomass harvest, material production, and competition for biomass resources between sectors was found essential in examining the complex question of resource efficiency of increased bioenergy demand, within the EU and globally.

The results show that increased bioenergy demand leads to a stronger pressure on the forests in the EU, i.e. higher harvest levels and more intensive use of forests throughout the EU. In addition, the results show that high future bioenergy demand levels are likely to lead to increased EU biomass imports, especially wood pellets. High bioenergy demand levels are also seen to counteract cascading use of wood, and even lead to increased combustion of roundwood to energy. While on the aggregate level it is seen that the total production of wood for material use is not largely impacted by increasing bioenergy consumption, there are large sectorial differences. Some material-producing industries (esp. sawmill industries) are projected to increase their profitability, driven by increased demand for their by-products to be used to energy, some industries will face increased competition for feedstocks (esp. particleboard production). The project also shows that without the additional biomass produced from fast-growing plantations such as short rotation coppice, the pressure to use roundwood directly for energy and EU biomass imports will heavily increase.

The modelling results point to significant implications for land use and GHG emissions, especially in scenarios assuming high imports or strong development of the bioenergy sector in RoW. If constraints of land conversion are introduced into the model important synergies between biodiversity protection and GHG mitigation can be identified.

INTRODUCTION

In the European Union, biomass use for electricity and heat production is expanding. This is happening within a context of increased use of renewable energy intended to reduce greenhouse gas emissions and increase energy security. In general, the impact of increased bioenergy use on resources and on other biomass-using sectors is not sufficiently well understood. The ReceBio study, therefore, seeks to develop understanding of the various interactions and impacts that can arise as a result of different levels of EU demand in bioenergy, and their implications for resource efficiency.

The aim of the "Resource efficiency impacts of future EU bioenergy demand" (ReceBio) project is to help better understand the potential interactions and impacts resulting from increased EU demand for bioenergy, and specifically the implications for resource efficiency. To achieve this, the study as a whole builds on the best available data and understanding of biomass resource at present, and models projected use of biomass for energy and materials up to 2050. The intention is to understand the consequences on resource efficiency and the environment of pursuing different bioenergy pathways. To this end, analysis has been undertaken to understand the consequences of fulfilling different levels of bioenergy demand up to 2050 and the impacts on: the utilisation of different biomass feedstocks; land use; land management; GHG emission and biodiversity consequences. The starting point for the study is the EU 2020 climate and energy targets and the proposed EU 2030 package. In this context the scenarios, and the basis for determining the level of bioenergy demand to be assessed up to 2050, are specified building on the 'EU Reference Scenario'[1] as described in the 2014 EU Impact Assessment[2] (hereafter, "2014 IA report"). The project team has conducted detailed analysis of the availability of biomass resources and current use of biomass in the EU. In parallel, a detailed assessment of literature reviewing the impacts of biomass use on natural resources and the global environment has been made. The outputs of these assessments provided key inputs to the model-based assessment of the implications of biomass resource use.

The starting point for the analysis under ReceBio is the EU 2020 climate and energy targets and the proposed EU 2030 package. In this context, the baseline and GHG emission reduction scenarios are based on the EU Reference Scenario used in the 2014 EU Impact Assessment. The analysis focuses on biomass use for heat and electricity, hence excluding biofuels.[3]

The study has used The Global Biosphere Management Model, GLOBIOM[4], to assess the potential impacts of policy scenarios that each addresses issues of key importance as to the future bioenergy demand. The project has built up the analysis in a number of steps including:

- an assessment of the state of play and availability of biomass for energy in the EU to understand trends and use patterns (task 1);
- a review of literature relating to the impact of bioenergy on the environment to understand critical issues and potential indicators (task 2);
- modelling of policy scenarios and supporting analysis of model assumptions to assess the consequences in terms of feedstocks use and competition between their uses, land use and land management of different bioenergy use patterns (task 3);
- assessment of the impacts of these patterns against key environmental parameters (task 4);

1. European Commission. EU Energy, transport and GHG emissions trends to 2050. Reference scenario 2013. (2013)
2. European Commission. Impact Assessment: Accompanying the Communication A policy framework for climate and energy in the period from 2020 up to 2030. (2014). http://ec.europa.eu/smart-regulation/impact/ia_carried_out/docs/ia_2014/swd_2014_0015_en.pdf - see p. 24 for details of reference scenario and p. 62 for details of biomass for energy purposes.
3. The consideration of changes in biofuel demand is outside the scope of ReceBio and as such has not been specifically analysed within the study. However, feedstock used for the production of biofuels for the transport sector is included in the model in accordance to the levels stemming from the relevant scenarios of the 2014 IA Report.
4. http://www.globiom.org

- analysis of three country case examples to understand the emerging trends in policy and use of biomass and how these compare with model outputs (task 5).

This final report gives an overview of the scenario modelling results and topics that have been produced and analysed during the project. Reports for each Task are published as individual reports, and can be found at http://ec.europa.eu/environment/integration/energy/studies_en.htm.

MODELLING APPROACH AND FRAMING OF THE STUDY

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[5] and has previously been used in several European assessments[6]. 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. 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. For further information concerning the biomass feedstock and end use categories as considered within the GLOBIOM model, see Box 1.

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

- As the focus of the project is to assess the potential impact of increasing bioenergy demand, the project makes no attempt to estimate future bioenergy demand levels and all bioenergy demand projections are exogenously defined. They stem from PRIMES and POLES modelling results developed for previous Commission work. 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.
- The PRIMES estimates of bioenergy demand related to the use of wood from forests, SRC and industrial by-products is, within the ReceBio modelling, expressed as a single total demand (and not as feedstock specific demands). Where technically feasible, full substitution between the use of wood, SRC, and forest based industrial by-products is considered. While this demand must be fulfilled, the model decides, based on the assumptions applied concerning costs and potentials, which feedstocks are the most appropriate to be used to fulfil the overall bioenergy. As a result, further disaggregation regarding the sources, feedstocks and land use impacts is possible as compared to previous work.
- There is no feedback from price signals of feedstocks upon total bioenergy demand i.e. increases in bioenergy use may well push up prices for feedstocks, however, this will not feedback to reduce demand for bioenergy (over other energy technologies). The demand of food and feed commodities is on the other hand price elastic and therefore changes depending on consumers' willingness to pay. 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 for each scenario.
- During the modelling, change 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, increasing or decreasing forest carbon stocks in relation to the forest management levels are not reflected back to the bioenergy demand, however, GHG consequences are analysed as outputs of the study.

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5. 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.
6. 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.

- The starting year of the assessment is that of the year 2000, and the potential impact of bioenergy demand is being assessed until 2050. Bioenergy demand and model outcome are presented on a ten-year basis.

The results of the scenarios are analysed in terms of feedstocks use and competition between their uses, focusing on the observed results for the time period from 2010 to 2030 and further to 2050. The main interest is on the wood biomass used for heat and electricity production, and the competition between the material and energy use of wood within the EU. More specifically, the results assess changes and impacts on:

- EU land use development
- Forest harvest levels within the EU
- Development of short rotation coppices for energy production in the EU
- Use of wood biomass for material and energy production, and production of semi-finished forest products (sawnwood, plywood, fiber- and particleboards, wood pulp)

Box 1 – Introduction to the feedstock and end use categories used within ReceBio

This box gives a short description of the central feedstocks and end use categories considered in the project. This is not an exhaustive list of the biomass types considered within the project, but instead gives an overview of the main categories where central project results are reflected.

Forest based industries – the project covers production of chemical and mechanical pulp, sawnwood, plywood, fibre- and particleboard (both referred to as particleboard), and wood pellets. The initial production of commodities within GLOBIOM is based on the production quantities in the year 2000 as of FAOSTAT. In terms of the representation of the paper industrial sector, the GLOBIOM model stops at the representation of the production and consumption of chemical and mechanical pulp. The full variety of paper grades are as such not represented or individually analysed within this study.

Firewood – wood used as fuel for cooking, heating and power production in a non-industrial scale (as household fuelwood). This type of wood use for energy is a large driver for forest harvests within the EU as well as globally. However, the statistics are highly uncertain. In this project, FAOSTAT estimates of firewood within the EU were refined using data from national statistics and Joint Wood Energy Enquiry (JWEE). For rest of the world, FAOSTAT statistics were used.

Roundwood for energy – in this project, we differentiate direct combustion of industrial-quality roundwood from firewood. Roundwood for energy is defined in this project as roundwood of sufficient quality and dimension to be used for material production, but is instead used directly for energy production in small or large conversion facilities. In GLOBIOM, direct competition is modelled between roundwood used for energy and material production (mostly for pulp and particleboard production). Initially (as of 2010), it is assumed that no roundwood is being used directly for energy in EU28.

Wood pellets - Wood pellets are refined wood fuels that are mostly made of industrial by-products, such as wood chips, sawdust and/or shavings. In the ReceBio project, wood pellets produced within the EU are included within industrial residues. EU imports of wood pellets, however, are differentiated as a separate feedstock, to facilitate trade analysis. EU trade of wood pellets as of 2010 is based on EUROSTAT and Indufor data.

Industrial by-products – By-products and residues of the mechanical wood-processing industry, including chips, sawdust, shavings, trimmings and bark. They are an important raw materials for pulp, panel and pellet production, and used also as such for bioenergy.

Recycled wood – all kinds of wood material which, at the end of its life cycle, 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, and unused or scrap building wood. The availability and consumption estimates for 2010 are based on collected data from JWEE, EPF, COST 31, Wood Recyclers' Association UK, BAV Germany, and Indufor data.

Short rotation coppice (SRC) – tree plantations (mostly poplar and willow) established and managed under an intensive, short rotation regime on agricultural land. In ReceBio, the land availability for SRC and other ligno-cellulosic biomass (miscanthus, reed canary grass) is based on CORINE/PELCOM (2000) land cover estimates, and the same as in the 2014 IA report.

Harvests – in the ReceBio project, harvests refer to removal of biomass from forests or SRC.

Forest residues – leftover branches, stumps and stem tops from logging operations that can be used for bioenergy. In this project, the estimated levels for forest residue harvests are based on a compilation of national statistics and JWEE reporting.

ASSESSING ENVIRONMENTAL IMPACTS - METHODOLOGY

In earlier tasks of the project a list of potential indicators had been defined that can be used to assess environmental impacts of increased biomass use. Selected indicators related to GHG emissions and removals, potential environmental impacts on biodiversity, soil and water were translated into GLOBIOM model variables. The indicators are used to assess model output and to detect potential impacts of changes in biomass use between different scenarios in EU28 and Rest of the World (RoW). The changes in scenario assumptions are expected to affect indicators differently. For further information concerning methodology used for the assessing the impact of environmental constraints, see Box 8.

The main indicators for assessing environmental impacts of biomass use in EU28 in different policy scenarios are derived from the following model output variables:

- 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; Area of Grazing land; Area of other natural land) (see Box 2 for further information concerning the various land use categories).
- Biodiversity (addressing the model variables Unused forest area; Unused forest converted to other land use; Land with high biodiversity value (HBV); Forest rotation period.
- Greenhouse Gases (addressing the model variables Emissions from agriculture and livestock; Emissions from forest activities and Harvested Wood Products; Total net land use emissions) (see Box 7 for further information concerning the emission categories as covered by the assessment)
- Water and soil (addressing the model variables Water used for agriculture; Irrigation area; Forest area with steep slopes)

Box 2 – Introduction to land use categories used in ReceBio

Within this box some land use categories and their features under the models GLOBIOM/G4M, are defined. These serve as the basis for establishing environmental indicators,

Forest - The FAO FRA 2010[7] definition is used when classifying land as forest. Forest that is not protected is considered as potential production forest. The model allocates harvests to this area so that the projected demand for wood for material and energy purposes will be satisfied. These forests include natural and semi-natural forests, as well as forest plantations.

Used forest - Forests that are used in a certain period to meet the wood demand 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 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.

Unused forest – Forests that currently do not contribute to wood supply (for economic reasons) as determined by the model. However, these forests may still be a source for collection and production of non-wood goods (e.g. food, wild game, ornimental plants).

Area classified as afforestation - Land that has been converted to forest after the year 2000 (the start of the model run). All new forests established through afforestation are considered to be used for wood supply.

Agricultural land – Includes cropland, grazing land, short rotation coppice and other natural land.

Cropland - Land used for crop production. This also includes set-aside areas declared as cropland, but not currently used for crop harvesting (e.g. fallow land). This land category also includes annual and perennial lignocellulosic plants (e.g. miscanthus and switchgrass) that are increasingly used for biofuel production as well as Short Rotation Coppice.

Grazing land – Pasture lands used for ruminant grazing. It does not include unused natural grasslands.

Other natural vegetation or other natural land – Other natural land is a residual land use category used in the modelling to represent land that does not fall under the other used land use categories. It contains a mixture of herbaceous vegetation, abandoned cropland (if not fallow), grassland not being used, natural grassland, and marginal land. However, the category does not include settlements, wetlands, bare and artificial areas.

