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, the 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-CO₂ 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 CO₂ 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’ as described in the 2014 EU Impact Assessment (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.

The study has used The Global Biosphere Management Model, GLOBIOM, 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);

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.
• 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.


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, ornamental 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.

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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.

<table>
<thead>
<tr>
<th>Study</th>
<th>EUWood</th>
<th>Indufor</th>
<th>ReceBio Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2010</td>
<td>2011</td>
<td>2010</td>
</tr>
<tr>
<td>Total Wood Consumption</td>
<td>825</td>
<td>942</td>
<td>841</td>
</tr>
<tr>
<td>Total Material Use*</td>
<td>457</td>
<td>649</td>
<td>535</td>
</tr>
<tr>
<td>Wood Products Industry**</td>
<td>314</td>
<td>308</td>
<td>367</td>
</tr>
<tr>
<td>Pulp and Paper</td>
<td></td>
<td></td>
<td>341</td>
</tr>
<tr>
<td>Pulp</td>
<td>143</td>
<td>162</td>
<td>172</td>
</tr>
<tr>
<td>Total Energy Use, excl. SRC</td>
<td>368</td>
<td>293</td>
<td>306</td>
</tr>
<tr>
<td>Wood products industry side streams***</td>
<td></td>
<td></td>
<td>150</td>
</tr>
<tr>
<td>Wood used primarily for energy****</td>
<td>143</td>
<td>151</td>
<td>158</td>
</tr>
<tr>
<td>Energy Biomass from SRC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy use, %</td>
<td>45%</td>
<td>31%</td>
<td>36%</td>
</tr>
<tr>
<td>Material use, %</td>
<td>55%</td>
<td>69%</td>
<td>64%</td>
</tr>
</tbody>
</table>

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.

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 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.](image)

**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 pulpwod 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% 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 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.

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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 CO2 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\textsubscript{2}O emissions from fertilizer application (mineral and organic), CH\textsubscript{4} emissions from rice cultivation, N\textsubscript{2}O and CH\textsubscript{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 CO₂eq 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 CO₂ and non-CO₂ 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 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 m³. 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 m³ (in the case of protection of unused forest) or 3 million m³ (protection of other natural land) additional imports are expected to the 52 million m³ 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.](image)

**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 the **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).
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 (CO₂) and total agriculture (non-CO₂) 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 CO₂ with a constraint on the conversion of HBV land, by more than 25 Mt CO₂ with a constraint on unused European forests, and by more than 10 Mt CO₂ 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).*
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 CO₂ to almost 40 Mt CO₂ 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-CO₂ 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 Mm³ 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.
Study on impacts on resource efficiency of future EU demand for bioenergy

Task 1 Report
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Executive summary

Biomass and its use for bioenergy are central in reaching the European Union’s 20% target of its primary energy consumption from renewable energy sources by 2020, and for ensuring sustainable energy production even thereafter. The Study on impacts on resource efficiency of future EU demand for bioenergy provides insight on different future trajectories of increased use of bioenergy in the EU, and their impacts on resource efficiency, natural resources and the environment. Three types of biomass are analysed in detail: wood biomass, agricultural biomass and biogenic waste.

This Task 1 report provides an analysis of the state of play of biomass use, production and price formation in the EU and globally. The focus is on the biomass used for material purposes and energy production, excluding transportation fuels.

EU state of play

Wood biomass

The forest-based industries within the EU are major producers of woody commodities (e.g. sawnwood, plywood and paper) as well as bioenergy. Of all wood consumption in EU, 31% to 45% is used for energy (Table 1). Of the wood biomass being used for energy purposes, about one third is firewood for heating purposes, half is used by forest industries mainly for processing heat and electricity production, and 16% is used as wood chips for bioenergy production. Forest industries have long traditions in utilizing production residues into energy supply – for example, pulp industry produces a majority of its energy demand from its by-product black liquor. However, while the use of bioenergy within forest industry accounts for a considerable amount of the total bioenergy consumption, the biggest prospects for increasing the current bioenergy uses or wood biomass lie within firewood and chip consumption.

It is important to note that energy use of wood is strongly linked to the forest-based industries, in particular sawmill industries, wood board industries, and pulp and paper industries. Thus, it is essential to consider these industries as a package, as they use different parts of the trees and even each other’s by-products. Saw logs are by far the most valuable tree parts, followed by pulpwod where smaller diameter or lesser quality trees are used. Tops, branches and stumps, together with the woody residues from forest industries, are used for bioenergy production. Thus, the production of bioenergy from wood biomass is strongly linked to paper and sawmill industries and the fluctuations within these industries have a strong influence on biomass availability and prices in Europe. Moreover, increasing competition of domestic wood raw material is likely to cause the EU becoming more dependent on wood imports and the ability to re-utilize the wood by recovering and recycling.

Firewood is a large source for heating, but it is criticized for its inefficiency in energy production together with health and environmental concerns. While firewood may in many rural areas be the only viable option for heating, there is also a large potential for increased energy efficiency through more advanced technologies for heat conversion.

Forest chips are increasing in importance, especially in combined heat and power (CHP) production. They are primarily used in Northern Europe where the demand for heating is more constant throughout the year, thereby providing better economic grounds for CHP plants. Due to their high moisture content, chips require relatively large storage space and are difficult to store for longer time period. This hinders the trade possibilities of forest chips, and as a result, the plants based on forest chips as
feedstock are strongly dependent on the local availability of large quantities of cheap raw material.

Wood pellets have a high energy value to size-ratio and are thus more advantageous to trade than chips (or roundwood). They are used for residential and industrial heating and CHP systems. The EU is the largest pellet supplier and consumer in the world. The capacity to produce pellets is already higher than demand and supply. Large scale investments to pellet combustion plants seem to be lacking due to uncertainty towards public support schemes.

Recovered wood has a very positive image and is used for energy production especially in Germany. However, lack of effective and established collection and sorting systems is preventing its more large-scale utilization.

**Agricultural biomass**

Agricultural biomass is largely used for biofuels in the transport sector. Within heat and power production, which is the focus of this report, agricultural biomass has less importance. The most used sources for bioenergy are short-rotation forestry (SRF), lignocellulosic species, and cropping and livestock residues. Globally, land competition and falling social acceptance due to rising food prices are obstacles for biomass production for energy in agricultural lands. Of agricultural biomass, agricultural residues provide the most recommendable energetic feedstock in the future, but their high moisture content and bulkiness cause them to be profitable mostly in local trade only.

**Biogenic waste**

Wastes contribute to 4% of the global primary supply of bioenergy. At the EU level, the share of wastes in the bioenergy consumption is about 12%. However, increasing rates of recycling of the municipal and food wastes is likely to decrease the availability of biogenic waste for energy production over time.

**Advanced biofuels from biomass**

The success and technological development of pilot projects of wood based liquid biofuels production will define whether it will become a growing wood consuming industry. However the production will likely be integrated to existing chemical pulp industry.

For agricultural biomass, advanced biofuels have progressed more slowly than expected in recent years. For example, the increase of production capacities from 2012 to 2013 was 22-fold lower than needed to reach the IEA 2°C Scenario (2DS) targets.

**Global supply and demand of biomass**

International trade of energetic wood biomass is mostly trade of wood pellets and wood chips. The EU is expected to become more dependent on imports in their consumption of industrial wood pellets. Although the domestic production is increasing, it consists largely of residential quality pellets and will not be enough to satisfy the growing demand. Today, Russia is a major trade partner of wood pellets with the EU. About 700 000 tonnes of wood pellets are imported annually from Russia to the EU; majority to Sweden, Denmark, Netherlands, Belgium and the UK. Globally, wood pellets are increasing in importance especially in North America and in China. Pellet production in the US tripled in two years between 2012 and 2013. The pellet
exports from North America to Europe doubled over these past two years, main importers being the Netherlands, Belgium and the UK. North American wood pellet manufacturers are building new facilities to enhance the volumes to the EU market, and it is probable that the exports continue to increase at least in the near future. Also China is rapidly gaining importance in the global pellet markets; 85% of the pellets produced are based on non-wood raw materials such as agricultural residues like rice husks and straws.

Majority of the total wood chip trade is related to pulp and paper industries. Wood chips for the EU residential market are primarily sourced locally. Most important non-EU countries drawing major trade flows are Turkey, Japan and China, of which Turkey is the most important due to its geographical proximity. Turkey imports a major volume of wood chips from North America. Japan and China import a large amount of wood chips for pulp production, China even for wood based panels, mostly from Vietnam, Thailand, Australia and Indonesia.

**Data quality**

Data quality and availability is good for traditional wood based commodities such as sawnwood, wood based panels and pulp and paper products. For wood biomass energy commodities there are often no established data collection protocols, thus only a few member states present good quality data of production and trade. Data related to production and trade of wood pellets is the most developed due to the fact being a globally traded commodity with relatively well developed and transparent reporting standards.

For agricultural biomass and biogenic waste, the figures are less reliable as data collection is not as well established as within wood industry, and in some countries and commodities, the figures can only be considered as rough estimates.
Glossary

Anaerobic digestion
Anaerobic digestion is a biological process making it possible to degrade organic matter, in absence of oxygen, by producing biogas and sludge. The organic matter is degraded partially by the combined action of several types of micro-organisms.

Bioenergy
Energy produced from biomass sources excluding biofuels.

Biofuels
Transportation fuels made from biomass; such as biodiesel, bioethanol and biogas. First-generation biofuels refer to fuels derived from food crops, such as grains, sugar beet and oil seeds. They are relatively easy to manufacture, and thus the main type of biofuels produced today. Second-generation, or advanced, biofuels are produced from non-food biomass such as ligno-cellulosic materials or biogenic waste. They are considered superior to first-generation biofuels especially in terms of their social and environmental impact; however, their production is much more complicated and commercial production methods are still under development.

Biogenic waste
According to Article 3(4) of the Waste Framework Directive (2008/98/CE), biogenic waste is ‘biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises and comparable waste from food processing plants.’

Biomass
“Biodegradable fraction of products, waste and residues from biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste”. (Renewable Energy Directive (article 2).

Bio-oil
Also known as pyrolysis oil is a liquid produced from pyrolysis. It has a calorific value of 17.5 MJ/kg and an energy density of 20-30 GJ/m3. Bio-oil can be combusted for power in boiler, stationary engines and turbines, or upgraded for transport fuel.

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

CHP
Combined Heat and Power production

Co-firing
Co-firing is a primary application of combusting industrial wood pellets aside with pulverized coal in older coal power plants. Typically co-firing enables 5-15% mixture of wood pellets combusted with coal in order to minimize investment costs, process modification and, most of all, overall process efficiency. However, with equipment modernization 40% share of wood pellets is possible.
Composting
Composting is a process by which organic matter is degraded by a microbial population consisting of bacteria and fungi consuming oxygen and producing CO2, water, compost or humus and heat (exothermic).

CSR
Corporate Social Responsibility

EU
European Union

FAO
Food and Agriculture Organization of the United Nations

Firewood
Firewood consists of wood that is harvested from forest of other wooded land and used in small dwellings for simple heating applications such as fireplaces, ovens or log boilers. Firewood is usually used in the form of split logs.

Food waste
According to the proposal for a Directive amending the Waste Framework Directive, food waste is 'food including inedible parts from the food supply chain, not including food diverted to material uses such as bio-based products, animal feed or sent for redistribution.'

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

Forest chips
Forest chips are fresh wood chips made directly of wood that is harvested from the forest, used for energy production, and has not had any previous use (as opposed to wood chips from industrial by-products). There are several raw material types of forest chips:
- Tops and branches removed from trees during final felling
- Sawlogs that are rejected being unsuitable for material purposes due to decay etc.
- Delimbed small size stems or un-delimbed small-size trees from thinnings
- Pulpwood size logs allocated to energy production from thinning or final felling
- Tree stumps.

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

FSC
Forest Stewardship Council

Fuelwood
Fuelwood is roundwood being used as fuel for such purposes as cooking, heating or power production. It includes wood harvested from main stems, branches and other parts of trees (where these are harvested for fuel) and wood that is used for the
production of charcoal (e.g. in pit kilns and portable ovens), wood pellets and other agglomerates. The volume of roundwood used in charcoal production is estimated by using a factor of 6.0 to convert from the weight (mt) of charcoal produced to the solid volume (m³) of roundwood used in production. It also includes wood chips to be used for fuel that are made directly (i.e. in the forest) from roundwood. (FAOSTAT)

**Hardwood**
Hardwood generally refers to all deciduous woods derived from trees classified botanically as Angiospermae, e.g. Acer spp., Dipterocarpus spp., Entandrophragma spp., Eucalyptus spp., Fagus spp., Populus spp., Quercus spp., Shorea spp., Swietonia spp., Tectona spp., etc. Sometimes referred to as broadleaves. (FAOSTAT)

**ICT**
Information and communications technology

**Industrial By-Products**
Industrial by-products include industrial chips, sawdust, shavings, trimmings and bark. They are supplied as by-products available in proportions from the processes of wood products industry, mainly sawmilling but also wood based panels and joinery production. Industrial by-products have to be clean and they are not altered by any chemical process. They are important raw materials for pulp, wood based panels (Particleboard, MDF/HDF) and wood pellet production as well as in bioenergy production as such.

**Landfill**
Directive 1999/31/EC on the landfill of waste defines landfill as a waste disposal site for the deposit of the waste onto or into land (i.e. underground), including internal waste disposal sites, and a permanent site (i.e. more than one year) which is used for temporary storage of waste.

**MDF/HDF**
Medium-Density Fibreboard (MDF) is a wood-based panel made of fibres bonded together with resin. When density exceeds 0.8 g/cm³, it may also be referred to as “High-Density Fibreboard” (HDF). It is reported in cubic metres solid volume. The board is relatively homogeneous throughout its thickness without distinctive surface and core layers. Therefore the processing qualities are better than with solid wood and particleboard. (FAOSTAT)

**Mtoe**
Million tonnes of oil equivalent. One tonne of oil equivalent (toe) refers to the amount of energy released by burning one tonne of crude oil.