Protected forest areas - Protected forest areas (as defined by WDPA Consortium 2004) are delineated outside from the analysis and no conversion or use is assumed. Other conservation initiatives (e.g. Natura 2000, which are often not reserves but where sustainable management is allowed) and local protection initiatives are not considered within the analysis.

Areas of high biodiversity value (HBV) – Within the model we consider HBV areas based on the Carbon and Biodiversity Atlas by WCMC[8]. This atlas presents a set of maps of different biodiversity hot spots. In this study, we assume that where at least three maps of biodiversity hot spots of species groups (e.g. birds, mammals) overlap, land is considered to be of high biodiversity value. These areas are then overlaid with the land use information in GLOBIOM. HBV areas can be found on cropland, grazing land, used and unused forests and other natural land.

7. FAO 2010: Global Forest Resources Assessment 2010. Main report. United Nations Food and Agriculture Organisation, Rome. p. 378 http://www.fao.org/docrep/013/i1757e/i1757e.pdf
8. http://www.unep.org/pdf/carbon_biodiversity.pdf

THE BASELINE SCENARIO – A STARTING POINT FOR ASSESSMENT

The basis for the baseline scenario examined in ReceBio is 'EU Reference Scenario' of the 2014 IA Report. The goal of the baseline scenario is to depict a future with continued increasing global population, intermediate economic developments including consideration to EU's economic downturn, and an overall long term increase of fossil fuel import prices to EU. More specifically, it is assumed that import prices of fossil fuels will increase by 50% or more in the period of 2010-2030, in line with projections from world energy system modelling exercises. Moreover, the scenario portrays a future in which consumption patterns of food, fibre, and fuels continue to evolve over time following current trends.

The baseline scenario also considers the same range of policy targets as assumed for the 'EU Reference Scenario'. It takes into account a broad range of policy commitments, currently implemented policies, legislations and targets that have been announced by countries and adopted by late spring 2012. Key policies for the EU that are considered include the EU ETS Directive (2009/29/EC), the Renewable Energy Directive (2009/28/EC), Energy Efficiency Directive (2001/27/EU), and GHG Effort Sharing decision (No 406/2009/EC). From 2020 onwards, no changes in policies are assumed and no new policies are considered.

Resulting from these policies, and as estimated for the 'EU Reference Scenario', renewable energy share (RES) in the EU28 would account for a 24.4% of gross final energy consumption by 2030, and 28.7% in 2050. Bioenergy plays an important role in this trend and total bioenergy production from biomass and waste increases from 85 Mtoe in 2005 to 124 Mtoe in 2010, 150 Mtoe in 2020, date after which bioenergy production increases at a slower pace until 2050 (to 153 Mtoe to 2030, and 164 Mtoe as in 2050)[1].

The ReceBio Baseline Scenario is based on the same underlying assumptions concerning socio-economic growth, statistical data, and policy targets as for the 'EU Reference Scenario'. It assumed the same total bioenergy demand as that for the 'EU Reference Scenario'. However, under the ReceBio Baseline Scenario certain assumptions made in the 'EU Reference Scenario' have been further developed to take account of additional information identified and assessed within the project and to enable more effective assessment of bioenergy demand. The key differences are set out below:

Data concerning wood-based industries, as collected in the state of play assessment (Task 1), has been integrated within the modelling framework. This allows for more accurate representation of these industries as well as the biomass sources being used for the production of the various woody commodities.

Collection and consumption of particular wood biomass resources has also been updated taking into account latest available data as collected with Task 1. In particular, firewood (household fuelwood) consumption, collecting of forest residues (e.g. leftover branches, stumps and stem tops from logging operations), and recycled 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.

International trade of primary woody products, namely chips for material use, pellets, and roundwood has also been updated within the project based on data as available and collected within the framework of the project.

Key results and trends in the Baseline scenario

The baseline scenario shows a clear increase in the use of wood up to 2050, for both material and energy purposes in the EU. The increased demand for wood biomass is seen to lead to an intensification in the use of forests in the EU28. There is an expansion in the area of used forest in Europe. There is also a significant expansion in the use of SRC both in terms of volume consumed and area of land devoted to production. These expansions in used forestry and land devoted to SRC lead to a decline in the area of unused forest (most notably leading up to 2050) and a more significant decline in the area of 'other natural land'. These trends of intensification of land use and land use change are also observed in the rest of the world (outside the EU).

Key results and trends identified in the baseline analysis are set out below.

Changes in wood flows and the use of bioenergy feedstocks

The baseline scenario projects a clear increase in the use of wood for both material and energy from the 2010 levels. Material use of wood is increasing over time, driven by socio-economic development and export of semi-finished wood products. The overall consumption of wood for energy is estimated to expand from 306 million m^3 in 2010 to 419 million m^3 in 2050. This includes black liquor and other industrial by-products used for energy, as well as firewood, forest residues, recycled wood, imported wood pellets and SRC produced for energy. In terms of the comparative uses of wood, the proportion of total wood consumption going to energy use increases between 2010 (36%) and 2050 (38%). It should be noted, however, that the consumption level for material use of wood also grows over the same period (from 535 to 686 million m^3, some of which will become residues and by-products, and be used for energy) although not as sharply as the wood to energy consumption (as indicated by the shift in proportions).

Figure 1 illustrates the flow of wood biomass between the different wood using industries in the EU. The figure provides an overview of the flow of wood in the Baseline scenario for the years 2010, 2030, and 2050. Analysis of these figures shows clear growth in the forest-based industries producing materials, driven by increasing population and GDP development. This growth is seen in all material production (sawnwood, wood-based panels and pulp production). The increased material production also leads to an increased production of industrial residues and by-products used for energy purposes.

The flow charts highlight that a significant amount of wood will be required for meeting the bioenergy demand. A large part of this is sourced from SRC, which increases from a negligible amount in 2010 to 60 million m^3 in 2050. By-products of the material-producing industries are also a notable source of biomass for energy. In addition, the net-import of wood pellets is expected to increase from 10 Mm^3 in 2010 to 23 Mm^3 by 2050. USA and Canada are still foreseen as major trading partners for pellets, but Latin America, the former USSR, and South-East Asia are also expected to develop into major players on this front. Contrary to other sources of wood biomass for energy, the amount of firewood is estimated to decrease within EU28, driven by an expected shift from domestic to district heating (this development is modelled in line with estimates from PRIMES).

Agricultural residues and biogenic waste are an important source of bioenergy. The increasing use of these feedstocks for energy purposes is within this project fully in line with that of the 2014 IA report.

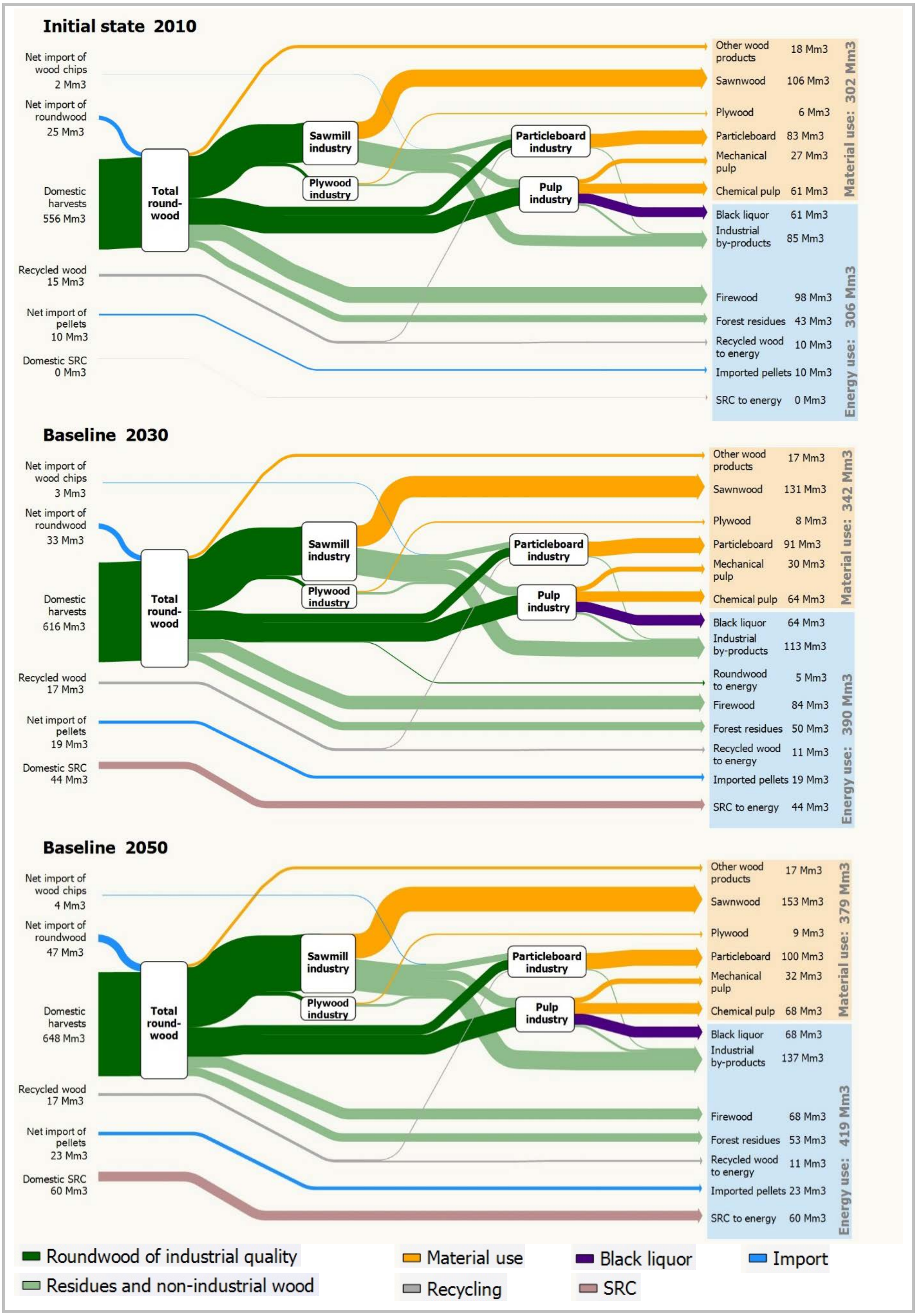

Figure 1. *Flow of wood in the EU in the Baseline scenario, in million m³ wood/solid wood equivalent. Note that the volumes of particleboard, mechanical and chemical pulp, and black liquor reflect the amount of wood in the products, not the actual material yield.*

Harvest rate and forestry production

In the baseline scenario, the total forest harvest level in EU increases clearly, from 556 million m^3 in 2010 to 616 million m^3 in 2030 and 648 million m^3 in 2050. In particular harvests for material production, especially sawlogs, show a steadily increasing trend, and this expanding trend appears to drive overall harvest level. Harvests for energy stay on a more stable level until 2030. After 2030, harvest levels for energy actually decrease (from 158 to 143 million m^3). The key driver for this decrease is the decreasing use of firewood. In addition, increasing import of wood pellets and the expansion in SRC for energy purposes replace harvested wood from forests for energy. Overall, this draws also the total harvest level downwards, causing a slightly slower increase of the total harvest level after 2030 than in the prior two decades.

As shown in *Table 1*, the baseline results for 2010 are on the same overall level as the corresponding levels reported by the EUWood study[9] and by Indufor[10]. Discrepancies between the different studies can largely be attributed to uncertainty/lack of reliable EU statistics relating to household fuelwood use.

Table 1. *Comparison of the project results and reference literature on wood consumption in the EU28, divided into material and energy uses.*

Study	EUWood	Indufor	ReceBio Baseline		
	2010	2011	2010	2030	2050
					Million m^3
Total Wood Consumption	825	942	841	1004	1106
Total Material Use*	*457*	*649*	*535*	*613*	*686*
Wood Products Industry**	314	308	367	436	498
Pulp and Paper		341			
Pulp	143		162	172	182
Total Energy Use, excl. SRC	*368*	*293*	*306*	*346*	*359*
Wood products industry side streams***		150	155	188	216
Wood used primarily for energy****		143	151	158	143
Energy Biomass from SRC			0	44	60
Energy use, %	**45%**	**31%**	**36%**	**39%**	**38%**
Material use, %	**55%**	**69%**	**64%**	**61%**	**62%**

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. The flowcharts used in this report (e.g. Figure 4) bypass this problem by showing the actual wood biomass flows through the industries.
*In ReceBio: Sawmill and board industries, pulp production, and recycled wood used for material
**In ReceBio: Sawmill and board industries
***In ReceBio: Sawdust, wood chips, bark and black liquor used for energy, and recycled wood
****In ReceBio: fuelwood, forest residues, industrial-quality roundwood used directly for energy, imported pellets.

9. See Mantau et al. 2010. Real potential for changes in growth and use of EU forests. EUWood final report. Project: Call for tenders No. TREN/D2/491-2008.
10. See Indufor 2011. Study on the Wood Raw Material Supply and Demand for the EU Wood-processing Industries. Final report. European Commission, Enterprise and Industry Directorate General.

KEY RESULTS FOR SCENARIOS WITH VARYING EU BIOENERGY DEMAND

The baseline selected for this study forms a point of comparison in terms of understanding different evolutions in bioenergy use. Within ReceBio, in addition to the baseline, four scenarios modelling different potential evolutions in the bioenergy demand profiles and trade were set out. These scenarios are:

- the EU Emission Reduction scenario – that GHG40/EE scenario from the 2014 IA Report. This scenario delivers 40% GHG emissions reduction in the EU by 2030 as compared to 1990, together with a 26.4% share of renewable sources in total energy consumption and total energy savings of 29.3% by 2030 (as compared to 2007 projection for 2030). The scenario also delivers a 2050 GHG emission reduction target of 80 % reduction of emissions with respect to the 1990 emission level. Further, energy savings are estimated to develop in line with the GHG40/EE scenario, and are -29.3% in 2030 compared to the 2007 baseline projections, leading to lower demand for biomass for energy as of 2030 than that of the ReceBio baseline scenario;
- the Constant Bioenergy Scenario – that uses the GHG40/EE as a basis but fixes levels of bioenergy demand for the EU at 2020 between 2020 and 2050, i.e. demonstrating consequences of a stabilised bioenergy demand. Bioenergy demand as of 2020 for the Constant Bioenergy Scenarios is lower than that in the baseline scenario for 2020, as a result of the implementation of energy efficiency measures that follow the development of the GHG40/EE scenario until 2020;
- the Increased Rest of the World Demand scenario – that assumes the GHG40/EE pattern of bioenergy demand for the EU, plus increased demand for bioenergy in the rest of the world, based on the GECO Global Mitigation Scenario[11] recently published by the European Commission; and
- the Increased EU Biomass Import Scenario – that assumes the GHG40/EE levels of bioenergy demand for the EU but an enhanced level of biomass imports modelled through decreased trade costs between the EU and Rest of the World for feedstocks for energy and material use.

This section of the final report will primarily focus on the results for the EU Emission Reduction scenario and associated consequences; the most important results from other scenarios under ReceBio are also presented here (see Box 4, 5, and 6). The full project results are published as five individual task reports, and can be retrieved at: http://ec.europa.eu/environment/integration/energy/studies_en.htm

It should also be noted that absolute energy consumption from renewable sources in 2030 is slightly lower in the EU Emission Reduction scenario than in the EU Reference Scenario. This is due to energy efficiency policies that contribute to reducing overall energy demand in the GHG40/EE scenario. Total bioenergy demand in the EU follows a similar pattern, reaching a level of 166 Mtoe in 2030 under the GHG40/EE as compared to 178 Mtoe in the EU Reference Scenario. After 2030, however, bioenergy demand increases in the GHG40/EE scenario at a much higher rate than in the EU Reference Scenario. The increase in bioenergy demand after 2030 in the GHG40/EE scenario is mainly driven by the imposed 80% GHG reduction target by 2050 with respect to the 1990 emission level.

Key results and trends – understanding different patterns of bioenergy demand

The development seen in the Baseline scenario is found to be accentuated in the EU Emission Reduction scenario up to 2050. In this scenario, the development of biomass use follows a trend to a large extent similar to that of the baseline scenario until 2030. Thereafter, the results show a considerable increase in the use of imported pellets (52

11. This scenario depicts a development wherein joint global efforts are taken to reduce GHG emissions beyond 2020 in line with ambitions to keep global warming below 2°C. Globally, the current use of biomass in the energy sector represents about 50 EJ/yr, which develops in 2050 to more than double in the Baseline Scenario and triples to 150 EJ/yr in the Global Mitigation Scenario.

Mm^3 in 2050, double to that in the Baseline), SRC (161 Mm^3 in 2050, almost triple compared to Baseline), and, additionally, we see also large quantities of roundwood (of pulpwood quality and dimensions) directly being used for bioenergy production (78 million m^3 in 2050). The increased use of biomass for energy has a direct impact on forest harvests, which are more than 700 million m^3 in the EU Emission Reduction scenario in 2050, almost a 9% increase when compared to the Baseline results for that year (*Figure 2*).

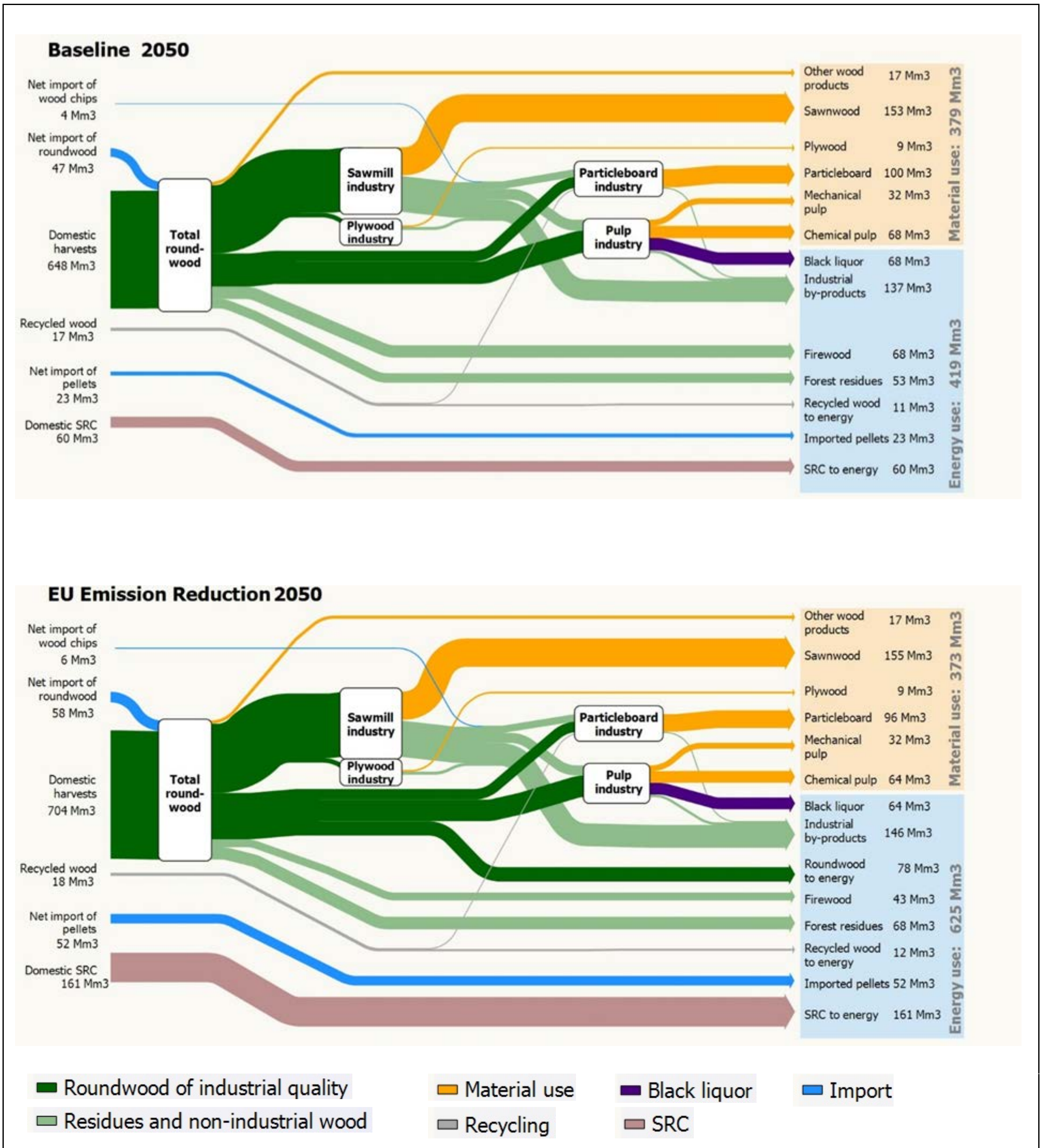

Figure 2. *The wood flows in the EU28 in 2050 in the baseline and EU Emission Reduction scenarios, in Mm3 solid wood equivalent. Note that the volumes of particleboard, mechanical and chemical pulp, and black liquor reflect the amount of wood in the products, not the actual material yield.*

Harvest rate and forestry production

The forest harvests in the EU Emission Reduction scenario increase over time. Until 2030 harvest levels are slightly lower than those seen in the baseline, associated with the reduced demand for energy resulting from higher effort in terms of energy efficiency; from 2030 onwards, harvest levels increase above and beyond the Baseline.

Up until 2030, use of wood for material purposes is expected to be the major driver for the increasing forest harvests in the EU (*Figure 3*). This development has its roots partly in the strong interrelationship between material and energy uses of wood; increasing material use of wood also provides more biomass for energy through industrial by-products. The increase in material production, and associated by-products, is almost enough to satisfy the bioenergy demand until 2030 (together with increasing SRC and pellet imports).

Beyond 2030 high bioenergy demand under the Emission Reduction Scenario has a clear impact on the overall forest harvest level. After 2030, the increasing harvests of wood for direct energy production is expected to become the main driving force for the increasing forest harvests in the EU. This development affects especially the harvest of wood that is of pulpwood-quality and a sufficient dimension to be used for material purposes, but that is used directly for energy production. *Figure 3* highlights the changing patterns of harvest and the associated drivers, comparing the results from the Baseline and EU Emission Reduction Scenarios.

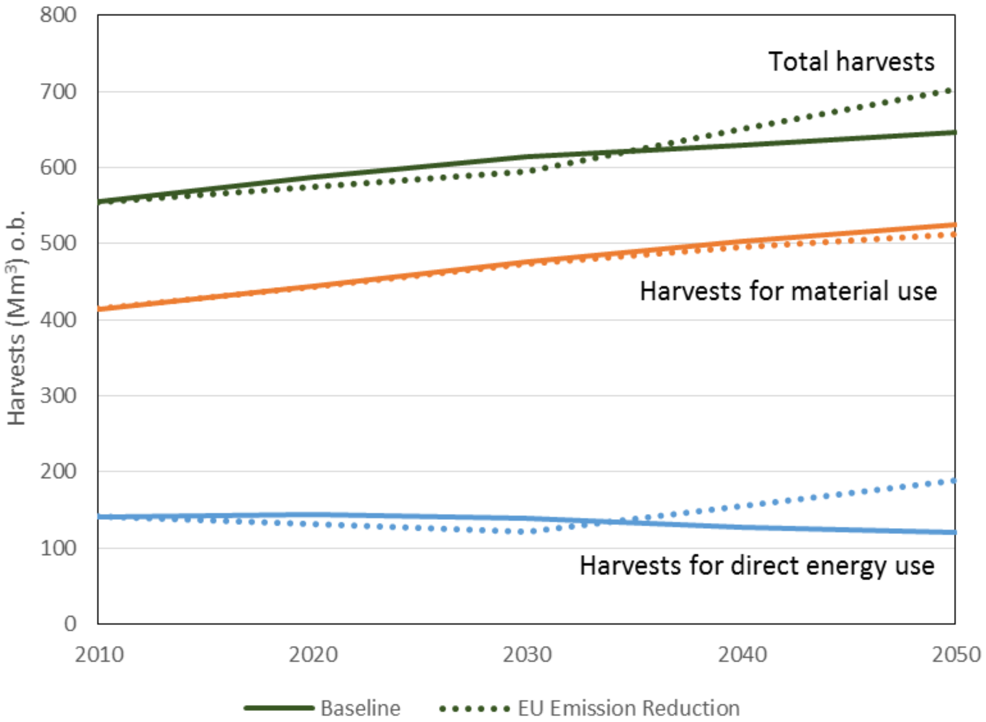

Figure 3. *Forest harvests in the baseline and the EU Emission Reduction scenario. The category "Harvests for direct energy use" combines harvests of forest residues, fuelwood, and pulpwood that are used for energy as such, or after chipping and/or pelletization. "Harvests for material use" shows the harvested amount of wood that is used for material production in the forest industries and production of other wood products (part of this volume will eventually become industrial residue and be used as energy as well). Total harvests is the aggregate of forest harvests for energy and material use.*

Box 3 – Examining the role of recycled wood and its relationship with forest harvests

Using more recycled wood for material production represents a potential opportunity to increase the resource efficiency of biomass consumption in the EU. Potential future amounts of recycled wood are, however, difficult to model due to data availability. Information on current and historical amounts and prices are not fully available or based on rough estimates. The level of recycled wood assumed in ReceBio is therefore based on the statistics collected in the Task 1 of the project and assumed to stay constant throughout the projection period.