**NREAP**
National Renewable Energy Action Plan

**OSB**
Oriented Strand Board is a structural board in which layers of narrow wafers are layered alternately at right angles in order to give the board greater elastomechanical properties. The wafers, which resemble small pieces of veneer, are coated with e.g. waterproof phenolic resin glue, interleaved together in mats and then bonded together under heat and pressure. The resulting product is a solid, uniform building panel having high strength and water resistance. It is reported in cubic metres solid volume. (FAOSTAT)
Particleboard
Particleboard is a panel manufactured from small pieces of wood or other lignocellulosic materials (e.g. chips, flakes, splinters, strands, shreds, shaves, etc.) bonded together by the use of an organic binder together with one or more of the following agents: heat, pressure, humidity, a catalyst, etc. The particle board category is an aggregate category, including for example oriented strandboard (OSB). (FAOSTAT)

Plywood
Plywood is a panel consisting of an assembly of veneer sheets bonded together with the direction of the grain in alternate plies generally at right angles. The veneer sheets are usually placed symmetrically on both sides of a central ply or core that may itself be made from a veneer sheet or another material. It excludes laminated construction materials (e.g. glulam), where the grain of the veneer sheets generally runs in the same direction. It is reported in cubic metres solid volume. (FAOSTAT)

Production capacity
Production capacity is the volume of products that can be generated by a production plant or enterprise in a given time period by using current machinery. Several factors e.g. lack of raw materials can cause the actual production to remain below the maximum production capacity.

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

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

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

Residential Wood Pellets
Residential wood pellets are manufactured from clean by-products of sawmilling industry (sawdust, chips, and shavings); according to strict standards in terms of size, shape, cleanliness and moisture content (i.e. EN 14961). They are used in small scale wood pellet heating applications requiring uniform quality of fuel.

Residue-to-crop ratio
Describes the ratio of the amount of residues resulting from crop production and the amount of crops produced.
Roundwood
Roundwood is an aggregate comprising of felled or otherwise harvested and removed wood, with or without bark. It includes sawlogs and veneer logs; pulpwod, round and split; and other industrial roundwood. It is reported in cubic metres solid volume.

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

Sewage sludge
According to Article 2(a) of the Directive on sewage sludge used in agriculture (86/278/EEC) sludge is ‘i) residual sludge from sewage plants treating domestic or urban waste waters and from other sewage plants treating waste waters of a composition similar to domestic and urban waste waters; ii) residual sludge from septic tanks and other similar installations for the treatment of sewage; iii) residual sludge from sewage plants other than those referred to in i) and ii).’

Short Rotation Forestry/Short Rotation Coppice
Short rotation forestry (SRF) is defined as tree plantations established and managed under an intensive, short rotation regime. They can be established with quickly growing tree species such as poplar, willow and eucalypt. The plantations have rotation cycles of 8 to 20 years (for single-stemmed trees) or they can be managed under a coppice system in a two-to-four-year rotation (Short Rotation Coppice, SRC).

Softwood
Softwood generally refers to all coniferous woods derived from trees classified botanically as Gymnospermae, e.g. Abies spp., Araucaria spp., Cedrus spp., Chamaecyparis spp., Cupressus spp., Larix spp., Picea spp., Pinus spp., Thuja spp., Tsuga spp., etc. (FAOSTAT)

Textile waste
Textile waste consists of all kinds of textile and leather material which are discarded. This includes used packaging, worn clothes and used textiles, and waste from fibre/leather preparation and processing, as well as separately collected textile and leather.

Torrefaction
Torrefaction is a pre-treatment technology where the biomass is slowly heated to 240-300 C° in the absence of oxygen. The treatment degrades the biomass into a coal-like product without major fibrous structure, making it easy to grind. The torrefied biomass has a calorific value of 19-23 MJ/kg and a high energy density. Torrefied wood pellets are sometimes called “black pellets” or “pelletized biocoal”.

Waste
The Waste Framework Directive (2008/98/EC) defines waste ‘any substance or object which the holder discards or intends or is required to discard’.
Waste prevention
According to Article 3(12) of the Waste Framework Directive (2008/98/EC) prevention means ‘measures taken before a substance material or product has become waste, that reduce a) the quantity of waste [...] ; b) the adverse impacts of the generated waste on the environment and human health; or c) the content of harmful substances in materials and products.’

Wood Based Panels
This product category is an aggregate comprising veneer sheets, plywood, particle board, and fibreboard. It is reported in cubic metres solid volume. (FAOSTAT)

Wood chips
Wood chips are wood that has been reduced to small pieces and can be used for material production or as a fuel. For pulping, particle board and/or fibreboard production, the chips need to be debarked, for fuel use the wood chips may contain bark.

Wood pellets
Wood pellets are refined wood fuels traditionally made of clean industrial by-products of the mechanical wood industry, mainly wood chips, sawdust and/or shavings. Wood pellets are cylinder shaped and their diameter varies between 6 - 8 mm and length between 10 - 30 mm. The heat value of one kilogram of pellets correspond almost half a litre of light fuel oil. Unlike other wood based commodities (sawnwood, wood based panels) the production, consumption or traded volumes of wood pellets are usually reported in tonnes. In trade of wood pellets price reference is commonly set per tonne of pellets.
1 Introduction

Bioenergy demand in the EU is increasing, affecting biomass resource availability as well as creating competition for biomass resources. Further investigation is needed especially on the interactions between the bioenergy sector and other sectors competing for the same raw materials, and the environmental impacts of bioenergy use. This is important for the economy as a whole, for safeguarding the ecosystem services that the landscape provides, and for ensuring material use in a way that is most beneficial for reaching overall climate mitigation targets. Biomass types should be allocated to industries so that that individual industry segments can best benefit them in terms of their technical suitability, added value, and employment potential. Efficiency in the use of biomass is also important for environmental reasons, as there is only a limited amount of biomass sources available.

Study on impacts on resource efficiency of future EU demand for bioenergy develops different future trajectories of increased use of bioenergy in the EU, and analyses their impacts on resource efficiency, natural resources and the environment. In order to understand the current basis for possible resource efficiency implications, this Task 1 report provides an in-depth analysis of the current standpoint in terms of production, trade and demand of biomass in the EU with its linkages to the global biomass use. The report includes three chapters looking into different angles around the topic:

EU state of play in biomass use illustrates the supply and demand situation of three main categories of biomass: wood biomass, agricultural biomass and biogenic waste. Within each category, a detailed examination of various types of biomass is presented. For every major biomass type, an overview of the supply and demand situation within the EU is presented, as well as relationships between the energy and material use of particular biomass types. The chapter includes also a description of the current standpoint in the utilization of energy conversion methods and pathways.

Global supply and demand of biomass looks into biomass use from the global perspective and aims to identify consumption hot-spots. This is important because biomass commodities are increasingly traded on a global level and having an increasing effect on the biomass raw material balance and prices in the EU. The chapter illustrates major trade flows and trends of most important biomass commodities within the EU and globally.

Costs and prices of biomass are strongly linked to biomass availability. This chapter provides insight to the production costs by assessing different biomass supply chain alternatives and explaining the drivers of cost development. An outlook of biomass market prices is also provided in this chapter, displaying price trends and drivers for major biomass fuels in different regions within the EU.

The purpose of this Task 1 report is also to provide data for ensuring well calibrated results and robust results in the further tasks of the Study. In addition, related information gaps and needs for further research will be identified in the report.

This study will give an in-depth view on affecting factors and issues related to biomass consumption in the EU in three main biomass types: wood biomass, agricultural biomass and biogenic waste. Biomass consumption is observed from two points of view: biomass refining for material purposes and for energy. Links between these two consumption types have become a vital issue. Questions related to resource efficient allocation of raw materials between these two options have gained high priority status as the EU is aiming to reach the targets for renewable energy use up to 2020.
The main driver for using biomass for energy is the RES (Renewable Energy Sources) directive (2009/28/EC). Directive 2009/28/EC also requires the EU Member States to adopt a national renewable energy action plan (NREAP). These plans have to indicate in detail how the national targets will be reached, including energy sources and uses, as well as their trajectories up to 2020.

In 2012, bioenergy constituted two-thirds of the renewable energy consumption in the EU (Figure 1). The largest source for bioenergy was solid biomass, which provided almost half of the total renewable energy consumed. The share of municipal waste was almost 5%, and biogas and liquid biofuels together about 15% of the total use of renewable energy.

**Figure 1** Consumption of different types of renewable energy in EU28 in 2012

According to the progress reports of the NREAPs, in 2010 about 75% of the total 95 Mtoe of biomass used for energy is utilized in heat production (Figure 2). According to NREAP targets, heat will remain as major final use due 2020 (65%) but the transport sector (14% in 2010) is expected to cover about 21% of biomass utilization in 2020 (Figure 3). If the NREAP targets are actualized the total consumption of biomass for bioenergy purposes will be 138 Mtoe.
Majority of currently used biomass is solid biomass. In 2010 almost 80% of biomass utilized in the EU was solid (Figure 4). According to the plans set by the NREAP the share of solid biomass will be 68%. Share of bioethanol, bioliquids and biogas will increase marginally. Bioproducts (bioliquids and biogas) are fast growing market segments; however the bulk of the biomass use will be originated from solid biomass as such and will continue to be the major energy carrier. The major share of solid biomass used for heat production can be largely explained by the net energy ratio of different energy production alternatives.
Even though the NREAP’s are legally binding targets for the Member States the fulfilment of these country specific targets are not certain. An assessment of the biomass use situation can be seen in the NREAP progress reports for 2010. The recent development forecast whether the renewable energy targets will be reached is not
clear, let alone the consequent impact on biomass used for material purposes. This is the macro-level viewpoint to the biomass use for energy in the EU. The following chapters include detailed examination of tree main biomass types used in the EU: wood biomass, agricultural biomass and biogenic waste.
2 EU state of play

2.1 Wood biomass

2.1.1 Total wood consumption in the EU

The EU has traditionally been a major producer, consumer and trader of wood biomass for a broad range of wood based products as well as bioenergy. The use and availability of various wood raw material types for the wood consuming industries is interlinked. They form a conglomerate of different streams depending economically on each other, not only from the availability of wood raw material point of view of, but also logistics.

The inter-relationships between the different wood consuming sectors have usually been in balance within a particular country. This means that in wood raw material allocation sawmills supply sawlogs and pulpwood is used in pulp making or wood based panels manufacturing. In general best quality by-product streams of mechanical wood products industry have been directed to wood based panels’ production and lower qualities to energy use as such. However, this traditionally balanced situation has changed as the major energy producers are reaching for more wood.

The single issue affecting the use of wood raw material in most of the EU is renewable energy. Member States are expected to reach their binding national 2020 targets for renewable energy in electricity generation, heating and transport. For Member States to more than double their total renewable energy generation by 2020, from the level of 2005, there will be a huge impact on the use of wood raw material along other types of biomass. In this development pulp and paper as well as woodworking industry companies have also started to act as biomass suppliers to the bio-energy sector. In addition, the future plans for bio-diesel plants (from bio-refineries) are based on substantial volumes of biomass, among others wood.

Two recent studies, e.g. EUWood (2010)1 and Study on the Wood Raw Material Supply and Demand for the EU Wood-processing Industries2 (2013) have portrayed the wood raw material demand between the material and energy uses and the interactions between the consuming industries. The results from these two studies serve as a standpoint in viewing how much of the wood raw material is currently allocated to material and energy use.

Table 1 shows the consumption of wood estimated in the EUWood and Indufor’s study. In Indufor’s study it was estimated that the total wood raw material use was 942 million m³ RWE (roundwood equivalent). About 31% of that was used by bioenergy sector. In the EUWood study the total wood consumption was estimated a bit lower, at 825 million m³ of which energy use consists about 45%. However in the EU Wood study in the demand of wood, sector specific consumption of particular wood type was not defined. The slightly larger share of wood consumption in bioenergy can be caused by the fact that the energetic use of wood is estimated by model (EFSOS) rather than actual consumption from statistical sources. Also, the EUWood study includes only raw wood material consumption within the pulp industry whereas the Indufor’s study includes also the consumption of recovered paper in the pulp and paper industry.

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2 Indufor 2013: Study on the Wood Raw Material Supply and Demand for the EU Wood Processing Industries
Table 1  Wood demand by wood-consuming industries by EUWood and Indufor studies

<table>
<thead>
<tr>
<th>Study</th>
<th>EUWood 2010</th>
<th>Indufor 2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference year</td>
<td>Million m³</td>
<td></td>
</tr>
<tr>
<td>Total Wood Consumption</td>
<td>825</td>
<td>942</td>
</tr>
<tr>
<td>Total Material Use</td>
<td>457</td>
<td>649</td>
</tr>
<tr>
<td>Wood Products Industry</td>
<td>314</td>
<td>308</td>
</tr>
<tr>
<td>Pulp and Paper</td>
<td></td>
<td>341</td>
</tr>
<tr>
<td>Pulp</td>
<td>143</td>
<td></td>
</tr>
<tr>
<td>Total Energy Use</td>
<td>368</td>
<td>293</td>
</tr>
<tr>
<td>Wood products industry side streams</td>
<td></td>
<td>150</td>
</tr>
<tr>
<td>Primary energy use</td>
<td></td>
<td>143</td>
</tr>
<tr>
<td>Energy use, %</td>
<td>45%</td>
<td>31%</td>
</tr>
<tr>
<td>Material use, %</td>
<td>55%</td>
<td>69%</td>
</tr>
</tbody>
</table>

Another recent study by Keränen & Alakangas (2013) has displayed total wood flows in the EU. Figure 5 extracted from the study explain the total wood used for energy is 246 million m³. Energywood from primary sources, i.e. firewood and forest chips cover about 120 million m³ of total. This wood material is used directly as fuel and it has no other use. Slightly larger part, 126 million m³ of wood used for energy is a result of by-product flows of wood consuming industries.
These recent studies give somewhat different estimates of the volumes of wood raw material allocated between energy and material use, caused by differences in study setting, scope and definition of consuming industries. Regardless, the studies highlight that the basis of all wood consumption, whether material or energy use, is the volume of roundwood harvested. Even though the total volume of virgin wood used in material purposes is greater than the volume used for energy, major amount of bioenergy from wood originates from forest industry side streams (industrial by-products, black liquor and recovered wood) and the collection of the forest chips. That is, bioenergy raw material supply is in strong connection with value chain of sawlogs and pulpwod. Wood is also a potential raw material for liquid biorefinery products such as biodiesel, bioethanol and bio-oil. The following sections gives and outlook to the supply and demand of wood in material and energy uses.