To investigate the impacts of the assumptions made for the level of recycled wood available for material use, the EU Emission Reduction scenario was run with varying levels of recycled wood. The amounts of recycled wood were increased by 20%, 40%, 100% and 200% by year 2050 from the amounts as assumed in the EU Emission Reduction scenario. The displacement impacts in material wood use and consequences for energy use of wood are elaborated in *Figure 4*.

The results show that, when recycled wood was increased, it released industrial by-products from material (left-hand side of *Figure 4*), which, consequently, are used for energy purposes and in turn decreased the use of pellets, roundwood and SRC for energy (right-hand side of *Figure 4*). In other words, the increasing use of recycled wood for material purposes leads to a decreasing use of pellets, roundwood and SRC for energy.

Increased wood recycling also increases the use of pulpwood in the material sectors: the majority of recycled wood is used for particleboard production, and a certain amount of virgin wood is needed in the production process alongside with recycled wood. Most of the industrial residues replaced by recycled wood in material production will instead be used for energy production. Nevertheless, even when increased by 200%, the amount of recycled wood for material production is only 3% of the total wood biomass used for material and energy. As a result, the changes modelled in the level of wood recycling were found not to have a notable impact on the forest harvest levels in the EU.

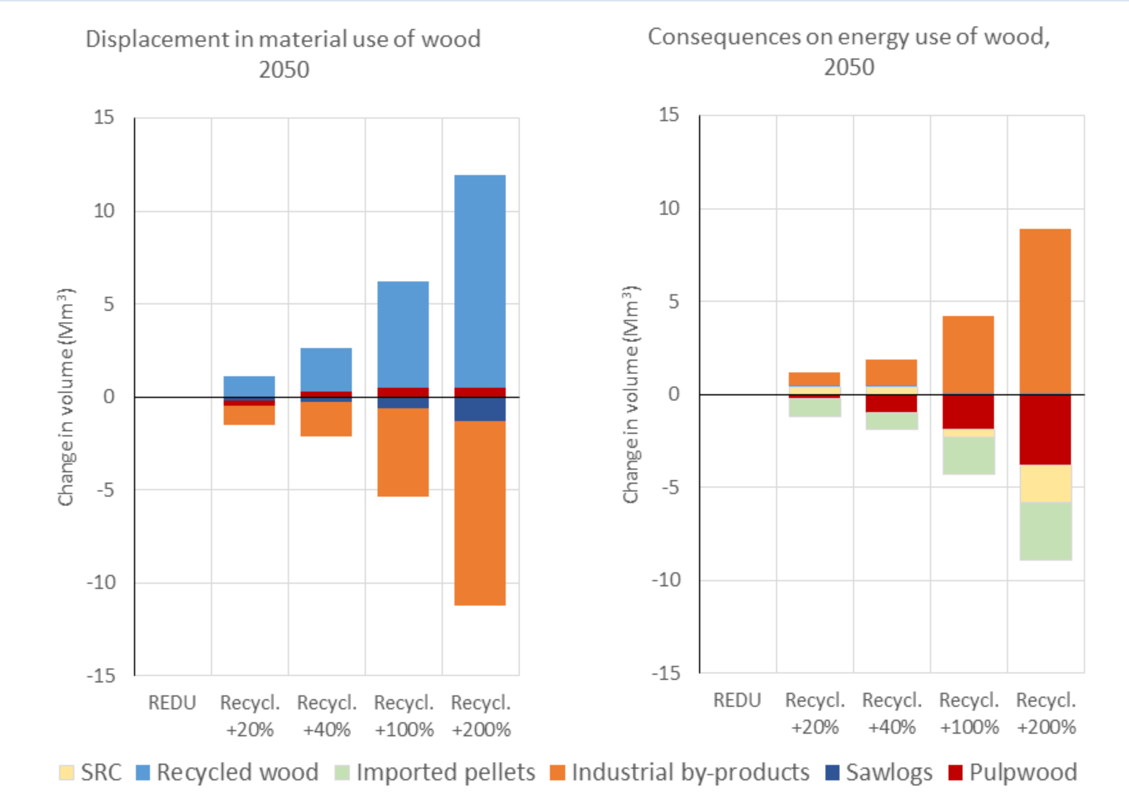

Figure 4. *Effect of increasing the amount of recycled wood used for material production on the types of woody biomass used for material and energy in 2050. Positive values represent an increase in the use of the biomass feedstock for material or energy use, while negative values represent a decreasing use of biomass feedstock for material or energy use.*

The changing profile of biomass feedstocks use

Analysis of the Emission Reduction scenario identifies several key trends in terms of the type and origins of biomass being used for energy production. This includes: the rising use of roundwood (specifically pulpwood) for energy production; increasing levels of pellet imports; and expanding use of SRC. These trends were all originally noted in the baseline, but are exacerbated by the increasing bioenergy demand seen to 2050 under the Emission Reduction Scenario. When considering the changes in feedstock use we found important to understand better both the nature of the feedstocks being used and what happens if a particular feedstock is not forthcoming as anticipated by the model.

The results from the model, for both the Baseline Scenario and to an even greater extent under the Emission Reduction Scenario, show a highly significant expansion in the EU in the use of SRC towards 2030 and 2050, rising both in volume and in surface area (from 0.4 in 2010 to 66 million m^3 by 2050 and from 10 000 ha in 2010 to 3.4 million ha in 2050 under the Baseline, and to 161 million m^3 and 8.9 million ha in 2050 in the EU Emission Reduction scenario). Rapid development of SRC in both scenarios indicates that satisfying a high demand of biomass for energy will rely increasingly on the development of SRC.

Evidence from other studies and from discussions with experts has suggested that SRC is often difficult to gain acceptance of in terms of promoting its expansion. There are barriers to farmers establishing SRC, which are perhaps not totally reflected in a purely economic model. This includes the loss of flexibility in terms of crop rotation/response to the market and the lack of income over the establishment period of the crop. As a consequence, the assumptions regarding feedstock availability were investigated further to better understand what would occur in the absence of the SRC expansion (*Figure 5*). The results show that, if SRC would not develop as estimated in the model, a majority of the ‘gap’ would be taken up by increasing use of roundwood for direct combustion and by imported pellets. A similar analysis for other feedstocks also shows the importance of SRC expansion in providing for any ‘gap’ in supply were, for example, forest residues or pellet imports to be restricted (available in the Task 3 report).

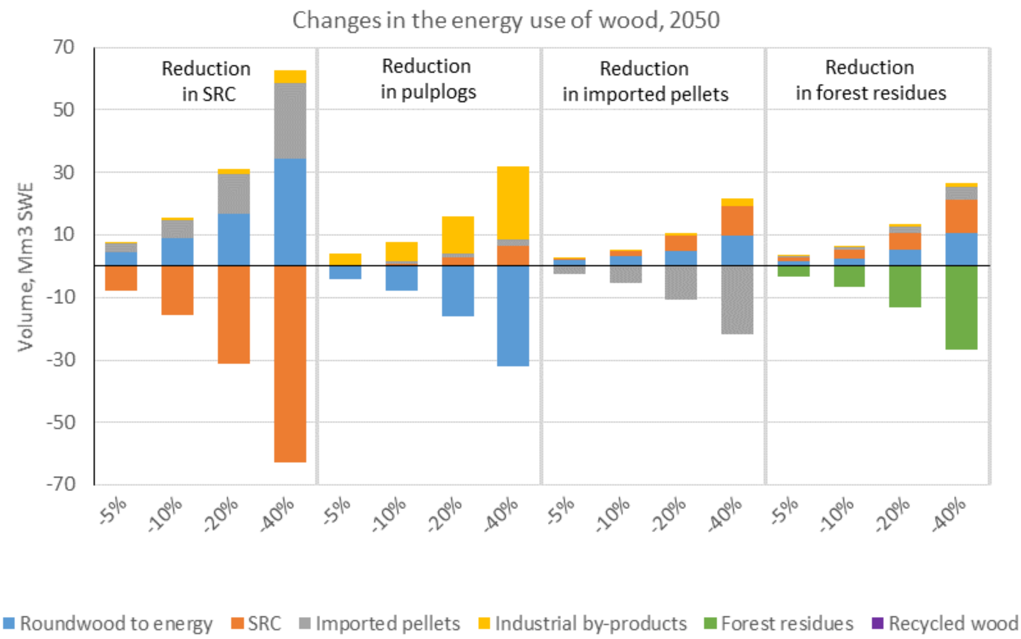

Figure 5. *The effects of a reduction in one type of feedstock on the use of other wood biomass for energy in 2050. In this analysis the levels of each feedstock category seen in 2050 under the Emission Reduction Scenario were progressively reduced by between 5 and 40 per cent to understand the consequences of reducing a specific feedstock stream and the feedstocks that might plug the ‘gap’ in supply generated.*

Box 4 – What is the Impact on Feedstock Use of Increased Imports of Biomass?

The increased EU Biomass Import scenario investigated the impact of increasing the EU reliance on imported biomass feedstocks to EU from the Rest of the World. The scenario as such assesses how the pressure on domestic production would react to increasing EU reliance on imported biomass. In this scenario, the trade cost of biomass feedstocks for energy and material purposes was decreased by roughly 12% for the year 2030, and 32%[12] for 2050. Under the EU Biomass Import Scenario the EU net import of pellets grows to 218 Mm^3 in 2050 (more than four times the amount foreseen in the EU Emission Reduction scenario), and the net import of roundwood grows to 71 Mm^3 by 2050 (a 22% increase when compared to the EU Emission Reduction scenario).

Recently, EU imports of wood pellets from North America, especially the USA, have increased considerably. This development is seen to continue in the ReceBio scenarios, but further expansion in pellet demand seen under the EU Biomass Import scenario suggests increasing EU pellet imports also from other parts of the world, especially from Canada, Latin America and South-East Asia. Following the growth of pellets into a major biomass feedstock for energy, domestic harvests in the EU will only increase modestly over time in this scenario. As a direct effect of the increased pellet imports, the EU forest harvest level decreases and is only 624 Mm^3 in 2050, an 11% decrease from the EU Emission Reduction scenario and a 3.7% decrease from the Baseline scenario. A further consequence is that the material production level in the EU also grows slightly (especially particleboard and chemical pulp production).

Box 5 – What if the bioenergy demand stabilises after 2020?

To investigate development where no further action for promoting the development of the bioenergy sector comes into play after 2020, a scenario referred to as the Constant Bioenergy Demand scenario was constructed. In this scenario, the bioenergy demand in EU28 follows the same trend as the other scenarios until 2020 and stays constant thereafter. This implies that the total energy production from biomass and waste for EU28 stays constant after 2020 at the approximate level of 150 Mtoe.

As the population and GDP development is still projected to continue under the Constant Scenario as in Baseline, the main driver for the consumption of woody products is the same between the scenarios and there are only small differences between this scenario and the Baseline on the material production side. There is, however, a clear difference in the composition of feedstocks used for energy production. Most importantly, pressure to produce SRC for energy is significantly reduced. Meeting bioenergy demand up to 2020 requires an increase in the production of SRC, thereafter the bioenergy demand can be increasingly satisfied through other feedstocks. As for SRC, pellet imports also increase until 2020, but remain almost constant thereafter. In this scenario, no roundwood of sufficient quality and dimensions to be used for material production is projected to be used directly for bio-energy purposes.

The stagnation in the heat and power sector in terms of bioenergy use under Constant Bioenergy Demand scenario results in a higher level of fuelwood used for domestic heating than in the Baseline. Overall, the harvest level in the EU in 2050 is 15 million m^3 (2.3%) lower than in the Baseline. When compared to the Baseline scenario under the Constant Bioenergy Demand scenario there is more particleboard production and less sawnwood production. This can be explained as follows:

- the demand for industrial by-products from sawmills (chips and sawdust) for bioenergy production is lower reducing sawmill profitability and leading to lower levels of production;
- the drop in bioenergy demand for the chip and sawdust by-products causes prices to drop making particleboard production, utilising these feedstocks, more profitable.

12. The levels were chosen so that they incur a notable change in trade patterns compared to the Baseline scenario, while still representing a plausible change in costs.

Box 6 – The impact of expanding global demand for bioenergy

In the EU Emission Reduction scenario, EU imports of both roundwood and wood pellets increase notably. From this follows that the availability of imported feedstocks is increasingly dependent also on the demand for biomass outside of the EU. The imports may not materialize if countries outside of EU are increasingly reliant on their own biomass sources to fulfil their own increasing bioenergy demand. This development was assessed in the "Increased Rest of the World (RoW) Bioenergy Demand" scenario, wherein joint global efforts to reduce GHG emissions beyond 2020 were assumed, thereby enhancing the development of the bioenergy sector for the RoW. In the EU, the bioenergy increase was modelled similarly to the EU Emission Reduction scenario. Consequently, this scenario depicts a situation where EU may not be able to import as much of the biomass feedstocks as in the other scenarios.