### 2.1.2 Supply and demand of wood in material use

Based on a study by Indufor (2013) total wood raw material consumption of the EU27 sawmill and wood based panels industry has increased by 38 million m³ to total 300 million m³ between 2000 and 2011 and is expected to continue to grow although at a slower pace than in the previous 10-year period. About 262 million m³ of total wood consumption in these sectors consists of roundwood. The study does not
distinguish the wood consumption between the sectors, but majority of this volume is sawlog consumption in the sawmill industry.

**Sawnwood**

Total production of sawnwood in the EU27 was about 100 million m³ in 2011 (Figure 6 and Figure 7). Softwood dominates the sawnwood market in terms of volume. The production of softwood sawnwood is increasing gradually, but there was a sharp decline after the year 2007. Softwood sawnwood production in the EU27 totalled about 91 million m³ in 2011.

**Figure 6** Sawnwood production in the EU27 in 2000-2011

![Graph showing sawnwood production in the EU27 from 2000 to 2011.](image)

Source: FAO Statistics Division
The yearly production of hardwood sawnwood has been fairly stable in the EU over the years. In 2011 the production was 9 million m³. Major hardwood sawnwood producers are Romania, France and Germany.

Sawmilling industry is in a key position at the start of the processing supply chain in this dynamic system, because sawlogs are usually the most valuable parts of the trees and hence often the most interesting ones from the wood sellers’ point of view. Their presence in the wood mix is often determinant in a forest owner's decision to harvest wood or not. If sawlog prices are low, the higher prices of other categories cannot typically offset that. To get the market of wood raw material running, it is therefore extremely important that sawmills are profitable and act as drivers for the downstream wood market. This brings also pulpwood as well as energy wood to the market and other forms of woodworking industries, pulp and paper industries and power plants can benefit from this as well as from the industrial wood-processing residues.

Major sawmilling driver is the construction industry in the EU but also in the US. Before the major economic recession especially Germany and Austria contributed to the growing construction segment in the US. This market decreased radically after 2007 and major recovery has not yet realized. The Czech Republic is expected to contribute to the recovering US housing market. Also Poland and Romania are expected to show higher annual output levels possibly based on new production capacity.

**Wood Based Panels**

European wood based panel production was around 48 million m³ in 2011 (Figure 8). Particleboard production is by far the largest segment, accounting for almost two thirds of the total panels output, followed by MDF, OSB and plywood. Wood based panels industry products are consumed in furniture and carpentry manufacturing,
automotive and industrial packaging as well as construction industry. Trends of these industry subsectors largely define the development of wood based panels demand.

**Figure 8  European wood-based panels production in 2011**

![European Wood-Based Panels Production in 2011](image)

Source: 1) EPF Annual Report; 2) FEIC Annual Report

European particleboard production was about 30 million m³ in 2011. Germany is both the largest producer and largest consumer of particleboard in Europe. Most of the trade occurs within the European countries, as particleboard is, to a large extent, consumed by European industries for further processing, e.g. into furniture. The transport cost for a product like particleboard is very high in relation to its price. European particleboard production is forecast to face a modest decline.

MDF is produced in 20 European countries with an overall production capacity of around 15 million m³ at the present. According to the European Panel Federation (EPF), actual MDF output amounted to about 11.7 million m³ in 2011. Overall production increased annually in the beginning of the decade and peaked at over 13 million m³ in 2007, decreasing rapidly thereafter due to the economic turmoil.

Germany is the largest MDF producer in the EU representing approximately one third of the overall European MDF output. Following the capacity expansions during the last couple of years, Poland has emerged as the second largest MDF producer country in Europe. France and Italy are the other significant MDF producers in Europe.

European OSB production is estimated at 3.6 million m³ in 2011. OSB production expanded rapidly after it started in Europe in the mid-90s; growth rates were in the double digits until 2007. OSB production is still fairly concentrated in a few companies in eleven European countries. Germany is the leading OSB producer in the EU27 area followed by Poland and the Czech Republic.

The production of plywood in the EU27 amounted to about 2.4 million m³ in 2011, approximately the same as in the previous year. However, the current production level is about 1 million m³ less than in 2007. EU27 production is expected to increase by
about 7% by 2016 which would still well be below the levels recorded in the first half of the previous decade.

According to the European Federation of Plywood Industry (FEIC), Finland is by far the largest plywood producer in the EU27 representing approximately 40% of the overall production. Italy, Spain, France and Latvia are the other significant producer countries where the annual production exceeds 200 000 m³/a.

The wood based panels sector is in direct competition for wood raw material with the bio-energy sector. Whilst bio-energy can use low-quality forest residues, this is not the case for wood-based panels, for which a higher quality is required for the wood chips and particles used in panel making. Both sectors use huge quantities of industrial wood-processing residues, mostly produced by sawmills, and the price will determine who gets the material.

**Pulp and Paper**

The total wood raw material usage of the pulp and paper industry in the EU27 in 2011, was approximately 341 million m³ (RWE) of wood, imported pulp and recovered paper. Recovered paper and roundwood are the two main raw material types consisting of about 145 million m³ (42%) and 96 million m³ (28%) of the total raw material consumption. The structural change among the different wood raw material types used for pulp and paper is foreseen to continue. The use of roundwood is expected to decline whereas the use of the recovered paper is set to increase.

Most of the pulp produced in the EU27 is chemical fibre (Figure 9). The production level in 2000 was on the same level as in 2011, but it was still 10% below the peak level in 2006. Production of chemical pulp in Central Europe is expected to slowly decrease as some of the paper producers switch to imported eucalyptus pulp. However in the Nordic countries, major industry companies Metsä Group, UPM and Södra have announced new projects in building up the chemical pulp capacity. This capacity increase is based mainly on increasing demand of spruce pulp in Chinese market.
Consumption of wood pulp mainly follows the production of paper (Figure 10). In average slightly less than 50% of all pulp in paper manufactured in the EU is virgin pulp, and the percentage is slowly decreasing. The main reason for the decrease is the improved characteristics of the pulp produced. Less pulp is sufficient. The pulp mills do tailor pulp grades for the paper machines they supply pulp for. The trend is expected to continue.

**Figure 9**  
**Production of wood pulp by grades in EU27 in 2000-2011**

**Figure 10**  
**Wood pulp consumption by grades EU27 2000-2011**
**Paper and Board**

The total paper consumption in the EU27 was 80.5 million tonnes in 2011 (Figure 11). During the economic recession consumption fell by 14% (2007-2009). By the end of 2010 the consumption had was equal to that of 2000, but was still 9.5% below the 2007 level.

**Figure 11** The largest consumers of paper and paperboards in EU27 (2011)

![Pie chart showing the consumption of paper and paperboards in EU27 (2011)](image_url)

Total: 80.5 mill. tonnes

Source: FAO Statistics Division

**Figure 12** Paper and paperboard consumption by grades EU27 (2000-2011)

![Graph showing paper and paperboard consumption by grades EU27 (2000-2011)](image_url)

Source: FAO Statistics Division
Several trends affecting the general consumption of paper in the EU can be identified. Printed media is competing with digital media with an impact on both newsprint and printing and writing grades. Demand for many of the graphic grades of paper, such as newsprint, magazine and office papers is in long-term, gradual but steady decline, except for some relatively small growth which may continue in the new EU member states.

In packaging the trend has two sides: while some consumers want less packaging and food grown in the neighbourhood, in general more and better packaging is needed to decrease the loss of food in transportation. In packaging of goods the package itself is still an important media for marketing and getting the customer to select one from a row of competing products in the shop.

Paper consumption is still growing in countries having joined the EU more recently. However, the consumption levels of printing and writing papers and newsprint per capita will not grow to the same level as the consumption in the old Member States, as it is more practical to move faster to the digital media.

In hygienic papers the trend in the EU is basically towards more fibre consumption. For some products, such as industrial, demand correlates to the strength of the economy and fluctuates with recession and recovery.

In general pulp is still produced close to the forest resources and paper close to the consumers. On the other hand international competition affects to the availability of fibre raw materials in the EU. Costs of pulpwood and pulping are much lower in developing economies (e.g. Brazil) than in Europe. Though Europe reaches the world’s highest levels of paper recovery and recycling, much of that material is set to be exported, while the recovered fibre available in Europe will have a lower average quality because of less high-quality graphic paper being manufactured and recovered.
2.1.3 Supply and demand of wood in energy production

Firewood

The term firewood consists of wood that is harvested from forest of other wooded land and used in small dwellings for simple heating applications such as fireplaces, ovens or log boilers. Firewood is usually used in form of split logs.

Major use of firewood exists in the EU. Establishing accurate number of utilization is difficult because it often does not show in statistics or is mixed in general energetic use of wood. According to statistics compiled from FAOSTAT, Joint Wood Energy Enquiry (JWEE) and National Statistics, about 105 million m³ of roundwood is used as source of energy in the EU (2011) (Figure 13 and Figure 14). If compared to total roundwood demand estimated by the study by Indufor the use of firewood consists about 23% of total raw wood demand (454 million m³ in 2011). According to FAOSTAT the total roundwood removals in 2011 in EU27 was 429 million m³. If compared to this figure, firewood consists about 24% of roundwood removals.

FAOSTAT numbers of firewood (fuelwood) include uncertainty because they may also include chipped wood. Data from JWEE can be considered somewhat more reliable because it is based on collection and quality control completed by working group of several national forest resources, wood energy and waste experts in particular countries. National statistics or JWEE data was primarily used and FAO figure if neither was available. Supposedly major part of the firewood consumption is based on procuring wood locally from own or neighbouring forest and is consumed in residential fireplaces. In this case firewood does not end up to open markets and thus not recorded into accounts or statistics. This makes the data related to firewood consumption uncertain and it should be considered only as a ballpark figure.

Based on the data, major consumers of firewood are Germany, France Finland, Austria, the Czech Republic, Spain, Poland and Sweden. These countries have strong tradition of household wood fuel consumption. This is the case especially in rural areas with abundant resource of wood that is not meeting quality requirements of industrial utilization and is freely available for forest owners. Insufficient energy (district heating) infrastructure drives the utilization of firewood in some East-European countries such as Romania and Bulgaria.
Figure 13  Consumption of firewood in EU27 major consuming countries

![Chart showing consumption of firewood in EU27 major consuming countries from 2007 to 2011.]

Source: Joint Wood Energy Enquiry, FAOSTAT

Figure 14  Consumption of firewood in EU27 major consuming countries (2011)

![Pie chart showing consumption of firewood in EU27 major consuming countries in 2011.]

Total: 105 Million m³

Source: Joint Wood Energy Enquiry, FAOSTAT

Firewood has little significance as internationally traded commodity. Most of the firewood is traded in domestic markets, and about 3.4 million m³ of firewood is traded in the EU annually, mostly between neighbouring countries.

Although the firewood consumption in small scale stoves and fireplaces is one of the oldest ways of providing heat it seems to remain popular in the EU. In major
consuming countries household consumption of firewood is often a secondary heating solution in the areas that can be accessed by district heating network. Although the use of firewood in space heating may be the only solution in distant rural areas the overall energy efficiency of small scale firewood consumption is low in comparison to established district heating or pellet heating solutions. As such, the potential in the EU to expand the use of highly efficient units is high. There is ongoing discussion about negative health effects of firewood use because of small particles resulted from wood combustion. It remains to be seen if this has a major negative impact on the firewood consumption.

Forest chips\textsuperscript{1,3,4}

Forest chips are becoming an important wood resource for energy production in Europe. Forest chips are fresh wood chips made of wood being harvested directly from the forest, used for energy production, and has not had any previous industrial use. There are currently several raw material types of forest chips:

- Tops and branches removed from trees during final felling
- Sawlogs that are rejected being unsuitable for material purposes due to decay etc.
- Small-size whole trees or stems
- Pulpwod size logs allocated to energy production
- Tree stumps.

Forest chips can be used in various energy use applications varying from single house heating to different scales of district heating and industrial scale combined heat and power production (CHP) plants. In Finland and Sweden major volumes of forest chips are consumed in large scale CHP installations. In Central Europe utilization of forest chips has more local character. It represents a significant local resource for heat and electricity production in areas with large forest resources, often located in areas with cold climate and/or high altitude and decentralized space heating infrastructure. In terms of international trade of biomass, forest chips have less significance due to their relatively high moisture content, low density and challenges in long term storage.

Use of forest chips made of tops and branches and small diameter stemwood is tightly integrated in industrial roundwood supply. Typically forest chip raw material can be harvested with similar machinery as industrial roundwood plus the chipper. Also large volumes of forest chips are sourced from areas used for industrial roundwood production. This is the case especially in the Nordic countries where tops and branches are collected from final felling sites after harvesting of sawlogs and pulpwood. Forest chip raw material is also collected from thinning operations in young and mid aged forest stands aside with pulpwood harvest. In Central Europe, proportion of stemwood used as forest chip raw material is higher due to smaller use of roundwood as pulp raw material. Currently the main raw material of forest chips in most of the countries is tops and branches because they are readily available in piles after final felling making them in economic terms the cheapest and most profitable forest chip raw material. In the near future a shift towards increasing use of stemwood is expected, because further volume expansion will require broadening the raw material basis. Cost efficient supply of forest chips require well developed road infrastructure, purpose designed harvesting and chipping technology and well organized logistics.

Several studies have made estimations of utilizable potential of forest chips. According to Asikainen et al. (2008)\(^3\), Mantau et al. (2010)\(^1\) and Diaz Yanez et al. (2013)\(^4\) the technically available potential vary from 117 to 277 million m\(^3\)/a. These potentials include all forest chip raw materials: tops and branches, stemwood and stumps. In these studies the stemwood potential is described as incremental volume of stemwood that could be used to both energy and industrial purposes.

Currently the total consumption of forest chips in the EU27 is estimated at about 45 million m\(^3\)/a (2011) (Figure 15 and Figure 16). Major consumers of forest chips in the EU are Sweden (10.5 million m\(^3\)/a,), Germany (9.0 million m\(^3\)/a), Finland (7.5 million m\(^3\)/a) and Italy (6.3 million m\(^3\)/a). The data illustrate strong increasing trend in the consumption of forest chips for the whole EU during 2007-2011. The consumption figures are based on compilation of statistics gathered from national statistics and UNECE – Joint Wood Energy Enquiry. The dataset is scattered and some countries lack data. Only Finland and Sweden provide official statistics of the use of forest chips that can be considered reliable. The figure has to be considered as a rough estimate giving direction of the use and trend in different countries.

**Figure 15** Consumption of forest chips in EU27

Figure 16  Major consumers of forest chips in EU27 (2011e)

![Forest Chips Consumption in EU27](image)

*20% for Germany, 24% for Sweden, 17% for Finland, 14% for Italy, 7% for Denmark, 4% for France, 3% for United Kingdom, 2% for Lithuania, 2% for Austria, 2% for Estonia, 2% for Slovakia, 2% for Latvia, 1% for Lithuania, 1% for Slovakia, 2% for Latvia, 1% for Others, 4% for Total: 45 Million m³.*


Figure 17 illustrates the development of forest chips consumption in three major countries: Sweden, Germany and Finland. The consumption of forest chips has increased at a steady pace throughout the last ten years. In Finland and Sweden the national targets of renewable energy and related investments to district heating applications utilizing forest chips have been driving the increasing trend of forest chip consumption. At the same time the development of harvesting and chipping technology and improved logistical solutions have been improving the cost efficiency of the supply. The similar technological solutions have been applied in other European countries as well.
The state of energy infrastructure in particular countries defines largely the development of forest chip use. Countries such as Finland, Sweden, Germany, Latvia and Estonia have a network of centralized heat and power production facilities to which majority of houses are connected. Larger facilities enable the use of lower quality forest chips with variable chip size, moisture content. Stumps can be generally used only in large scale industrial CHP plants. In these countries the most commonly used supply chain is the roadside chipping chain where the wood is chipped at the roadside and transported to the plant with a chip truck.

In countries with mainly decentralized space heating infrastructure such as UK, the district heating networks are considerably smaller. In small scale applications the combustion technology is usually grate boilers requiring good quality forest chips with uniform particle size, moisture content, low amount of needles and impurities. In this kind of situation chipping at the terminal or at the plant is favoured.

Several challenges need to be addressed if the supply of forest chips is targeted to increase. As the supply increases the procurement of forest chips is expected to move to areas with poorer resources and longer transport distances. Production of forest chips in energy production is highly dependent on public subsidies laid on the supply. The end product has relatively low added value, and the profitability depends how efficiently the production costs can be lowered by using efficient harvesting technology and supply organization. Storage management in supply chain will become increasingly important factor when aiming at increased utilization of forest chips. Forest chips raw material is exposed to variable weather conditions during storing at the roadside or terminal. Storing of forest chips affects several quality attributes of forest chips. In industrial raw material procurement the aim has been in maximizing the supply chain speed because of freshness of roundwood being the most important quality attribute. In forest chips procurement, a correct (not necessarily fast) storage management that minimizes the moisture content, increases the value of forest chips. The development is still in an early stage. Correct storage management applications
require multidisciplinary inputs including e.g. information of wood moisture relationships, logistics, ICT and meteorology.

**Industrial by-products**

Industrial by-products include mainly wood chips (from wood processing residues), sawdust as well as shavings, trimmings and bark. They are supplied as by-products available in proportions from the processes of wood products industry, mainly sawmilling but also wood based panels and joinery production. Industrial by-products have to be clean and they are not altered by any chemical process. Wood chips and sawdust and shavings from planing are important raw materials for pulp, wood based panels (Particleboard, MDF/HDF) and wood pellet production as well as in bioenergy production as such. Bark is used only in energy production usually within the processing facility.

Flow of solid by-products from wood products manufacturing follow the trend of sawnwood, wood based panels, and joinery production. Figure 18 presents the total supply of sawdust, chips and bark as by-product of wood processing industries in 2000, 2005 and 2010. The supply of industrial by-products increased throughout the early part of 2000’s up to 2008 when the global financial crisis caused drop of wood products manufacturing. The volumes have been slowly recovering since but overall do not show an increasing trend as for other products such as wood chips.

**Figure 18**  
Supply of sawdust, chips and bark in EU27

![Supply of sawdust, chips and bark in EU27](image)

Source: Indufor, Study on the Wood Raw Material Supply and Demand for the EU Wood-processing Industries

Figure 19 shows the supply of sawdust, chips and bark supplied by individual member states in 2010. Germany is the largest supplier of industrial by-products, at an estimated volume of 19.3 million m³/a of wood chips and sawdust. Other major suppliers are Sweden (14.5 million m³/a), Austria (10.4 million m³/a), Finland (9.0 million m³/a) and France (7.4 million m³/a). Major suppliers of industrial by-products are also major consumers.
Figure 19  Supply of sawdust, chips and bark by Member States in EU27 (2010)

Figure 20 illustrates the breakdown of major supply sources and consumption segments of industrial by-products. Bark is not included in the figure since it is used only in energy production and does not have a competitive use. Otherwise wood chips and sawdust can be used in several competing segments; mainly pulp production, wood based panels, wood pellets or energy production as such. Although increasing shares of industrial chips and sawdust are used in wood pellet production, energetic use of them as such still exists. Presented figures are an estimate based on compiled data from several different statistics and studies. The reason for the supply and demand figures not being matching in some countries is the variability of conversion factors used in several sources as well as the difference between the actual supply and volume of stock within a calendar year.

An important observation can be deducted from the Figure 20. Almost all by-products are being used, and practically no unused volume of industrial by-products is available unless production volume of sawmilling and other roundwood consuming industries increases. In Finland and Sweden, major volumes of wood chips are used in pulp production. Germany, Poland and France use large shares of industrial by-products in wood based panels manufacturing. Four countries with traditionally large forest industry sector, namely Germany, Sweden, Finland, and Austria use large volumes of industrial by-products for energy as such. In Sweden, Germany and Austria decreasing volume of industrial by-products is used as energy directly due to increasing raw material of wood pellet production. In Finland wood pellet production has not gained equally strong position in domestic markets. In Finland the export oriented wood pellet sector has lower wood paying capability in comparison to strong pulp industry sector.

The only noted country with untapped resource of industrial by-products is Romania. In Romania number of small local sawmills and wood products manufacturers produce goods to the local markets. Small companies are not linked to further processing facilities and have no other option than dispose the by-products. Only larger wood
products manufacturing facilities, mainly in Austrian and German ownership utilize the by-product streams in wood based panels or pellet production.

Figure 21 shows the shares of industrial by-product consumption by end-use segments in the whole EU27. Pulp and paper sector dominates clearly, holding over 1/3 of the market. Wood based panels are the second largest consuming segment. The volume of industrial by-products for energy as such and as wood pellet raw material was about same size in 2010. The present share of industrial by-products to pellet production has probably surpassed the direct energetic use because of increased production of wood pellets in the EU27.
Figure 20  Supply and consumption of industrial by-products (excl. bark) in the EU27 (2010)

Sources: JWEE, European Panel Federation, FAOSTAT, AEBIOM European Bioenergy Outlook 2013, CEPI, VDP – Germany, Austropapier, Finnish Forest Research Institute, Skogsstyrelsen, Indufor, Study on the Wood Raw Material Supply and Demand for the EU Wood-processing Industries
Wood pellets\textsuperscript{5,6,7}

Wood pellets are refined wood fuels traditionally made of clean industrial by-products of the mechanical wood industry, mainly wood chips, sawdust and/or shavings. Pellets are used for energy production in variable applications. They can be used for heating of single small-sized dwellings, competing with oil and electricity heating systems. Pellet combustion is also an alternative for district heating stations and in larger CHP/co-firing plants. Wood pellets can be burned as such but also co-combusted with other biomass in CHP plants and with coal in coal- and oil-fired pulverized combustion boilers. Main advantage of wood pellets compared to chips is the lower moisture content and, mainly, higher bulk energy density which makes them more advantageous when transport distances are long.

EU is the biggest supplier and consumer of wood pellets in the world. Consumption of wood pellets has increased from 3.7 million tonnes to 13.4 million tonnes during 2005-2012 (Figure 22). At the same time the production of pellets in the EU has increased from 3 million tonnes to 10.5 million tonnes. The share of wood pellet imports from outside the EU has increased and was about 20% in 2012. As shown in Figure 23, the biggest wood pellet consuming countries are Denmark (1.8 million tonnes), Germany (1.7 million tonnes), UK (1.7 million tonnes), Sweden (1.5 million tonnes), Italy (1.4 million tonnes), and Belgium (1.3 million tonnes). These countries account for about 70% of total wood pellet consumption in the EU.

\textsuperscript{5} IEA Bioenergy – Task 40: Sustainable International Bioenergy Trade: Global Wood Pellet Industry Market and Trade Study
\textsuperscript{6} Sikkema R. et al. 2011. The European wood pellet markets: current status and prospects for 2020
\textsuperscript{7} Verhoest C., Ryckmans Y. 2012 Industrial Wood Pellets Report. Laborelec, Gdf Svez. Supported by Intelligent Energy Europe.
As seen in Figure 22 the European wood pellet production capacity is majorly underutilized. The reason for this is that domestic market of traditional raw materials of wood pellets i.e. industrial by-products has been saturated to the point where no unutilized streams of sawdust or chips are available.

**Figure 22** Production, consumption and production capacity of wood pellets in EU27

![Production, consumption and production capacity of wood pellets in EU27](image)

Source: AEBIOM European Bioenergy Outlook 2013.

**Figure 23** Consumption of wood pellets in EU27

![Consumption of wood pellets in EU27](image)

Source: AEBIOM European Bioenergy Outlook 2013.
Pellet market can be distinguished to two main sections: residential wood pellets and industrial wood pellets. The division is necessary because the product characteristics, market dynamics, prices and production costs differ between the types.

**Residential Wood Pellets**

In the EU, the production of residential wood pellets is mainly integrated to sawmilling industry. Residential wood pellets are manufactured according to strict standards in terms of size, shape, cleanliness and moisture content. They are used in small scale wood pellet heating applications requiring uniform quality of fuel. Trade of residential wood pellets is local, mainly within domestic markets or between neighbouring countries.

In the Nordic countries and Central Europe, the production of residential wood pellets is closely linked to the production of sawmills providing feedstock residues such as sawdust or wood shavings. Traditionally, conversion of by-products to wood pellets generated an additional income stream and value added to low cost and low price side product. The situation still remains, however the amount of independent wood pellet manufacturers has increased. Due to recent increasing trend in closures of a number of smaller sawmills the traditional raw material sources are more centrally available.

Roundwood is not used as residential wood pellet raw material due to limited wood paying capability of domestic wood pellet industries. Other wood consuming industries such as sawmills, pulp mills and wood based panels manufacturers have generally better wood paying capability for roundwood. Residential wood pellet manufacturers are able to secure raw material from sawmilling industry by product streams.

Most of the residential wood pellets follow ENplus wood pellet standard which sets the characteristics for wood pellets in terms of technical characteristics (set by EN 14961) and transparency of the whole supply chain. About 3.5 million tonnes of wood pellets consumed in the EU (26% of total) are ENplus certified.

Increasing volumes of certified residential wood pellets are manufactured in Eastern-Europe in close vicinity of sawmills and wood product manufacturing facilities owned by West-European companies. This production is largely exported to consumer markets in Germany, Italy, Austria and Sweden.

**Industrial wood pellets**

Industrial wood pellets are mostly made of virgin wood raw materials such as roundwood. Regions that have major industrial wood pellet manufacturing industries such as South-Eastern US and Western Russia because of favourable wood biomass surplus situation in these areas. The wood pellet manufacturers with comparatively low wood paying capability are still able to purchase abundant wood raw material with low price due to minor or non-existent competition of roundwood resource.8

Trade flows of industrial wood pellets are global and this market has developed primarily as a result of public incentives to biomass power and heat production. Consumption of industrial wood pellets take place in large heat and electricity producing facilities. Two main large scale pellet consuming segments exist: co-firing and CHP production which both produce heat and electricity simultaneously.

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8 *The Risk of Indirect Wood Use Change, Pöyry Management Consulting 2014*
Co-firing is a primary application of combusting industrial wood pellets together with pulverized coal in existing coal power plants. Biomass co-firing has expanded rapidly in recent years, particularly in northern EU, as it can be done with limited investment cost and efficiency losses. Typically co-firing enables 5-15% mixture of wood pellets combusted with coal; however with equipment modernization or by using torrefied wood pellets, 40% share of wood pellets is possible. Further developments and pilot plants are still required before such high shares of co-firing would become standard.

In CHP production mixture of solid biomass is combusted together by using various alternatives of combustion technology (e.g. fluidized bed combustion, fixed bed combustion, grate furnace). Fossil and biomass fuels with variable moisture contents can be used simultaneously. In CHP plants wood pellets are combusted alongside with other biomass fuels. Future CHP applications allow majority of fuel to be biomass. In Denmark, Belgium, Sweden, Germany and the Netherlands the future strategy is to move future industry projects towards full biomass plants.