The results show that, with an increased RoW bioenergy demand, net EU import of wood pellets is only 39 million m^3 in 2050, 25% less than in the EU Emission Reduction scenario. In addition, also EU roundwood imports decrease by more than 20%. This puts more pressure to the development of the SRC sector in the EU: in this scenario, the production of SRC in the EU28 is the highest of all scenarios at 172 million m^3 in 2050 (a 7% increase to the EU Emission Reduction scenario). Material production levels stay at almost the same level as in the EU Emission Reduction scenario. However, as EU roundwood imports decrease, the domestic forest harvest level increases to 718 million m^3 in 2050 (14 Mm^3 higher than in the EU Emission reduction scenario, and 162 Mm^3, or 29%, higher than in 2010).

There are significant impacts on land use and environmental factors as a consequence of expanding rest of the world demand for bioenergy in combination with that of the EU28. These impacts on land use change and environmental indicators are discussed below, and in more detail in the Task 4 report.

LAND USE CHANGE AND ENVIRONMENTAL CONSEQUENCES

Land use change

The key changes in land use already under the Baseline scenario are an increase in the area of cropland and used forest in the EU, driven to some degree by the increased demand for SRC and increased forest harvest level, respectively (***Figure** 6*). Following this development, we see a decline in the area of unused forest and, most significantly, other natural land. These trends are seen to be enhanced further under the Emission Reduction scenario with, by 2050, higher amount of land being used in the EU for SRC, and lower amounts of other cropland and other natural land (including abandoned cropland and grazing land) and grazing land (2030 and 2050). When comparing the Baseline and Emission Reduction Scenario, the total forest area (sum of used and unused forest) does not differ significantly; however, there are comparably large shifts within the forest, converting unused forest to used forest.

Land use change in the rest of the world, i.e. outside the EU 28, is seen to change under the Baseline Scenario with again other natural land and unused forest being converted into cropland, grazing land and used forest (*Figure 7*). However, there is an additional impact in terms of land use change in the rest of the world associated with the EU Emission reduction scenario: if only EU increases its bioenergy demand, leading to relatively more cropland and SRC area in 2050 and less other natural and unused forests. For 2030, similarly to the development in EU28 the reverse effect can be observed due to efficiency increases reducing biomass demand.

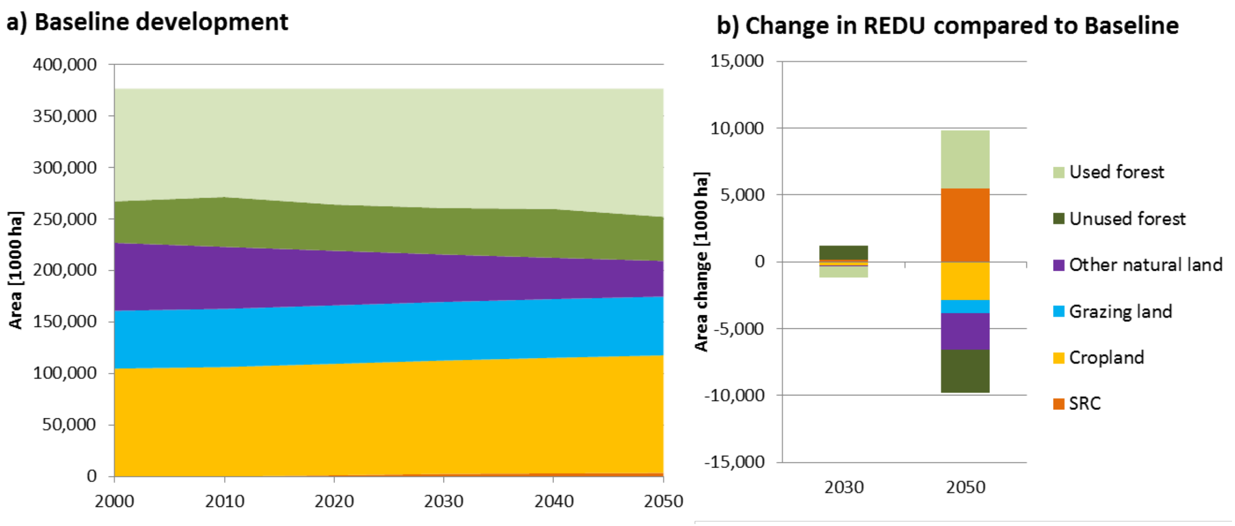

Figure 6. *Land use in EU28 in the Baseline a) and differences in the EU Emission reduction scenario (REDU) between 2010 and 2030/2050 b).*

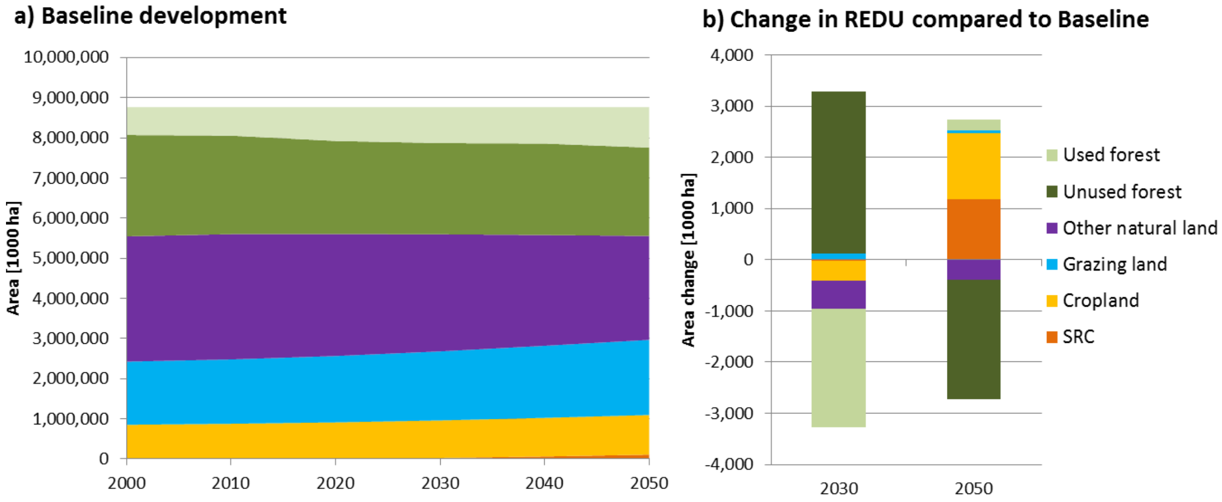

Figure 7. *Land use in RoW in the Baseline a) and differences in the EU Emission reduction scenario (REDU) b).*

Biodiversity

Under both the baseline and the EU emission reduction scenario, the impacts in the EU28 on land classified as high biodiversity value are comparably low. This is due to the fact that less than 1% of the area considered in the model in the EU28 is categorized as area of high biodiversity value, according to the global biodiversity data set from IUCN-WCMC. Looking at the rest of the world, the conversion of land with high biodiversity value is more important because 20% of the global land area considered by the model is highly biodiverse. Unused forests form the largest share of the areas impacted, followed by other natural land and grazing land. It should be noted that, as for land use change, the Baseline results already show a significant impact on highly biodiverse areas in the rest of the world. Under the EU emission reduction scenario, these impacts are further increased but rather limited compared to the Baseline.

Box 7 – Introduction to LULUCF and Agriculture GHG emissions and removal categories used in ReceBio

This box gives a short description of the various GHG categories reported in this project. This is not an exclusive list of all the sources and sinks that are accounted for within the project, but instead gives an overview of the main categories where central project results are reflected.

Afforestation – the category includes emissions and removals related to afforestation and accounts for changes in biomass, soil, and dead organic matter.

Deforestation – the category includes emissions and removals related to deforestation related to changes in biomass, soil, and dead organic matter.

Forest Management – the category includes emissions and removals related to change in the above and below ground forest carbon stock. The change in the forest carbon stock mainly relates to changes in the thinning intensity and choice of forest rotation length.

HWP – the category accounts for emissions and removals related to changes in the Harvested Wood Products (HWP) following the Durban Accords (Decision 2/CMP.7) and respective Tier 2 IPCC guidelines. The pool is initialized in the year 2000 and as such assumed to be in stable state at that time period.

Net Forestry emissions – total net emissions and removals from Afforestation, Deforestation, Forest Management, and HWP.

LULUCF – the category represents the total net emissions and removals from Land use, Land use Change, and Forestry (LULUCF). In addition to the net forestry emissions, the category accounts for emissions/removals from land use change in terms of biomass stocks and soils, and CO_2 emissions/removals from cropland management. Soil carbon emissions are reported using a Tier 1 approach based on GHG accounting IPCC guidelines. Emissions/removals from wetlands, settlements, and other land use are not considered in this project.

Agriculture – the category represents the total net emissions from the agriculture and livestock sectors. This includes soil N_2O emissions from fertilizer application (mineral and organic), CH_4 emissions from rice cultivation, N_2O and CH_4 emissions from the livestock sector (enteric fermentation, manure management, and manure dropped on pastures).

AFOLU – the total net of emissions and removals from LULUCF and Agriculture.

GHG emissions

Land use change has a number of important associated environmental impacts and consequences. Under ReceBio specifically, besides biodiversity impacts, GHG emission balance implications have been investigated. GHG emissions effects primarily stem from changing patterns of forest use, patterns of afforestation and deforestation, the decline in other natural land and the changes in the use of agricultural land i.e. cropland and grassland.

When considering the GHG emissions, there are a number of aspects that were analysed. Compared to the Baseline, the forest management carbon sink is seen to decline more strongly by 2050 in the EU under the EU Emission reduction scenario (see *Figure 8*), demonstrating a more intensive use of the forests. In 2050, the EU emission reduction scenario shows decreased EU deforestation emissions that are compensating for the loss of the forest sink to a large degree. Under the EU Emission reduction scenario, sequestration into harvested wood products in 2050 is 6 Mt CO_2eq higher compared to the Baseline. More products are being produced causing the stock of carbon stored in wood products to increase. Under the Baseline, there is already a strong increase in afforestation GHG removals over time and, comparatively, there is only a small effect on afforestation GHG removals in the EU Emission reduction scenario. In total, compared to the Baseline, the EU emission reduction scenario is reducing net annual emissions from LULUCF and Agriculture for the EU28 in 2030 and 2050 (see *Figure 9*). Agriculture emission reductions are mainly caused by reduced livestock production that is shifted outside EU while demand for livestock products remains more or less unchanged.

Under the EU Emission reduction scenario, both CO_2 and non-CO_2 annual GHG emissions increased in the rest of the world in 2050 when compared to the baseline (see ***Figure*** *10*). This implies that the EU exports emissions to the rest of the world as a consequence of increasing land used for bioenergy in the EU but also reduction of livestock production and increased imports of such products.