Market of industrial wood pellets in consumption side is highest in the UK, Denmark, Belgium, the Netherlands, Poland and Sweden. Major producers of industrial wood pellets in the EU are Germany, Lithuania, Estonia, Latvia, Portugal, Finland and Sweden.

Large scale wood pellet consumers have gradually raised their requirements on pellet quality both in terms of technical characteristics and sustainability. This is a result of requirements of subsidy schemes as well as corporate social responsibility (CSR) issues that the investors are dealing with. This sets increasing requirements wood pellet manufacturers e.g. in Russia to source sustainably produced (FSC-certified) wood pellet raw material.

Figure 24 shows the consumption of wood pellets by end-use segments in major consuming countries. Pellet consumption in the CHP/Co-firing segments mainly consists of industrial wood pellets use in the above explained facility types. Wood pellet consumption in district heating segment refers to the use of wood pellets in small to large scale facilities producing only heat. Here, both types of wood pellets may be used. In residential heating, wood pellets are of residential quality because of higher technical requirements related to size and quality, caused by small scale combustion equipment.

The biggest consumer Denmark is a major importer of wood pellets. Imports originate from the Baltic countries, Portugal, North America and Russia. About 1.3 million tonnes of industrial wood pellets are used in the CHP production, however Denmark has also notable (0.5 million tonnes) markets of residential scale use of consumer wood pellets. In Germany the wood pellet market is dominated by consumption in residential heating segment. Besides the consumption of domestically produced residential wood pellets, Germany imports major volumes from East-European countries. Wood pellet consumption in United Kingdom, Belgium and Netherlands is concentrated in large scale co-firing facilities. Wood pellet markets in these countries are highly import driven and are mainly sourced from North America. Sweden is the pioneer in wood pellet markets. Wood pellet production started there in the early 1990’s and the consumption has increased steadily since. The strong status of domestically produced pellets in residential heating but also in district heating segment is based on high taxation of fossil fuels, which has enhanced the competitiveness of wood pellets against fossil fuels. In Sweden the consumption of industrial wood pellets has been increasing and is based mainly on imported wood pellets from Baltic countries and Russia.
Figure 24  Consumption of wood pellets in main end-use segments in the EU27 (2012)

Source: AEBIOM European Bioenergy Outlook 2013.

Most markets of residential wood pellets in the EU are largely self-sufficient. In the markets of residential wood pellets the subsidies have been directed to support investments in small scale pellet combustion equipment. This is the case e.g. in Austria. This kind of subsidy system has generated stable market as the owners of the heating applications have been engaged to use wood pellets for longer period.

Industrial wood pellet markets depend on the import of wood pellets from outside the EU27. According to Eurostat, import of wood pellets to EU from outside grew to about 5.7 million tonnes in 2013. Both the US and Canada export over 2 million tonnes of pellets to the EU, Russia about 0.7 million tonnes. Most of the exports from North America are going to the UK, the Netherlands, Belgium and Denmark. Russian exports are targeted to Sweden and Denmark.

Industrial wood pellet markets depend mainly on the establishment or abolishment of public support schemes. In large scale CHP production, feed in tariffs and market premiums of biomass produced electricity keeps up the competitiveness of wood pellets in comparison to coal. Policies have aimed securing the stable level of market price for energy produced from pellets by feed in tariffs or market premiums. So far, major investments in large wood pellet heating plants have been delayed since the investors do not have certainty of long term productivity of the projects. On the other hand, industrial pellet markets are relatively mature compared to residential wood pellet markets, because of their advanced storage facilities and long term price setting.

Due to limited availability of traditional wood pellet raw materials from industrial by-products pellet producers are seeking new alternative raw materials to increase production. Possible feedstocks include industrial roundwood, clean recovered wood and roundwood from short rotation forestry plantations. Some producers, such as German Pellets GmbH, are already using chips from debarked fresh roundwood in production of residential wood pellets. Some pellet producers are integrating their
feedstock portfolio by aiming for either long term forest concession leases or supply agreements with local forest owners.

The development of global industrial wood pellet market can already be detected in the increase in global trade. Further developments in the torrefaction pre-treatment system will also support this trend, improving the long term storing and drying possibilities. Consequently, the combination of pelleting and torrefaction of wood biomass can be expected to lead to a new commodity in global biomass trade. Especially large scale pellet plants with global feedstock supply chains will most certainly focus on the production of torrefied wood pellets, since their value chain profi ts the most through torrefaction.

The EU demand could range between 20-50 million tonnes by 2020, depending to a large extent on two factors: a) the policies on co-firing in amongst others the UK, the Netherlands, Germany, and Poland, and b) on the price of heating oil and the related attractiveness to switch to wood pellets for small scale users (households and medium-sized residential buildings).

**Recovered wood**

Recovered wood includes all kinds of wood material which, at the end of its life cycle in wooden products, is made available for re-use or recycling. This group mainly includes used packaging materials, wood from demolition projects, unused or scrap timber from building sites, and parts of wood from residential, industrial and commercial activities.

The general increased interest in recycling of materials as well as their energy utilisation has put pressure on expanding the use of European resources of recovered wood. Due to the lack of effective and established collection and sorting systems and clear and consistent legislation full potential of recovered wood not unutilised in many European countries.

Few estimates of total available potential of recovered wood exist. The EU total wood fraction of municipal solid waste, such as discarded furniture or renovation debris, amounts to 26 million tonnes per year. The available potential of post-consumer wood for energy production is assumed to be 18.2 million tonnes.

The available amount of wood debris is generally linked to population size of the EU Member States. In 2020, Mantau et al. (2010) estimate 58.7 million m³ of post-consumer wood to be available in the EU. This calculation assumes an annual growth of 1.2% for the period 2010-2020. However, this figure does not take into account the increasing recycling rate of recovered wood over time. Assuming an 1.5% annual decrease of recovered wood going to landfill or incinerated, based on the period 2008-2020, the quantity of recovered wood available in the EU for energy production decreases to 17.7 million tonnes, showing negative annual growth of – 0.3% in 2020.

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9 Used wood in the EU – Part 1, Classification, properties and practices. BioNorm II – Pre Normative research on solid biofuels for improved European standards.
The growing demand for wood material has led to increasing interest in the untapped potential of recovered wood across Europe. Generally European management of resources prioritizes the re-use of materials (e.g. waste hierarchy). The second option is recycling, while the last option is extracting the energy potential of the used material. The usage should be based on this hierarchy.

Countries with high utilization rate of recovered wood in material and energetic purposes have developed regulatory framework on dividing recovered wood to various quality classes based on cleanliness and level of contamination. Clean qualities can be further utilized to material purposes, such as particleboard production whereas the lower quality classes are suitable only for combustion (Figure 25). It is clear that the utilization of recovered wood can be increased by development of recycling practices and related regulations. Urbanization and consequent use of wood in construction and packaging are the dominant drivers in the countries with high utilization rate of recovered wood. Increasing urbanization means that more people are living in urban areas, where majority of wood products are consumed. Recovered wood resources are becoming more centrally available thus the recycling and handling facilities and networks can be established easier than in sparsely populated areas.

According to a review of several data sources, Germany, the UK, Italy and France are the biggest consumers of recycled wood in the EU (Figure 26). The total consumption of recycled wood in the EU27 is estimated at about 21 million tonnes. When a conversion factor of 1.67 m³ per 1 tonne of recovered wood (according to JWEE) is applied, this correspond app. 35 million m³ of wood. Based on general increase of wood biomass for energy production and increasing requirement of efficient recycling of waste materials the European market for recovered wood is expected to grow; however, no solid official data showing trends is available. Most of the trade of recovered wood occurs between companies but some independent market places on the Internet are becoming established. The two main importers are Italy, due to their particleboard industry and Germany with developed energy generation plants. Price levels are expected to increase in the future because of growing demand and the integration of the market. Recovered wood markets are highly interrelated with policy matters as well as energy prices. Owing to its high bulk/value ratio, recovered wood is

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not transported long distances and therefore it is usually used close to the place of collection.

**Figure 26** Consumption of recovered wood in main end-use segments by country in the EU27 (2010e)

![Bar chart showing the consumption of recovered wood in main end-use segments by country in the EU27 (2010e).](image)

Sources: JWEE, EPF, COST 31, Wood Recyclers’ Association UK, BAV Germany, Indufor Estimate.

Figure 27 shows the shares of recovered wood consumption in three main end-use segments. Majority of recovered wood is used in energy production. Wood based panels sector constitute almost 30% of recovered wood consumption. Other uses such as mulch, animal bedding etc. cover about 13% of the total consumption.
Recovered wood that contains heavy metals or hazardous materials can only be utilised for energy purposes and even then it is very important to control the nature and amount of pollutants formed during the combustion process. Usually large scale combustion boilers have an efficient flue gas cleaning, but combustion of this material in small ovens or single house heating is not recommended nor allowed. There are several EU directives that control and define the use of recovered wood for different purposes. Recovered wood related legislation has been issued by the EU since the early 1970s through various directives.

Most importantly Directive 91/689/EEC – “The Directive on Hazardous waste” and Commission Decision 2000/532/EC – “The List of Wastes and Hazardous Wastes” are the basis of defining the recovered wood in the different classes described above. The directive defines categories or generic types of hazardous waste that are relevant to recovered wood.

Contaminants originating from different sources need to be taken into account in the utilisation of recovered wood. Different risks are associated in their preparation and use. From the aspect of occupational toxicology the dust from wood processing needs to be considered. The possible releasing of contaminants poses a risk to the environment as a consequence of processing recovered wood.
**Black liquor**

Black liquor is the spent cooking liquor produced from the kraft process when digesting pulpwood into paper pulp. Lignin, hemicelluloses and other substances are removed from the wood to free the cellulose fibres. The pulp industry derives a significant share of its energy consumption in the form of bioenergy from black liquor. This by-product is entirely used in energy production within the pulp and paper industry. In most cases the produced energy is utilized within the processes of integrated pulp and paper industry. In some cases the pulp and paper mills may sell the excess heat and/or electricity to the neighbouring community.

Figure 28 displays the estimated black liquor production in the EU27 countries. In this respect the production volume equals the consumption since black liquor is used to energy at the pulp mill where it is produced. The estimated annual black liquor production in the EU27 is around 41 million tonnes. The consumption of black liquor cannot be converted to cubic meters since it is a derivate of chemical process in which the output yield of black liquor varies depending on factors like produced pulp type, tree species etc. The biggest producers in descending order are Sweden (12.8 million tonnes/a), Finland (11 million tonnes/a), Portugal (3.4 million tonnes/a), Spain (2.6 million tonnes/a) and Germany (2.6 million tonnes/a). Figure 29 show that two biggest producers and consumers, Sweden and Finland, contribute almost 60% of the total black liquor consumption in the EU. This is largely due to the share of virgin wood raw material being the highest in these countries. Black liquor is produced only as a result of pulp production from virgin pulpwood sources. In major Central European pulp producing countries such as Germany and France the raw material basis is dominated by recycled paper and the share of virgin pulpwood raw material is considerably lower.

**Figure 28** Production of black liquor in the EU27

Source: Indufor, Study on the Wood Raw Material Supply and Demand for the EU Wood-processing Industries.
In the future trend of black liquor utilisation volumes are strongly linked to the development of chemical pulp production. The utilisation of black liquor takes place at the site of production. There are a very few instances of domestic trade of black liquor between pulp mills. This happens only locally for specific reasons.

**Liquid biofuels from wood**\(^\text{15,16}\)

Liquid biofuels such as biodiesel, bioethanol and bio-oils represent a major potential in refining wood to fuels used e.g. in the transportation. Liquid biofuels are developed all over the world. The primary driver is to displace fuels currently derived from fossil sources. Energy security and flexibility and both rural and urban job development are other important drivers. Liquid biofuels can also be used as raw material for a number of bio-based chemicals.

The most developed liquid biofuel concepts based on woody, i.e. ligno-cellulosic, biomass, are pyrolysis to bio-oil and fermentation to bioethanol, which both processes are in a commercial stage today. Several pyrolysis oil plants have been operating for years. These processing plants are considered as the “1\(^{st}\) generation biorefineries”. Biofuel production can be integrated with large sawmills or the biofuel plant can be a section in some other integrated forest industry complex such as a pulp mill.

In the EU the production of liquid biofuels are on a pilot project level. The first commercial lignocellulose-based bioethanol plants are functioning, but only demo plants are based solely on wood. The deployment of new biorefinery concepts, based largely on ligno-cellulosic feedstocks, will need to rely on the technical maturity of a range of processes to produce materials, chemicals, and energy. Considerable development work is underway and new biorefinery concepts are expected to be


\(^{16}\) Indufor data
commercially deployed by 2020. The mix of market and government support for green materials and chemicals and for bioenergy will be an important factor in determining the type and rate of deployment of biorefineries. Regardless their currently minor effect on wood consumption larger investments of biorefineries using wood are planned and they can have a major effect on the regional demand of wood raw material if realized.

2.1.4 Energy and material use of wood biomass

Different wood raw material types (industrial roundwood, forest residues, recovered paper, and recovered wood) each have their own optimal uses from technical and economic points of view. Some categories can in principle be used for a wide range of end products, others (for instance bark) practically only for energy. Therefore, the level of competition for categories varies. There are also a number of by-product flows from one use to another.

As stated in the Indufor’s “Study on the Wood Raw Material Supply and Demand for the EU Wood-processing Industries”, sawmills are in a key position to keep the market of wood raw material running for both material and energy uses. Sawlogs are the most valuable part of the tree, and thus the most interesting part from the producer’s point of view (Figure 30). Procurement of proportions with lesser value (pulpwood, tops and branches) is tightly integrated to the supply of sawlogs. Enhancing the availability of sawlogs improves also the raw material acquisition possibilities of pulp and paper, woodworking and bioenergy industries.