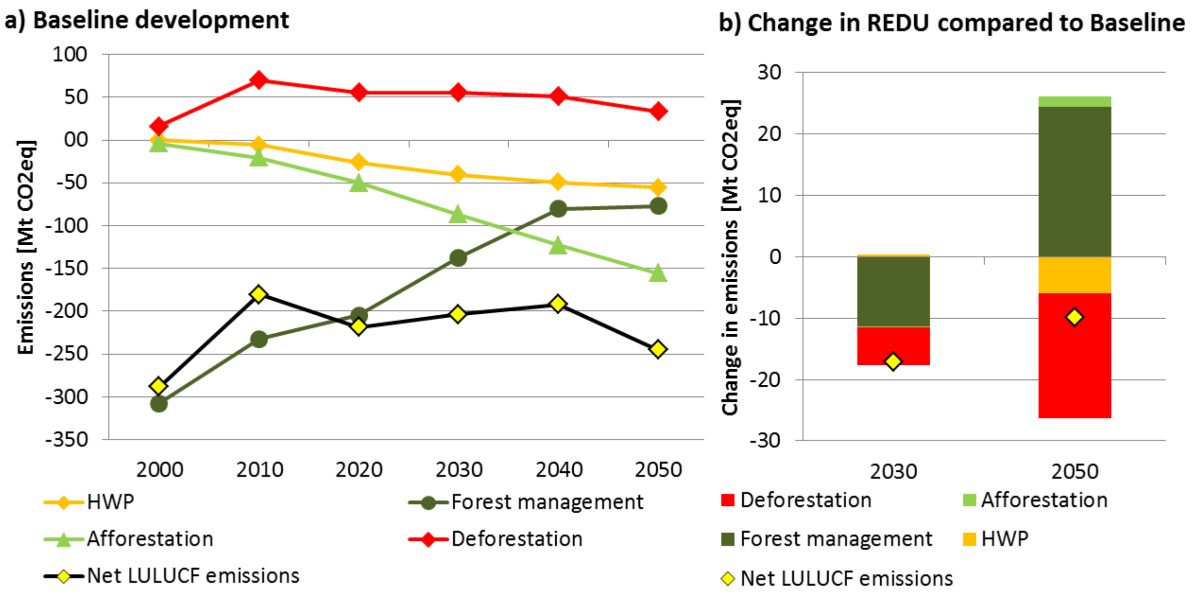

Figure 8. *LULUCF GHG emissions in EU28 in the Baseline a) and differences in the EU Emission reduction scenario (REDU) b). Net LULUCF emissions represent the change in net annual emissions and removals from Land use, Land use Change, and Forestry.*

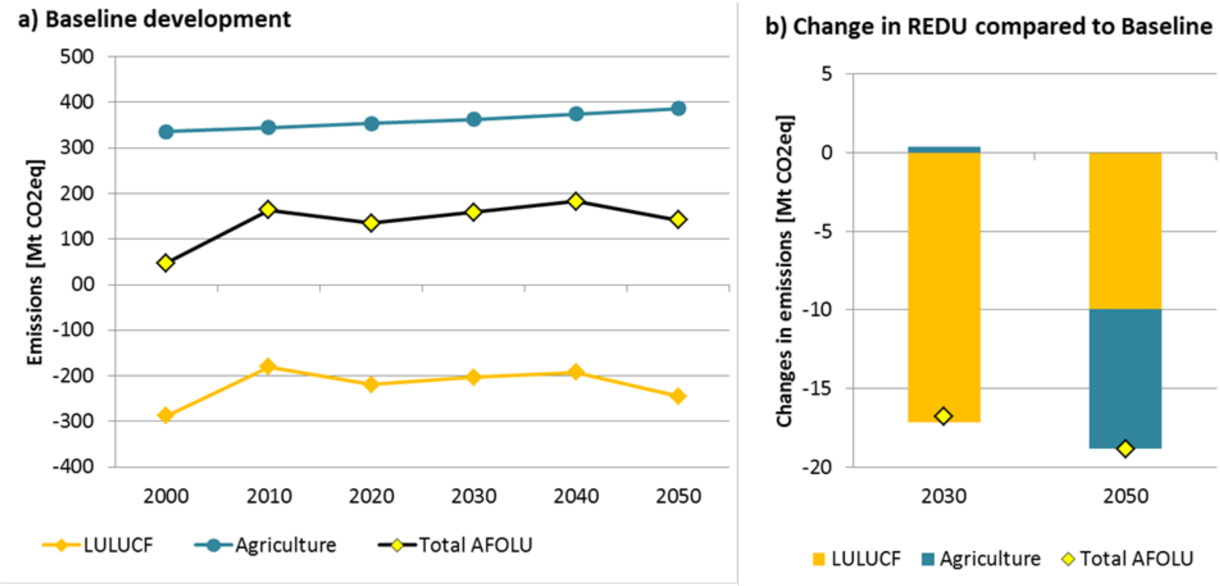

Figure 9. *Total annual land use GHG emissions (LULUCF plus agriculture) in EU28 in the Baseline a) and differences in total net annual emissions for the EU Emission reduction scenario (REDU) b).*

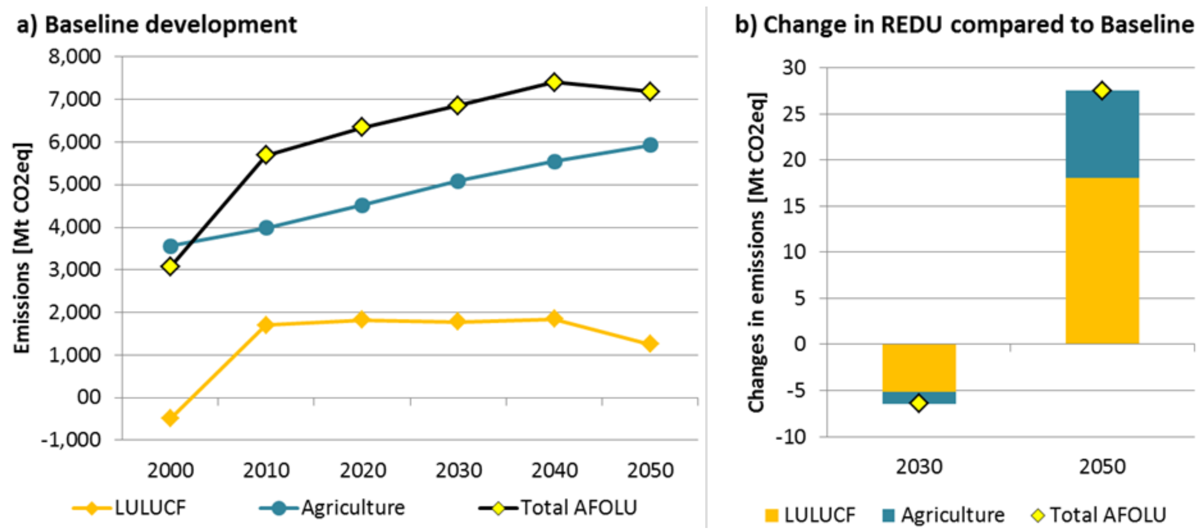

Figure 10. *Total land use GHG emissions in RoW in the Baseline a) and differences in total net annual emissions for the EU Emission reduction scenario (REDU) b).*

CONSEQUENCES OF ENVIRONMENTAL CONSTRAINTS ON BIOMASS SUPPLY

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

- **Conversion of areas of High Biodiversity Value (HBV)**: Areas defined worldwide as HBV (all areas where three or more high biodiversity hotspots are overlapping) are excluded from any land conversion above the developments seen in the baseline. The initial land use of such areas (in the year 2010) is not allowed to change through land conversion. However, the land might still contribute to production. For example HBV forest area will remain forest and (if actively managed) supply biomass but cannot be converted to cropland. The constraint is to be applied globally. It has to be noted that only a small amount of areas are classified as HBV within EU28.
- **Area of unused EU forest converted to used forest:** The indicator is a good proxy for assessing changes in the intensity of forest management due to increased biomass demand. For the constrained scenario, the model will not be allowed to convert unused forest to used forest above the level observed in the Baseline scenario in EU. The constraint is applied for each MS within the EU. No such constraint is applied for the RoW.
- **Conversion of other natural land in EU:** no conversion of other natural land to any other land use is allowed beyond EU baseline levels. One exception from this rule is that the land can be afforested. The constraint is applied to EU28.

Box 8 – Methodology for assessing the impact of environmental constraints of EU biomass resource efficiency.

After the assessment of environmental impacts, a set of environmental constraints were introduced into the model. These constraints are based on key environmental indicators, such as 'Conversion of areas of HBV', 'Area of unused EU forest converted to used forest', and 'Conversion of other natural land in EU'. These indicators showed significant impacts across the policy scenarios. In a second stage the respective model variables are constrained to not exceed a certain threshold (e.g. no conversion of highly biodiverse grazing land beyond Baseline levels). The result of combination of individual constraints for the EU Emission reduction scenario, and analysis where all constraints are combined are implemented and assessed for each of the four policy scenarios. Indicators looked at in the constrained scenarios are:

- Production of biomass in the EU by biomass type (i.e. round wood, forest and agricultural harvest residues, energy crops, industrial-by products).
- Import and export of biomass to (and from) EU with breakdown by type and export/import region.
- 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.

Implications for production of biomass in EU

As stated earlier, land of HBV is mostly located outside EU. Nevertheless there are implications for biomass production for EU28 when a constraint on HBV is implemented. Five million m^3 more harvest of sawlogs can be observed in EU in 2030, 20 Mm^3 in 2050 (see *Figure 11*) in the constrained scenario compared to the unconstrained EU Emission reduction scenario where 272 million m^3 and 315 million m^3 of sawlogs are harvested respectively. At the same time less pulpwood is harvested in EU28.

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

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

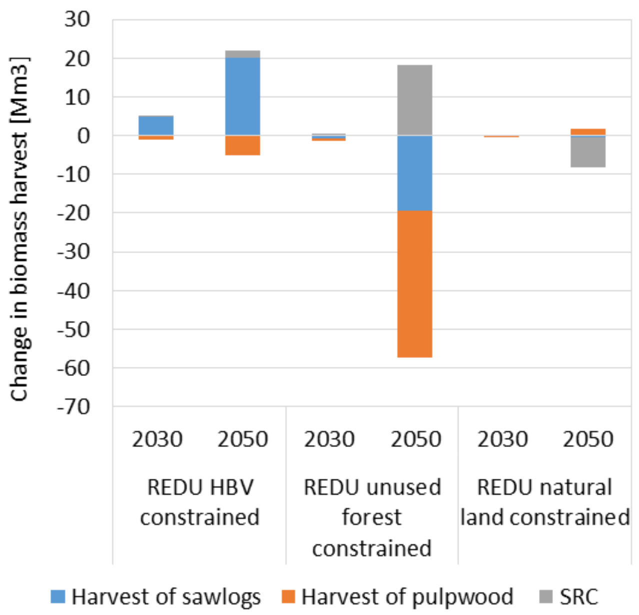

Figure 11. *Change in biomass production in EU across constrained scenarios compared to the unconstrained EU Emission reduction scenario.*

Implications for trade of biomass

Changes in EU biomass production that can be observed across the three environmental constraints have diverging implications for biomass trade between EU and RoW.

The protection of HBV land mostly affects land use outside EU and leads to decreased EU net-imports of pulp logs, sawlogs, wood pellets and industrial by-products in 2050 (see *Figure 12*). At the same time, this constraint leads to increasing net-export of sawnwood from EU28 to RoW and a small decrease in the net-import of chemical pulp. This increase in export of sawnwood from EU28 is directly related to the reduced availability of biomass sources in regions with high shares of HBV areas, which in turn decreases the competitiveness of the forest based industries within these regions.

Constraining in EU either land use change from unused forest to used forest or the conversion of other natural land to cropland or grazing land leads to increased EU imports of biomass feedstocks in 2050. This is especially true for wood pellets of which more than 16 million m^3 (in the case of protection of unused forest) or 3 million m^3 (protection of other natural land) additional imports are expected to the 52 million m^3 in the case without the environmental constraint. The increase in EU28 wood pellets imports would mostly be met by imports from USA, Canada, and the former Soviet Union.

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

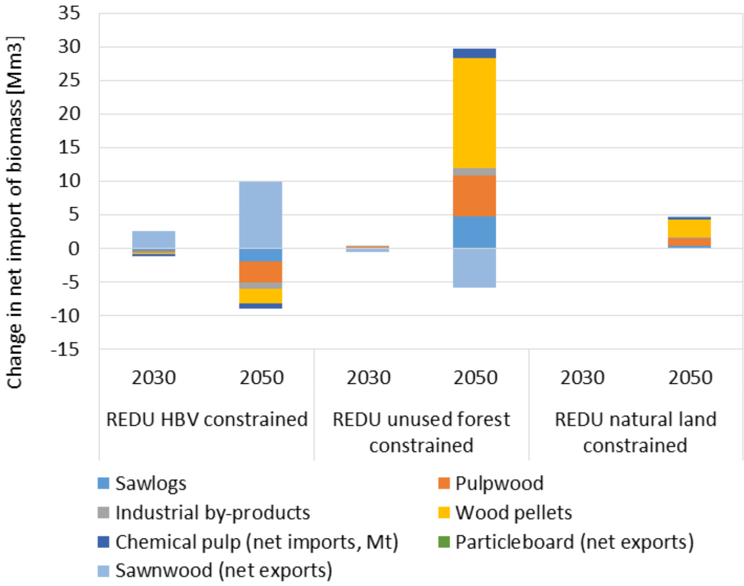

Figure 12. *Change in EU net trade across constrained scenarios compared to the EU Emission reduction scenario.*

Implications for land use in EU and in the RoW

If land of HBV is protected from being converted, more pressure on the remaining areas is expected. This leads to an increased conversion of unused forest to used forest **in the EU**, i.e. an intensification of forest management on areas that are not considered of HBV (see *Figure 13*).

A constraint on the conversion of unused forest in EU prevents an intensification compared to the EU Emission reduction scenario. But also other land areas are affected: in order to compensate for reduced biomass supply from EU forests, EU SRC production expands in 2050 at the expenses of grazing land, cropland and other natural land.

As expected, land use **in RoW** is mostly affected by the constraint that is targeted at areas outside EU (HBV area constraint, see *Figure 14*). Already in 2030, this leads to a relative reduction of cropland area compared to the EU Emission reduction scenario and increases other natural vegetation but also grazing land. Unused forests in RoW are not affected in the constrained scenario of HBV conversion. In fact, the net balance (only this can be assessed here) shows a reduction of unused forest area in the medium-term (in 2030). A likely cause for this is the fact that the HBV forests that are protected in this scenario are also relatively fertile compared to forests with no HBV. If these more fertile forests are protected from conversion there is the need for more conversion of unprotected forest to compensate for the loss of yield.