![Figure 30](image_url) Volume and value from different parts of a tree (softwood) in final fellings in privately owned forests in Finland, 2012

The supply of various wood categories is strongly interconnected. Harvested trees (especially in the final harvest) usually consist of a sawlog portion (bottom), pulpwood portion (middle) and the fuel wood or biomass energy wood portion (tops, branches and roots). Sawlogs are typically the most valuable part of the stem, and the revenue
from logs is typically the key driver for forest owners. If sawlog prices are low, the higher prices of other categories cannot typically offset that. In Figure 31 below, the use of wood has been divided among three main categories; the pulp and paper industry, the wood products industry (woodworking) and the bio-energy production.

**Figure 31 Interrelations of wood consuming industries and wood raw materials**

<table>
<thead>
<tr>
<th>Raw material types</th>
<th>Sawnwood</th>
<th>Plywood</th>
<th>Pulp, Paper &amp; Board</th>
<th>OSB</th>
<th>Particle Board</th>
<th>MDF</th>
<th>Pellets</th>
<th>CHP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulpwood</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
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<tr>
<td>Forest residues</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Industrial Residues</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bark</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chips</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sawdust</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recycled Material</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Recovered paper</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recovered wood</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Indufor, Study on the Wood Raw Material Supply and Demand for the EU Wood-processing Industries. OSB = Oriented Strand Board, MDF = Medium Density Fibreboard, CHP = Combined Heat and Power production.

As there is competition for certain wood categories in several end-uses, the wood paying capability of different end-uses largely determines who gets to use any given category. In recent years especially, the wood based bioenergy products (wood pellets and CHP) have competed for the same raw material base. It appears that pellet- and bio-energy plants can currently pay equal or somewhat higher prices for raw materials than e.g. particleboard plants. Therefore, the competition for sawdust and low-grade roundwood materials in certain areas is fierce. Energy subsidies have an impact on this competition and they can alter the competitiveness of various end-uses considerably.

Figure 32 presents a recap of consumption of examined wood biomass types in energy production in the EU. To make the biomass types commensurate, the volumes and masses presented in the section 2.2.3 have been converted to energy (PJ) based on their average energy content. The average energy conversion factors for the respective products were derived from JWEE.

The total estimated wood biomass consumption is estimated at 2 600 PJ. Over one third of this volume is accounted by firewood (105 million m³/a). Together with forest chips these two primary wood energy sources cover about half of the examined consumption. Wood energy use from secondary and tertiary sources is estimated to account to another 50% of the total volume. Black liquor is the largest source of secondary wood energy and second largest source of energy of all wood biomass. Wood pellets cover about total 9% and the remaining share is divided between industrial by-products and recovered wood and bark. As discussed earlier, it must be noted, that the estimate of firewood consumption and forest chips includes high
uncertainty. They are not based on solid data and are rather an indirect estimate based on several different data sources. Official data of these types of wood biomass is available only for a small number of countries. Even though the estimate of these biomass types can only be considered as ballpark numbers, their share of the total consumption should be considered as notable.

**Figure 32  **Total consumption of wood biomass in energy production in EU27 (2011e)

![Total consumption of wood biomass in energy production in EU27 (2011e)](image)

Source: Data presented in section 2.2.3.

Figure 33 illustrates the wood raw material used in the EU27 for material and energy purposes. The volume for wood consumed in material use is presented on the left stacked bar by raw material types. This volume is based on the data from study by Indufor (2013). The volumes of wood consumed in energy production are based on the data examined in the section 2.2.3.
In Figure 33, wood consumed in material use is about the double to amount of wood consumed in energy production. About 1/3 of the wood for energy presented in Figure 33 is resulted from processes linked to either wood products industry or pulp and paper industries. From these wood biomass types only firewood and at least part of the forest chips can be considered as “wood consuming industry independent” biomasses. An important question arising from this comparison is: How much of the firewood consumption is wood that could be utilized in e.g. wood products industry? Furthermore, development of the energy conversion methods has major potential in adding value to the otherwise low-margin bioenergy products, and turning them from locally marketed goods into globally traded commodities.

Figure 34 shows the same wood consumption between material and energy use but broken down to main consuming segments. The consumption within wood products industries and pulp and paper industries is based on the data from study by Indufor (2013). The division of wood biomass for energy is divided between residential and CHP production. In this respect CHP merges heat and power production, combined or heat-only production in all scales. It is assumed that all firewood is consumed in residential sector. Industrial by-products and recovered wood is assumed to take place in CHP production. Wood pellets are divided between residential and CHP use based on shares illustrated in Figure 24. From forest chips 10% is expected to take place in residential heating and rest in CHP segment.
Figure 34  
Estimated current consumption of wood biomass between main consuming segments within material and energy use in the EU27 (2011)

Source: Material use: Indufor, Study on the Wood Raw Material Supply and Demand for the EU Wood-processing Industries. Excludes recovered paper and imported pulp (RWE). Energy use: Data used in section 2.2.3.

Pulp and paper industries figure does not include recovered paper and imported pulp. These raw materials were presented in the study by Indufor as part of the total wood consumption of these segments and they cover about 58% of their raw material consumption (roundwood eqv.). Also bark and black liquor are left out of the energy use segment. The reason for leaving these materials out of the figure is that it shows aside the wood material that, at least in theory, could be interchangeable from material use to energy use.

Considering the inter-relationships both in supply and demand of various wood categories, the following developments are possible. Based on the study by Indufor (2013) sawnwood production can be expected to increase only marginally. Consequently this means that no significant increase in the supply of industrial by-products can be expected either.

On the other hand, pulp production from virgin sources is expected to increase since several large companies have announced new investments to chemical pulp production capacity in Finland and Sweden. New mills will use virgin wood as raw material meaning that increased bark and black liquor usage as energy can be expected. This also increases the regional competition of pulpwood between the wood consuming industries.
2.2 Agricultural biomass

Bioenergy from agriculture is today mainly used for biofuels in the transport sector and many studies already covered this field during the last years (see e.g. results from BIOMASSFUTURES17, REFUEL18). Here, the focus is put on agricultural biomass that is not typically used as biofuels for transport. These are:

1. Woody/ligno-cellulosic biomass
   - Biomass from short rotation coppice (e.g. willow, poplar)
   - Biomass from ligno-cellulosic species (e.g. miscanthus, reed canary grass)
2. Cropping residues (mainly straw from cereals and rapeseed)
3. Residues from livestock (manure, slurry)

This report focuses on the current use, supply and demand and their trends of these three biomass fractions. However, these biomass categories are not sufficiently covered in European and/or international statistics like EUROSTAT or FAOSTAT. To give an overview over these feedstocks we summarise (among other sources) findings from two EU projects (BIOMASSFUTURES and Biomass Energy Europe19) that analysed these biomass fractions. Besides future biomass potentials (which are not focus of this study), both projects described also the current use of different biomass feedstocks including yields, cultivation areas, harvest volumes and costs.

2.2.1 Woody/ligno-cellulosic biomass

Biomass from lignocellulosic energy crops can contribute to primary energy supply in the short term in heat and electricity applications and in the longer term in transport fuel applications. Lignocellulosic material can generally be divided into three main components: cellulose (30-50%), hemicellulose (15-35%) and lignin (10-20%). Cellulose and hemicelluloses make up approximately 70% of the entire biomass and are tightly linked to the lignin component through covalent and hydrogenic bonds that make the structure highly robust and resistant to any treatment (Limayem & Ricke 2012). Ligno-cellulosic material constitutes the world’s largest bioethanol renewable resource. Grassland encompasses primarily agricultural residues that cover food or non-food crops and grasses such as switch grass and alfalfa. Aside from being an environmentally friendly process, agricultural residues help to avoid reliance on forest woody biomass and thus reduce deforestation. Unlike trees, crop residues are characterized by a short-harvest rotation that renders them more consistently available to bioethanol production (Limayem & Ricke 2012). Lignocellulosic Biomass can be used for material and energy use (see Figure 35).

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17 http://www.biomassfutures.eu
19 Biomass Energy Europe: http://www.iiasa.ac.at/web/home/research/researchPrograms/EcosystemsServicesandManagement/BEE.en.html
Miscanthus is a C4 perennial grass, and therefore adapted to warmer climates. Reed Canary Grass (RCG) is native in Sweden as in many other parts of northern Europe. Several thousand hectares of RCG have been established in Sweden due to earlier grants for converting arable land into non-food crops. However, only very little of the grass is used for energy, as the Swedish market for straw/grass combustion is not developed. Of 15 plant species investigated for non-food purposes in Finland, RCG turned out to be the most promising for Finnish conditions. Switchgrass is a perennial C4 grass native to North America and is being investigated in the EU as a novel lignocellulosic C4 biomass crop for adaptation to European conditions. It is propagated by seed, which contributes to low cultivation costs (in contrast to Miscanthus where split rhizomes have to be used) (Eppler et al. 2007).

Short rotation coppice (SRC) is a specialised form of forestry plantation and refers to a perennial, fast-growing, high-yielding woody crop that is harvested every two to five years and managed under a coppice system. Willow and Poplar are the most common species planted in the short rotation coppice in Europe. Willow is mainly produced in Sweden, Finland, Denmark, the Netherlands, the UK and Ireland. In warmer climates such as the Mediterranean area (Italy, France and Spain), Poplar and Robinia are grown (Uslu et al. 2010). Poplar was identified as an alternative SRC crop to willow. There yields are comparable to yields from willow. Perennial energy crops are an alternative to conventional forestry to increase biomass production. Therefore high-yielding short rotation coppice plantations can fill the gap between this new demand for biomass and the current supply levels (Wickham et al. 2010), e.g. the chips produced from the willow stems can be used in heat and power generation projects. It is currently expected that an SRC plantation should be viable for 30 years before it needs replanting (Bauen et al. 2010).

24 Wickham, J. et al. (2010): A review of past and current research on short rotation coppice in Ireland and abroad. Report prepared for COFORD and Sustainable Energy Authority of Ireland
The cropping area of cellulosic energy crops has increased steadily over the last decade. Between 2008 and 2011, the total cropping area increased from 93,000 ha to 138,000 ha. However, the cellulosic energy crops are very unevenly distributed over the EU countries. The amount of crop harvested varies with land quality, among other factors, and yields range between 21 and 27 oven-dried tonnes per hectare (odt/ha) (Glithero et al. 2013).

Table 2 shows the production of ligno-cellulosic energy crops. Romania (switchgrass), Finland (reed canary grass), Sweden (willow) and UK (Miscanthus) are the largest producers. The produced mass in weight units is based on the following assumption: short rotations coppice and miscanthus have harvest yields (dry) between 10 and 12 t per hectare and year (Eppler et al. 2007). Based on minimum values the following structure results:

<table>
<thead>
<tr>
<th>Area (ha)</th>
<th>Reed Canary Grass (RCG)</th>
<th>Willow</th>
<th>Poplar</th>
<th>Miscanthus</th>
<th>Hemp</th>
<th>Switchgrass</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>AT</td>
<td>0</td>
<td>6,600</td>
<td>9,900</td>
<td>8,000</td>
<td>0</td>
<td>0</td>
<td>24,500</td>
</tr>
<tr>
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<td>0</td>
<td>0</td>
<td>600</td>
<td>1,000</td>
<td>0</td>
<td>0</td>
<td>1,600</td>
</tr>
<tr>
<td>DK</td>
<td>190</td>
<td>56,970</td>
<td>28,070</td>
<td>640</td>
<td>550</td>
<td>0</td>
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</tr>
<tr>
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<td>187,000</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>187,000</td>
</tr>
<tr>
<td>FR</td>
<td>0</td>
<td>0</td>
<td>23,000</td>
<td>25,000</td>
<td>0</td>
<td>0</td>
<td>48,000</td>
</tr>
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<td>0</td>
<td>40,000</td>
<td>50,000</td>
<td>20,000</td>
<td>0</td>
<td>0</td>
<td>110,000</td>
</tr>
<tr>
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<td>0</td>
<td>22,000</td>
<td>0</td>
<td>0</td>
<td>31,300</td>
</tr>
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<td>0</td>
<td>6,700</td>
<td>54,900</td>
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<td>62,350</td>
</tr>
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<td>LT</td>
<td>0</td>
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<td>0</td>
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<td>0</td>
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<td>5,500</td>
</tr>
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<td>0</td>
<td>900</td>
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<td>0</td>
<td>900</td>
</tr>
<tr>
<td>PL</td>
<td>0</td>
<td>70,000</td>
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<td>73,000</td>
</tr>
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<td>500,000</td>
<td>500,000</td>
</tr>
<tr>
<td>SE</td>
<td>7,800</td>
<td>110,000</td>
<td>5,500</td>
<td>4,500</td>
<td>3,900</td>
<td>0</td>
<td>131,700</td>
</tr>
<tr>
<td>UK</td>
<td>0</td>
<td>19,000</td>
<td>0</td>
<td>105,000</td>
<td>0</td>
<td>0</td>
<td>124,000</td>
</tr>
<tr>
<td>Sum</td>
<td>194,990</td>
<td>324,070</td>
<td>174,970</td>
<td>187,790</td>
<td>4,450</td>
<td>500,000</td>
<td>1,386,270</td>
</tr>
</tbody>
</table>

Source: Aebiom 2013 and own calculation

The EU-Reference Scenario 2013 (EC 2013) assumes that in 2030 perennial crops cultivated in the EU will sum up to 7 million hectares (7% of total cropland). That would be 50 times as much as 2011.

2.2.2 Cropping residues
Crop residue is defined as the non-edible plant parts that are left in the field after harvest. Agricultural residues are biomass residues originating from production, harvesting and processing on farms. They are separated from food processing residues. Residues from livestock will be discussed separately. Biomass from agricultural residues is generally used as litter for livestock, mulch and humus-building, as well as for making compost or fertilisers and mulch. Energy use is mainly through its use as a biogas substrate and burning (Raschka, Carus 2012\textsuperscript{28}).

A further classification of residues is related to their production quantities. Therefore it will be divided into primary, secondary and tertiary residues.

Figure 36    Refunds of agricultural residues

![Refunds of agricultural residues](image)

Source: Zeller et al. 2012\textsuperscript{29}

\textsuperscript{29} Zeller, V. et al. (2012): Basisinformationen für eine nachhaltige Nutzung von landwirtschaftlichen Reststoffen zur Energiebereitstellung. DBFZ Report Nr. 13
http://webdoc.sub.gwdg.de/ebook/serien/yo/DBFZ/13.pdf
Factors that determine the amount of residues include crop type and yields, the biomass ratio of crop residues to crop main produce (RPR), and percentages of residues removed from the field for potential use. Cultivars of higher yielding varieties aim at higher shares of the primary productivity to be stored in the harvested parts. As a consequence the relative amount of crop residues is generally lower as compared to lower yielding traditional cultivars (Fischer et al. 2009). Primary agricultural residues depend on cultivation area and crop yields. The maximum amount of crop residues that can be removed from the field without significantly affecting soil fertility is debated. The importance of retaining residues on fields depends largely upon specific local conditions (Fischer et al. 2009). Furthermore major reasons for the variability in estimates are using different combinations of crops and using different grain/straw ratios.

The BEE project (2010) uses official data from Eurostat and FAO. On the basis of the crop-to-residue ratio and availability factors the assessment showed the following results for agricultural residues:

The total technical potential of EU27 is about 806 PJ (Table 3). The largest part comes from common cereal straw (562 PJ), followed by rapeseed straw (89 PJ) and maize straw (86 PJ). The largest total potentials are for France (167 PJ), Germany (126 PJ) and Spain (103 PJ)\textsuperscript{32}.

### Table 3 Potential of primary agricultural residues in 27 EU countries (in PJ)

<table>
<thead>
<tr>
<th>Cereals</th>
<th>Rice</th>
<th>Maize</th>
<th>Rape-seed</th>
<th>Sunflower</th>
<th>Olive</th>
<th>Wine-yards</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>6</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>10</td>
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<tr>
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<td>1</td>
<td>0</td>
<td>0</td>
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</tr>
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<td>Bulgaria</td>
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<td>2</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>18</td>
</tr>
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<td>0</td>
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<td>0</td>
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<tr>
<td>Czech Republic</td>
<td>16</td>
<td>0</td>
<td>1</td>
<td>5</td>
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<td>0</td>
<td>22</td>
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<tr>
<td>Denmark</td>
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<td>0</td>
<td>3</td>
<td>0</td>
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<td>22</td>
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<td>Estonia</td>
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<td>0</td>
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<td>0</td>
<td>2</td>
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<tr>
<td>Finland</td>
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<td>0</td>
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<tr>
<td>France</td>
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<td>23</td>
<td>23</td>
<td>6</td>
<td>0</td>
<td>167</td>
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<tr>
<td>Germany</td>
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<td>7</td>
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<td>126</td>
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<tr>
<td>Greece</td>
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<td>4</td>
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<td>5</td>
<td>0</td>
<td>18</td>
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<td>Hungary</td>
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<td>11</td>
<td>3</td>
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<td>0</td>
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<td>5</td>
</tr>
<tr>
<td>Italy</td>
<td>40</td>
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<td>12</td>
<td>0</td>
<td>1</td>
<td>7</td>
<td>69</td>
</tr>
<tr>
<td>Latvia</td>
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</tr>
<tr>
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<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>Luxembourg</td>
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<td>0</td>
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<td>0</td>
<td>10</td>
<td>0</td>
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<td>62</td>
</tr>
</tbody>
</table>

**TOTAL**  
 | 562  | 10  | 86 | 89 | 18 | 28 | 12 | 805 |

*Source: Böttcher et al. 2010*

\textsuperscript{32} Böttcher, H. et al. (2010): Biomass Energy Europe. Illustration Case for Europe. Deliverable 6.1. – Annex I. Funded by the EC under 7\textsuperscript{th} Framework Programm. No 213417
The theoretical potential of secondary agricultural residues is 88 PJ. The technical potential of residues in the EU is 51.5 PJ. The largest part of the potential comes from sugar beet bagasse (25 PJ) followed by sunflower and rice husks (17 and 8 PJ respectively). The largest potentials are for France, Germany and Spain. The share of different residues on total potential varies significantly in different countries (Böttcher et al. 2010).

2.2.3 Residues from livestock

According to the BEE project the total manure potential produced in the EU countries is currently 796 million tons\textsuperscript{32}. The energy content of this manure is 765 PJ, with France, Germany and Spain as the three largest manure producers. The largest share of manure comes from cattle manure, about 380 PJ. The shares of different types of manure vary between countries (Table 4). While in the UK, Germany and France manure stems mostly from cattle, manure from pig farms is dominating livestock residues from Denmark and Spain.
Table 4 The energy content of cattle, pig and hen manure in 27 EU countries (PJ)

<table>
<thead>
<tr>
<th></th>
<th>Pigs</th>
<th>Cattle</th>
<th>Chicken</th>
<th>TOTAL</th>
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<tr>
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<tr>
<td>France</td>
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<td>10</td>
</tr>
<tr>
<td>United Kingdom</td>
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<td>40</td>
<td>15</td>
<td>63</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>270</td>
<td>378</td>
<td>118</td>
<td>766</td>
</tr>
</tbody>
</table>

Source: Böttcher et al. 2010
2.2.4 Supply and demand

The present EU agricultural and forest biomass supply is estimated at 314 Mtoe of which 42 Mtoe are waste, 89 Mtoe agricultural residues and 9 Mtoe short rotational and perennial crops (BE 201233, Elbersen et al. 201134). Agricultural and forestry residues could fulfil more than half of the biomass demand, followed by wastes and perennial crops. However the total supply of the rotational crop will not be sufficient to fulfil the policy driven demand in the transport sector. Results of the BIOMASS FUTURES project indicate that most of the cheap domestic feedstock will be utilized (i.e. wastes and residues) to meet the demand and the gap is likely to be filled by imported biomass feedstocks and biofuels. Cropping with perennials will remain underutilized domestic sources because at the domestic prices they can hardly compete with imported resources. Stricter sustainability criteria will increase the demand for residues, waste and perennials. This will create a larger demand for lignocellulosic materials which is likely to lead to larger utilisation of domestic wastes and cropped biomass (BE 2012). A significant amount of agricultural residues can be expected to be available for energy purposes in 2020, most of them from cereal straw35 (Uslu et al. (2010)35).

Supply will especially rely on the farmers’ willingness to grow crops like SRC and miscanthus. The main reasons cited for not growing these crops were impacts on land quality, lack of appropriate machinery, commitment of land for a long period of time, time to financial return and profitability. Reasons for willingness to grow included land quality, ease of crop management, commitment of land for a long period of time, and profitability (Glithero et al. 2013).

De Witt (2010)36 notes that the total supply potential for woody crops like poplar and willow on arable land is mostly concentrated in central and eastern Europe and some low-cost production in southern Europe. In southern Europe the use of eucalyptus dominates (4.4 EJ/a). Miscanthus, switchgrass and reed canary grass have a total supply potential of 6 EJ/y in Europe. The total supply potential for agricultural residues decreases over time from 3.9 to 3.1 EJ/a between 2010 and 2030. This decrease can be explained from the residue-to-crop ratio which decreases over time due to assumed yield increase37.

Large biomass-for-energy resources exist in Europe when considering crop residues e.g. from wheat, barley, rye and oats, and maize residues. The estimates vary over time due to assumed yield increases per region and due to the assumed area reductions for cereal and maize for the benefit of energy crops. The largest potentials are found in countries with important cereal production (e.g. France, Germany).

Agricultural biomass is expected to make up a major part of future bioenergy supplies. Estimates on the current supply of energy crop resources (2010) range from 1 to 2 EJ/year with an overall increasing trend. Residues from agricultural production e.g. cereal straw, corn stover and rape straw are estimated within a range from 1 to 4 EJ/year. There is no unambiguous trend in estimates towards increasing or

33 BE Sustainable (2012): Sustainable biomass supply in EU. September 8, 2012
34 Elbersen, B. et al. (2011): Securing a sustainable biomass supply in EU by 2020. paper prepared under the Biomass Futures project funded by the Intelligent Energy Europe Programme.
35 Uslu, Ayla; Gomez, Natalia; Belda, Martha; Ciemat, Both (2010): Demand for lignocellulosic biomass in Europe. Policies, supply and demand for lignocellulosic biomass.
decreasing resources in the future (Bentsen, Felby 2011). The European Environmental Agency (EEA) assesses the secondary biomass resources to 3 EJ/year in 2010. The supply of short rotation crops will increase, according to EU Common Agricultural financial Policy.

The demand for biomass for energy in the European Union will increase from the current 6 EJ/year (2010) to 10 EJ in 2020. Dedicated energy crops grown on liberated agricultural land or marginal lands are expected to be able to meet the major part of the increasing biomass demand. Residues from agriculture are not expected to increase significantly in the future. The demand for biomass for energy will probably increase also beyond 2020 and not only in Europe (Bentsen, Felby 2011).

2.3 Biogenic waste

The biogenic fraction of waste (or biodegradable waste) is a type of waste which can be broken down, in a reasonable amount of time, into its base compounds by microorganisms and other living things, regardless of what those compounds may be. The EU defines biodegradable waste as ‘any waste that is capable of undergoing anaerobic or aerobic decomposition, such as food and green waste, and paper and paperboard’. A specific fraction of biodegradable waste is termed bio-waste which includes ‘biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises, and comparable waste from food processing plants’. This study analyses the main streams of biodegradable waste generated in the EU, including paper and cardboard waste, bio-waste, textile waste, and sewage sludge.

Biogenic waste is subject to a range of different end uses in the EU, including: recovery and recycling for material use; incineration (with and without energy recovery); anaerobic digestion for the production of heat, electricity, and fuel; and composting. The fraction of biodegradable waste currently disposed in landfills is outside the scope of this study, as is that fraction used for the production of transport fuels.

The priority order among the different end uses of biodegradable waste is established by the EU waste hierarchy, set out in the EU Waste Framework Directive. The waste hierarchy prioritises the material reuse of waste over energy recovery and landfilling. The degree of competition between the different uses of biodegradable waste depends on a number of factors, such as their profitability, the volume available for each waste stream and the drivers of demand from the different industry sectors.

This section discusses the state of play of biodegradable waste use in the EU, including an analysis of current supply and demand of biodegradable waste for energy production and material uses. The inconsistency among the different waste reporting systems at Member State level prevents a full assessment on the subject. In addition, as noted by Eunomia (2010), in most cases while information is available on the different treatment and disposal methods, the composition of the quantities processed per method is, in general, not reported. For these reasons, primary information from Eurostat has been complemented with a variety of other data sources, such as Eunomia (2010), STOA (2013) and JRC (2010), and estimates have been made where official data were not available.

2.3.1 Supply and demand of biogenic waste for energy production and material uses

The following sections analyse in detail the supply and demand of different categories of biogenic waste: paper and cardboard waste; sewage sludge; textile waste; and bio-waste, i.e. green waste and food waste. Of these categories paper and cardboard waste and food waste contribute most significantly to energy production and material use in the EU.

Paper and cardboard waste

Paper and cardboard are a substantial component of the collected biogenic municipal solid waste (23% of the total share). According to the Confederation of European Paper Industries (CEPI), about 81.5 million tonnes of paper and cardboard waste were consumed in the EU in 2011 (CEPI, 2012). Paper and cardboard usually have a short life-cycle and are discarded 1-2 years after production. In 2011, 59% of paper and cardboard (amounting to 48.4 million tonnes) was recycled in the EU, while about 0.4 million tonnes (0.5%) were composted and 0.2 million tonnes (0.2%) were recycled in other ways.

According to CEPI, Germany is by far the largest consumer of paper for recycling, accounting for the 34.6% of the total paper recycled, followed by Spain, Italy and the United Kingdom (Figure 38).

Figure 38 The largest consumers of paper and cardboard waste in the EU (2012)


In 2012, almost two thirds of the recycled paper demand in the EU (31.5 million tonnes) came from the packaging industry, followed by the newsprint industry with 11.6 million tonnes (24%), the sanitary and household paper industry with 3.2 million tonnes (6.8%), and other paper related industry sectors with 1.6 million tonnes (3.3%). The demand for paper packaging, as well as the general demand for paper for recycling, is growing rapidly in emerging economies, such as China, India and the rest.
of Asia. This is driven by the increase in the transit packaging sector in Asia, combining with growing consumerism. Between 2000 and 2012, the demand for paper for recycling from Asia increased fivefold from 2.8 million tonnes to 10.2 million tonnes. As a consequence, exports of recycled paper from the EU are expected to increase in the future, potentially leading to an increase in the production of recycled paper and cardboard.

Figure 39 Utilisation of Paper for Recycling by Sector in 2012

![Utilisation of Paper for Recycling by Sector in 2012](image)


Although according to the EU waste hierarchy recycling of paper and cardboard should be prioritised over energy recovery, because of the higher value given to materials when recycled, the paper and pulp industry is in direct competition for the use of paper and cardboard waste with the bioenergy sector. CEPI reported that 5.5 million tonnes (7%) of paper and cardboard waste were incinerated in 2012 and, according to Eurostat, about 90% of paper and cardboard waste incineration is for energy recovery, which can be classed as bioenergy production.