Land use in RoW is also noted to be affected by the constraints that are targeted only at areas inside of EU. There is a significant conversion of unused forest to used forest in the RoW that is accompanied with constraining forestry intensification within EU. The area affected in RoW (more than 5 Mha) is of a similar size compared to the area prevented from conversion in EU (see *Figure 13*).

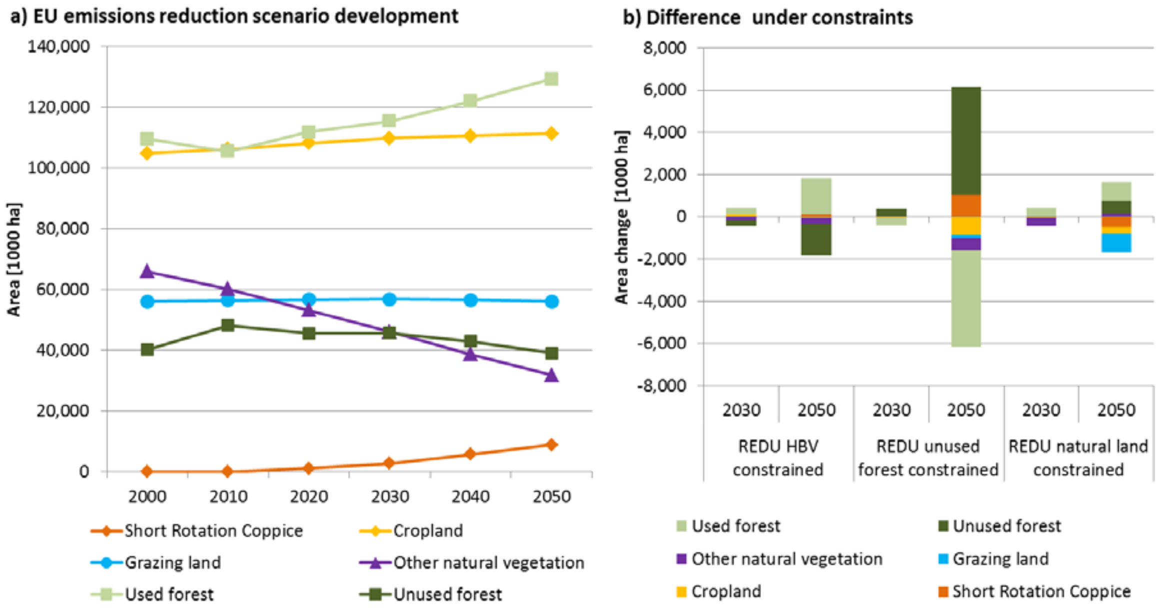

Figure 13: *Implication of environmental constraints for EU land use (b) compared against the EU emission reduction scenario (a).*

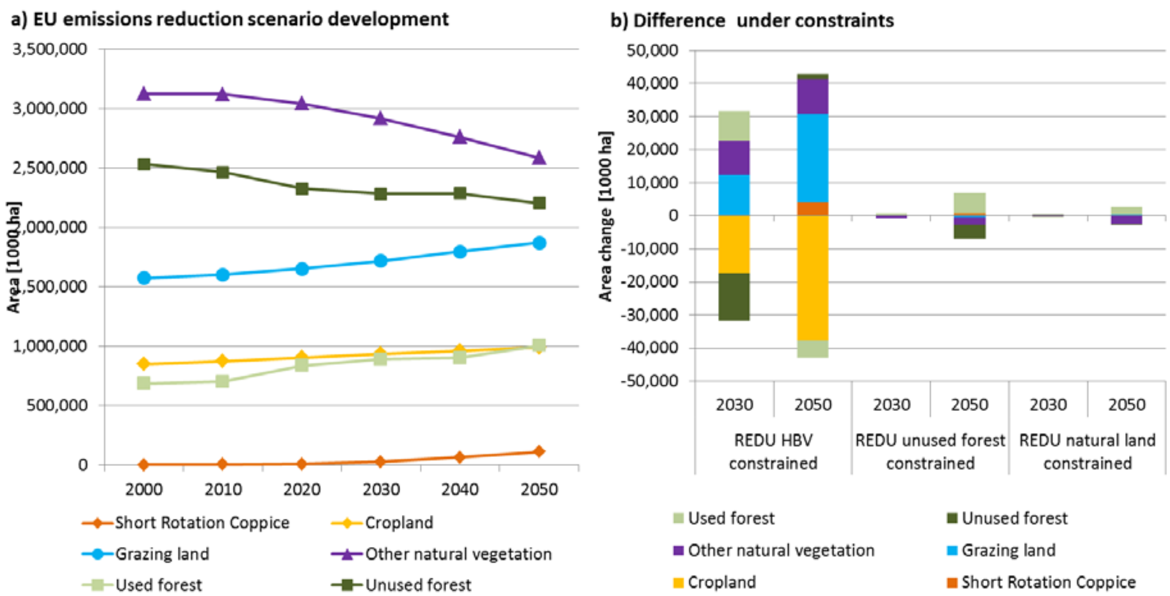

Figure 14: *Implication of environmental constraints for RoW land use (b) compared against the EU emission reduction scenario (a).*

Implications for GHG emissions from the land use sector

Figure 15 describes changes of net GHG emissions from the land use sector in EU28 aggregated to total LULUCF (CO_2) and total agriculture (non-CO_2) emissions compared to the EU Emission reduction scenario. For the EU, changes in net LULUCF emissions dominate changes in net Agricultural emissions across all scenarios and in all years. On the global level and in the long-term, **all environmental constraints that were assessed lead to net global GHG emission reductions.** In 2050 net land use emissions would relatively be reduced by more than 5 Mt CO_2 with a constraint on the conversion of HBV land, by more than 25 Mt CO_2 with a constraint on unused European forests, and by more than 10 Mt CO_2 with a constraint on the conversion of other natural land. *Figure 16* shows that these relative emission reductions are associated with increases in emissions in RoW in 2050 in the case of a scenario where EU forest management is not intensified (unused forest constraint). The increases in emissions in RoW are though lower than the reduction of emissions in the EU, mainly related to an overall global reduction of the harvest of wood. Other constraints lead to net GHG emission reduction in RoW. This is especially true for constraints on HBV areas where large emission reductions compared to the reference can be observed for agricultural emissions. This is due to a reduction in global meat and milk production by 8 Mt of meat and 2 Ml of milk (about 1-2% of total production). As the conversion of HBV areas to the most productive grazing land for cattle is limited, prices for meat and milk increase compared to the unconstrained scenario. Also, more grazing land has to be created to compensate for high productive land not being available. Therefore the net balance of land use results in more grazing land under constraints. This effect is more pronounced in the RoW than in EU28.

In the global sum of net land use emissions, **all environmental constraints result in emission reductions compared to the EU Emission reduction scenario** (sum of Figures above, not shown). This means that there are **positive trade-offs of constraints to protect biodiversity, unused forests and other natural land from conversion regarding global net GHG emissions from the land use sector**. There are regional differences (here we show only EU28 and RoW) and the effect differs for LULUCF and agriculture emissions.

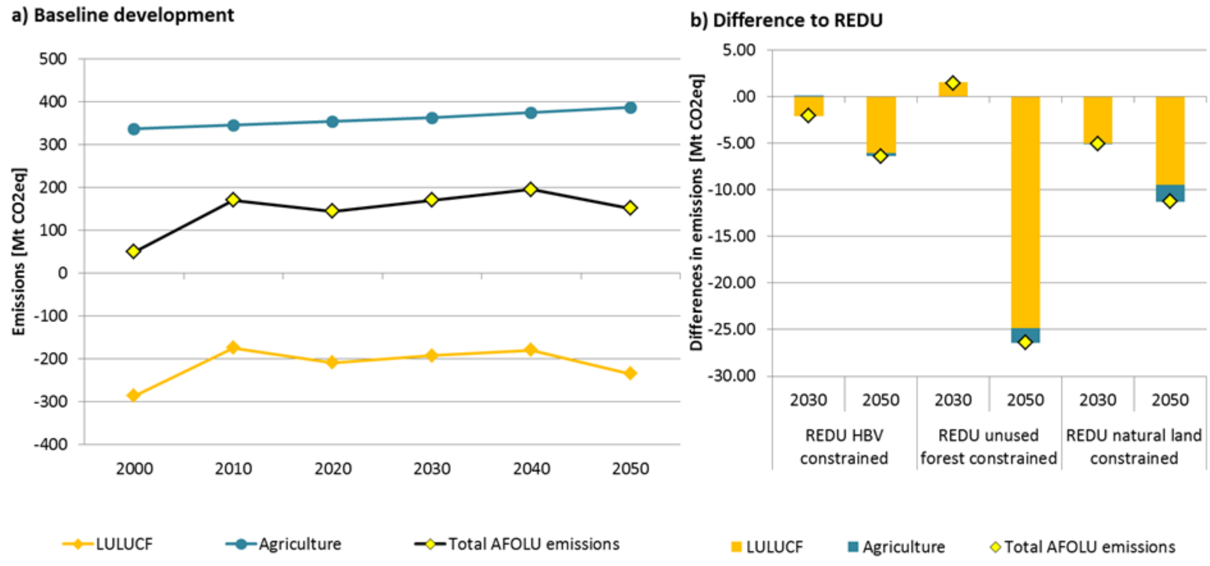

Figure 15: *Implication of environmental constraints for EU net land use emissions (b) compared against the EU emission reduction scenario (a).*

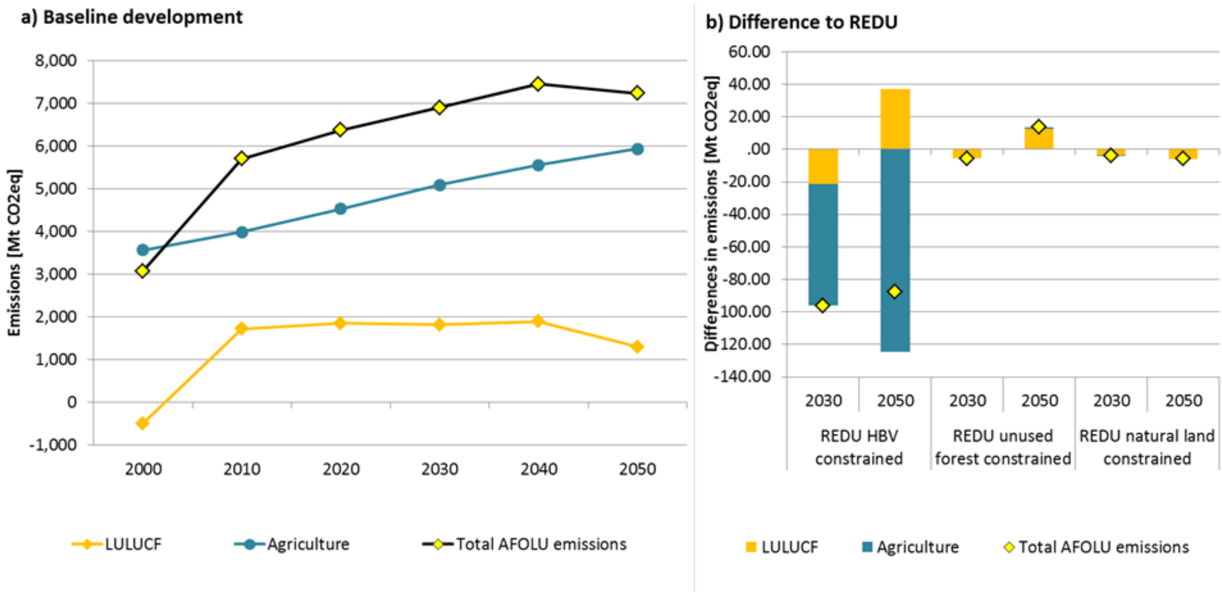

Figure 16: *Implication of environmental constraints for RoW net land use emissions (b) compared against the EU emission reduction scenario (a).*

Implications of combined constraints for biomass resources efficiency

The environmental constraints were also assessed in terms of their combined effect for each of the four policy scenarios developed in the ReceBio project (EU Emission Reduction scenario, Constant EU Bioenergy Demand scenario, Increased Rest of the World Bioenergy Demand scenario, Increased EU Biomass Import scenario). For this assessment, all the environmental constraints were simultaneously applied (protecting HBV land, restricting conversion of unused forest into used forest to Baseline level, and restricting other natural land conversion to Baseline level).

As for the single scenarios, **the combination of the environmental constraints also resulted in reductions of net GHG emissions, both in the EU28 and in the Rest of the World**. Figure 17 presents net land use emissions for EU28 as the difference between constrained and unconstrained policy scenarios. For the EU, changes in net LULUCF emissions dominate changes in net Agricultural emissions across all scenarios and in all years. Net EU forestry emissions in 2050 are reduced in all scenarios between 7 Mt CO_2 to almost 40 Mt CO_2 if the combined constraints are applied. The effect of combined environmental constraints is most prominent for the EU emission reduction and Increased RoW bioenergy demand scenarios, where the constraints lead to a reduction in forest management intensity, which in turn leads to an increased sink in the existing forests. In the rest of the world, agriculture emissions are more affected by the environment constraints than in EU (Figure 18). The constraint on HBV area conversion contributes most to this effect by a reduction in agricultural and livestock production and reducing the amount of land available to afforestation. While the implications for agriculture GHG emissions of constraints are consistent across all scenarios, the effect for LULUCF emissions is less straightforward. In all four scenarios the combined constraints decrease net LULUCF emissions for RoW in the short run (2030) and increase them in the long run (2050) but with different intensity, ranging in 2050 from 16 Mt for the Increased RoW bioenergy demand scenario to almost 60 Mt in the EU emission reduction scenario.

On the global level, **net land use emissions in all scenarios are reduced when jointly combining the environmental constraints, due to large reductions of non-CO_2 emissions from the agriculture and livestock sectors.** This is due to increased prices for livestock products. Under HBV constraints only less fertile land is available, leading to higher costs of conversion and more grazing land to be created to compensate for relative productivity losses.

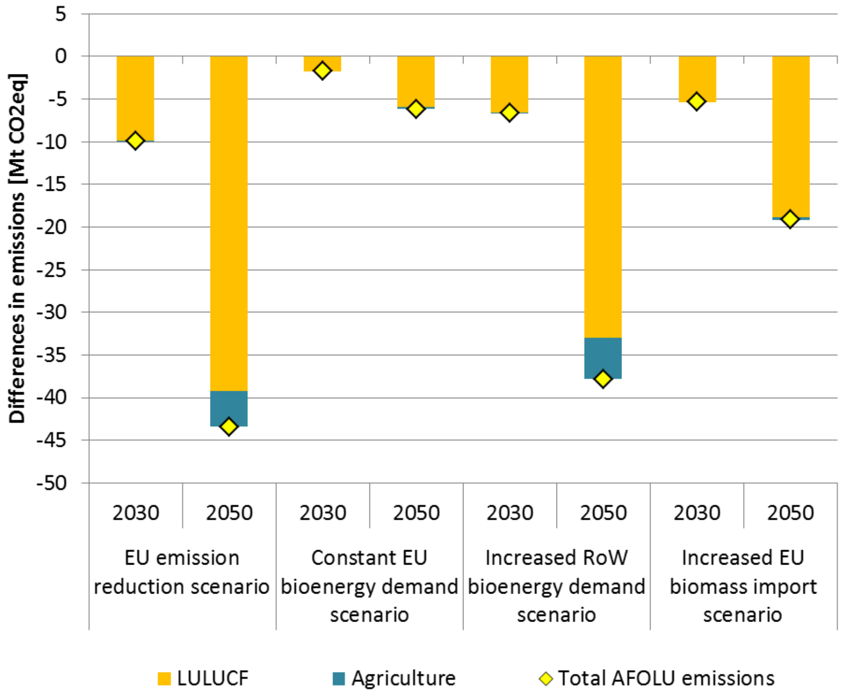

Figure 17: *Differences in EU net land use emissions in constrained policy scenarios compared to unconstrained scenarios.*

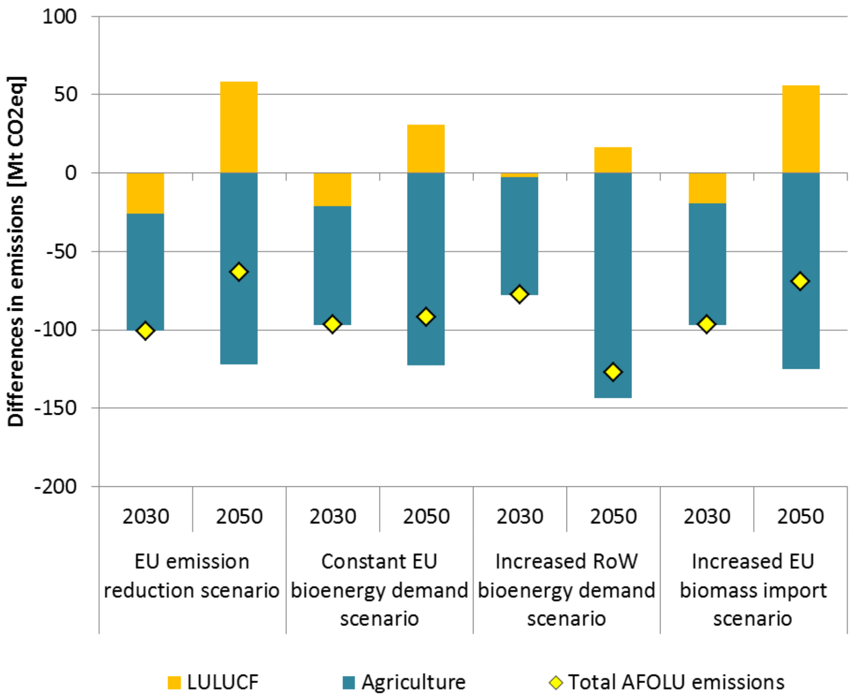

Figure 18: *Differences in RoW net land use emissions in constrained policy scenarios compared to unconstrained scenarios.*

RESOURCE AND POLICY ANALYSIS FOR SELECTED CASE STUDY COUNTRIES

Three case study countries, Finland, Germany and Italy, were analysed in more detail in terms of their current biomass use and availability, as well as their existing national policies affecting the use of biomass resources. These case study countries represent EU Member States of different climatic zones from Northern, Central and Southern parts of Europe, and also showcase countries with a different emphasis and intensity in their wood use. The aim of the case studies was to acknowledge the heterogeneity of the Member States, requiring in-depth analysis of the effects of possible future bioenergy development in different parts of the EU, while also exploring the modelling results on a Member State level to highlight issues that are significant for individual countries, but maybe not shown on a larger scale analysis. For more detailed results of the case study analysis, please refer to the Task 5 report.

The boreal forests of Finland are mostly privately-owned, and managed more intensively than in Germany or Italy. However, the timber harvest volumes remain lower than in Germany due to lower increment rates. There is a well-established pulp and paper industry and sawnwood production is also an important sector in Finland. The energy use of woody biomass, especially industrial by-products and forest residues, is large. In Germany, a large proportion of the forests are under public ownership. The forest increment is the largest of the studied case study countries, and Germany has also the highest harvested volume. Material production is focused particularly on sawnwood and board production. Germany has the largest rate of biomass recovery and recycling among the three case study countries, and is at the forefront of recycling also on the European scale. In Italy, by contrast to the other two case study countries, the forests are less actively managed, and the forest industry plays a smaller role in the national economy. As the domestic harvest volume is relatively low, the forest industry in Italy is largely reliant on imported biomass feedstock.

With respect to policy in the case study countries, those targets included in the EU Renewable Energy Directive (RED) are the main drivers for current renewable energy production and it is in this context that efforts to promote bioenergy are framed. These targets are in all cases supported by incentives to promote production of bioenergy and the expansion of bioenergy infrastructure, largely for heat or CHP. However, the nature of the bioenergy use and feedstock production varies: Finland is almost exclusively focused on forestry, woody biomass use and associated waste and residues, while by comparison, Italy's focus is around the expansion of agro-forestry, short rotation coppice and use of general residues and wastes. Germany shows a broader focus reflecting the potential availability of a wider range of feedstocks. This difference impacts on the nature of policy support and the consequences of increasing demand for biomass i.e. increased intensity of forest use compared to expansion in the agro-forestry area.

The model results for the Baseline scenario were analysed for the three countries to evaluate developments in land and resource use over time from the period 2010-2050. For Finland, the Baseline scenario estimates almost negligible change in land use over time until 2050. However, the increase in demand for bioenergy and woody material results in some unused forest being taken into use, and the overall land use structure of the country remains dominated by actively managed forests used for wood harvests. There is not much change across the timeline in terms of the wood flows, except for some small changes in the imports of roundwood. There are increases in sawnwood outputs and industrial by-products: increased energy demand creates more demand for sawmill by-products and hence makes sawnwood production more profitable. On the supply side, the most noticeable trend is the doubling of imported wood chip from 2.2 to 4.6 Mm^3 between 2010 and 2050. Otherwise this already well-evolved wood production market does not change much over the simulated timeline.

For Germany, the most notable trend is the emergence of short rotation coppice (SRC) as a feedstock over the 2010 to 2030 time horizon. A relatively small increase in the harvest and use of wood for material purposes is seen within the country.

For Italy, as for Germany, there is significant expansion in SRC use for energy. Within the Italian model outputs there are significant domestic impacts in terms of land use change in Italy – most noticeably with conversion of other natural land to forest - and also significant rises in roundwood imports and pellet imports.

All in all, the three case study countries were found to vary considerably with respect to the resource availability, existing wood-based industries, and the scope of the use of biomass for material and energy purposes. Nevertheless, the emergence of an emphasis on the bioeconomy is evident in all three countries, which is reflected in the policy analysis and shown also in the model results. Overall, the case study analysis supported the modelling approach, finding the projected biomass use over time to 2050 to be in line with the current resources and policies in place.

VALUE ADDED AND LIMITATIONS OF THE ASSESSMENT

In this study we have used an integrated modelling approach. The key assets of this study include:

- A cross sectorial approach was used, covering the forest, agriculture and livestock sectors. This made it possible to assess the potential direct implications of increasing bioenergy and also enabled the analysis of indirect and displacement effects;
- A global approach made it possible to assess the implications of a policy focusing on the EU but also having implications for the Rest of the World;
- The study provides an assessment of potential impacts across a multitude of indicators, including environmental consequences, greenhouse gas emissions impacts, land use change, harvest of wood, as well as the use of biomass and wood across sectors;
- Environmental constraints on biomass supply were applied to assess the cross sectorial benefits of policies focusing on enhancing key environmental indicators.

However, like for all modeling studies, there are limitations for this project and its conclusions. These limitations include:

- As always in scenario analysis, the study results critically depend on the assumptions and constraints of the modelling framework.
- There are limitations to the data sources available for modelling environmental indicators and the assessment is restricted to only considering a subset of all potential environmental implications of biomass use.
- Some feature are challenging to capture within a modelling framework: For instance, how land owners and biomass producers react to changes in policies and prices; and the institutional and infrastructural barriers to the mobilization of biomass feedstocks.
- There are inevitable uncertainties in projecting the development of new goods, new markets, new trade routes, new technologies and changes in end-consumer consumption patterns. These are all aspects where large changes may occur in the future that influence future developments.

More specifically to this project which uses an integrated modelling approach, a number of limitations should also be considered when interpreting the results of the assessment:

- The scenarios only represent cases where the bioenergy demand for heat, electricity and transport is exogenously defined and not sensitive to changes in feedstock prices. Interactions between different energy options for reaching policy targets were out of the scope of this study.
- 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.
- There are limitations to data available for modelling GHG emissions on a global level. In particular, consistent datasets of forest age structure, location of management, as well as local forest treatment regimens are challenging to collect.
- The data sources underlying the study for representing land classes, vegetation cover, and the management of land types carry uncertainties. This creates challenges in representing aspects such as ownership structures, typical size of an ownership, status of protection and local regulations.

CONCLUSIONS

This project examined the resource efficiency implications of increased EU use of bioenergy for electricity and heat until 2050. Methods of analysis include an extensive literature and statistical review, detailed modelling of wood biomass production and use, and in-depth analysis of the implications on a multitude of sustainability indicators. In addition, three case studies were carried out to examine the results against country-specific policies and resources. The chosen approach of integrating trade, land use, biomass harvest, material production, food and feed production and competition for biomass resources between sectors was found essential in examining the complex question of resource efficiency of increased bioenergy demand, within the EU and globally.

The results show that increased bioenergy demand leads to a stronger pressure on the forests in the EU, resulting in higher harvest levels and more extensive use of forests throughout the EU. In addition, the results show that high future bioenergy demand levels are likely to lead to increased EU biomass imports, especially wood pellets. High bioenergy demand levels are also seen to counteract cascading use of wood, and even lead to increased combustion of roundwood to energy. While on the aggregate level it is seen that the total production of wood material is not largely impacted by increasing bioenergy consumption, there are large sectorial differences. Some material-producing industries (esp. sawmill industries) are projected to increase their profitability, driven by increased demand for their by-products to be used to energy, some industries will face increased competition for feedstocks (esp. particleboard production). The project also shows that without the additional biomass produced from fast-growing plantations such as short rotation coppice, the pressure to use roundwood directly for energy and increase EU biomass imports will heavily increase.

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