**Sewage sludge**

Sewage sludge can be contaminated with heavy metals and toxic organic compounds; however it is also rich in nutrients such as nitrogen and phosphorous making it employable as a fertiliser or organic soil improver.42 The use of sewage sludge as a by-product from the treatment of urban waste water is regulated at the EU level43; in particular, its deployment on agricultural land is restricted as to prevent harmful effects on soil, vegetation, animals and humans.44

According to Eurostat, the total annual production of sewage sludge in the EU28 is 9.4 million tonnes (dry matter)45, these data are in line with the estimates made by Milieu

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et al (2008) of 10.1 million tonnes (dry matter).\textsuperscript{46} The UK is one of the largest producers of sewage sludge in the EU, with around 1.4 million tonnes (dry matter) of sewage sludge produced, followed by Belgium (1.4 million tonnes), France (1.3 million tonnes), Spain (1.1 million tonnes) and Italy (0.8 million).\textsuperscript{47} Concerns have been raised, however, regarding the reliability of these statistics given that it would be assumed that sewage sludge would be linked to population size, hence Germany would be anticipated to also be a major producer.

In the EU, the main fraction of sewage sludge produced is used as an organic fertiliser in agriculture. A smaller portion is also used in forestry and composting. Sewage sludge can also be dried and used in incineration (with or without energy recovery), gasification or pyrolysis plants. As sludge has high moisture content, dewatering and drying before such use can be costly in energy and financial terms. As with other high water content biomass, anaerobic digestion is an attractive option that does not require drying.\textsuperscript{48} However, the data available are not sufficient to provide a quantitative assessment of the shares for the alternative treatment options of sewage sludge in the EU.

**Textile waste**

Textile waste includes all types of textile and leather material which are discarded. This category mainly includes used packaging, worn clothes and used textiles, and waste from fibre/leather preparation and processing, as well as separately collected textile and leather.

The textile industry is widely developed in Europe, where over one third of large European clothing companies are now based in Germany, followed by Italy with 14% of all large textile companies and 32% of clothing companies.\textsuperscript{49} Recently the production of cotton and textiles substantially declined in both countries due to the economic crisis and to competition with lower-cost markets, such as Asia. It is thus likely EU Member States will increase their reliance on textiles imports in the future.

Due to inconsistencies in the data availability, the estimates on the amount of textile waste generated in the EU vary widely over time. In 2004, the total textile waste generated in the EU27 was estimated to be 12.2 million tonnes, while a more recent study for the European Commission found that EU consumers discarded 5.8 million tonnes of textiles every year.\textsuperscript{50} The five most populated Member States – Italy, Germany, France, Spain and the UK – account for three quarters of the EU-27 production of textiles and clothing.

As shown in Figure 40 below, the main source of textile waste (49%) is municipal solid waste, followed by an aggregated category of worn clothing & miscellaneous textiles wastes coming from either municipal or industrial sources.


\textsuperscript{47} Eurostat (2010)

\textsuperscript{48} Biomass energy centre (2014) Sewage sludge.
http://www.biomassenergycentre.org.uk/portal/page?_pageid=75,187228&_dad=portal&_schema=PORTAL


\textsuperscript{50} Friends of the Earth (2013) Less is more. Resource efficiency through waste collection, recycling and reuse of aluminium, cotton and lithium in Europe
Figure 40  Estimated textiles waste generation in the EU by sources


Figure 41  Estimation of waste textiles flow

Figure 40 above shows the estimated share of textile waste for different end uses. In 2004, 2.5 million tonnes of textile waste were estimated to be collected separately or collected and then separated in sorting plants to be used for recycling or energy recovery by the textile manufacturing industry. The energy use was estimated to be approximately 20,400 TJ.

According to JRC (2010), it is estimated that in 2004 almost 1.2 million tonnes of textile waste was used for recycling or energy recovery in Germany, followed by 600,000 tonnes in France and around 400,000 tonnes in the UK. Refined data on the share of recycling and energy recovery for textile waste in each Member State are not available.

Recycled textiles in the EU are used as raw material in a variety of industry sectors. Around 40-50% of textile disposed is suitable for reuse as wearable textile. These products are re-sold nationally or abroad. 20-30% can be used as a raw material to the flocking industry (i.e. as fillers in car insulation, roofing felts, loudspeaker cones, etc) or by specialised firms for fibre reclamation or to produce paper, board and fleece. The remaining 25-30% of silk and other textile waste is sorted into different grades to become cleaning cloths for a range of industries from automotive to mining and to be used in paper manufacture.51

Bio-waste

As noted earlier, the Waste Framework Directive defines bio-waste as ‘biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises, and comparable waste from food processing plants’.52 This section analyses either green or food waste.

Green waste

Determining the level of production of green waste is challenging, due to the potential overlaps with agricultural biomass. The category considered in this study excludes

51 Friends of the Earth (2013)  
cuttings and pruning of permanent crops such as orchards, vineyards and olives, as well as grass toppings from agriculture. Following the approach adopted by Elbersen et al (2012), all grass from non-agricultural areas, apart from road side verge grass, falls beyond the scope of this study, as well as any park waste.  

The total amount of green waste produced in 2010 in the EU27 is estimated to be 12.3 million tonnes. This amount includes 309 000 tonnes of road side verge grass and 12 million tonnes of other vegetal waste generated in the EU in 2010. The major producers of green waste in the EU are Germany (3.2 million tonnes), France (2.5 million tonnes), the United Kingdom (2 million tonnes), Italy (1 million tonne) and Belgium (0.4 million tonnes) (Figure 43).

![Figure 43 Total amount of green waste in the EU27](image)

Source: Own compilation based on Elbersen et al (2012) and Eurostat. *Data on vegetal waste for Bulgaria, Greece, Spain, Croatia, and Portugal are not available.

Green waste is widely treated through composting and anaerobic digestion at EU level. According the European Compost Network (ECN), in 2009, about 40% of 2500 sites for composting of source segregated materials in Europe only treat green waste. Additionally, there were 800 small agricultural co-composting plants, mainly in Germany and Austria, and 195 large anaerobic digestion sites were operational in 2010, with 5.9 million tonne capacity for organic waste, including green waste.

**Food waste**

A substantial portion of biodegradable waste comes from food. However, the estimates on the total amount of food waste at EU level vary. In 2010, the European Commission estimated, on the basis of Eurostat data, that 89.3 million tonnes of food waste

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is wasted each year in the EU (excluding agricultural production), while FAO (2011) stated that only 53 million tonnes of food waste produced in the EU in the same year.

A refined set of data were provided by the Institute for Technologies Assessment and Systems Analysis (ITAS) which estimated the amount of food waste along the supply chain, including agricultural production, post-harvest handling and storage, processing and packaging, distribution, and consumption. According to the study, a total amount of 138 million tonnes of food waste was produced in the EU27 in 2006. The major producer of food waste in the EU is the manufacturing sector, accounting for 74.1 million tonnes, followed by households with 56.8 million tonnes and the retail sector with a smaller 7 million tonnes. The biggest producers of food waste are Italy and France, with respectively 12 and 11.5 million tonnes a year, followed by Spain, the UK, Poland, Germany and Romania (Figure 44).

Figure 44  Production of food waste in Europe

Composting is a major material use of food waste and is ranked higher in the waste hierarchy under the EU Waste Framework Directive. However, according to ERM (2006), processing food waste via anaerobic digestion can yield higher net carbon savings than composting. This could justify the preference for energy recovery of food waste via anaerobic digestion over composting. A predictable reduction of food waste will lead to a lower volume of environmentally sustainable material for energy production in the future. There is pressure to reduce food waste, increasingly, under the waste prevention agenda.

An example of a food waste is used cooking oil. In Germany, around 80-90% of the UCO collected is used for biodiesel production, while largely used for transport fuels such bioliquids might also be used for heating. Similar percentages apply to Spain. Alternative material uses are in the oleochemical industry and for other energetic use. The latter is rather small (around 70,000 tonnes) due to quality issues of the liquid. The use of UCO for human consumption and food feed is not allowed in Spain.

Within the EU, the EU biodiesel industry competes with the oleochemical industry on the use of UCO and animal fats as a raw material. The competition between the two industries on the use of the feedstock has led to a change in the previous status quo in which animal fats were reserved for oleochemistry and UCO for biodiesel.\textsuperscript{37}
3 Global supply and demand of biomass

3.1 Biomass supply and demand in major global regions

3.1.1 Wood biomass\textsuperscript{58,59,60,61}

The EU is a major trader of sawnwood, pulp and paper products. The trade of wood based panels majorly takes place within the EU. Regarding the energetic use of wood, wood pellets and wood chips are the most important wood commodities that are traded globally. Wood pellets are most commonly globally traded wood energy commodity and wood chips can be utilized in several end uses, mainly pulp and paper, wood based panels and energy. Trade of both products occur actively between the EU and global regions, thus the changes in supply and demand in global regions will likely have effect also to the supply situation in the EU.

Wood Chips

At a global level, wood chips are one of the few wood commodities that have seen a steady increasing trend in globally traded volumes during the past decade. However, a study by IEA Bioenergy estimates that less than 10% of annually reported global wood chip trade volumes are energy-related. Majority of the chip trade globally is destined for pulp and paper production, with some trade for other uses such as fibre and particle boards. Globally two main markets wood chip can be distinguished: Atlantic wood chip trade and Asia-pacific wood chip trade region (Figure 45).

Figure 45  Global major wood chip trade routes

![Global major wood chip trade routes](source: Indufor databanks, RISI International Pulpwood Trade Review 2012)

The Atlantic trade region involves trade of wood chips from Latin-America, North-America and marginally from Africa to Europe and Turkey. Wood chip trade flows to and within the EU are discussed in detail in the section 3.2.1. Close to Europe, Turkey

\textsuperscript{58} RISI International Pulpwood Trade Review 2012  
\textsuperscript{59} Wood Resources Quarterly  
\textsuperscript{60} IEA Bioenergy – Task 40: Sustainable International Bioenergy Trade: Global Wood Pellet Industry Market and Trade Study  
\textsuperscript{61} Wood Resources International LLC - Global Timber and Wood Products Market Update
is the key destination for international softwood chip imports. As the country does not impose strict sustainability requirements, and is not part of the EU, it can and has imported large volumes of softwood chips from North America. Turkey imports annually about 1.5 million m³ of mainly coniferous wood chips that are used within the wood based panels industry.

In the Asia-Pacific region, Japan and China present two globally major import hot spots of wood chips (Figure 46). Majority of traded wood chips is consumed in the pulp (Japan, China) and wood based panels industry (China). The growing Chinese demand of pulpwod and wood chips has increased the total traded volumes of hardwood chips from 12 million m³ to about 35 million m³ in 2008-2013. In Japan, imports have been stagnating at the same time. Several large pulp mills located in southern China have a strong reliance on imported wood chips. Major sources of these imports are Vietnam, Thailand, Australia and Indonesia. However, it is difficult to estimate how much of the traded wood chip volumes originate from wood plantations and if it includes wood that can be linked to illegal logging and deforestation in e.g. Laos and Cambodia.

The wood chip trade in the Asia-Pacific region does not cast a direct effect to the wood chip trade flows to the EU since it is not part of these trade interactions. The wood chip trade flows to the EU are presented in the following section.

![Figure 46 Major importers of hardwood chips in Asia-Pacific region](source: WRQ)

### Wood pellets

The total global wood pellet consumption (2012) is estimated at about 20.4 million tonnes. The majority of global wood pellet consumption occurs in the EU. As displayed in Figure 47 the consumption in the EU27 in 2012 was about 13.4 million tonnes.
Some sources estimate consumption for 2013 as high as 19.5 million tonnes\textsuperscript{62}. Rest of the world consumes about 7 million tonnes of wood pellets, majority of this in the US.

**Figure 47  \hspace{1cm} Global wood pellet consumption (2012)**

North America has doubled the export of wood pellets to Europe over the past two years. In 2012 about 4.8 million tons of pellets were exported from Canada and the US to the Netherlands, Belgium and the UK. It is probable that the exports continue to increase at least in the near future. North American wood pellet manufacturers keep building new facilities to enhance the volumes to the EU market. Wood pellet production capacity has increased especially rapidly in the South-Eastern US. As a result, US pellet production tripled during 2012-2013 in just two years. The expansion is entirely driven by the demand in the EU. Wood pellet production capacity increase has not been as drastic in Canada, but the steady increase of exports is foreseeable due to several announcements of pellet mill investments.

The US and Canadian domestic policies are promoting the increasing use of pellets within North America, however strong increase of domestic pellet consumption is unlikely because of currently cheap shale gas used for heating sector. Wood Pellet consumption in North America is estimated at 4.2 million tonnes, which almost entirely takes place in the US residential heating sector.

Russia is nowadays a major trade partner of wood pellets and wood chips to the EU. Industrial wood pellets are traded from Russia to Sweden, Denmark, the Netherlands, Belgium and the UK and are mainly intended for large scale industrial utilisation such as co-combustion with other biofuels in medium to large-scale CHP plants. Russia exports about 700 000 tonnes of wood pellets to the EU per year. The domestic consumption of wood pellets and wood chips in Russia is largely undeveloped, only about 100 000 tonnes of wood pellets is used in district heating domestically.

South America has so far not been very important as a source of bio-energy feed stocks for Europe. Plans of establishing wood pellet mills e.g. in Brazil exists, but large export volumes are highly unlikely. Existing pulp mills have strong influence to wood raw material markets because they have the strongest wood paying capability. The situation is probably going to remain due to announcements of several new pulp mill projects and increasing local prices of wood and forestland.

China is rapidly gaining importance in the global pellet markets. In China the pellet markets are still in an immature state. During 2010 the pellet consumption in China was about 600,000 tonnes and the estimated consumption in 2012 was 1.4 million tonnes. The most of Chinese pellets, about 85%, are based on non-wood raw materials such as agricultural residues like rice husks and straw. Thus the growth of the Chinese pellet industry can be expected to have small influence on the international trade flows of wood residues. There are 19 wood pellet mills in China, located close to the Eastern coast with total capacity of about 750,000 tonnes/year. In the future the Chinese consumption of pellets is estimated to reach 10 million tonnes by 2020 making China to account about 20% of the global demand. However, most of the demand will be satisfied through domestic sources, so China is not expected to have major interaction in intercontinental trade of wood pellets.

Combined consumption of wood pellets in Japan and South-Korea is estimated at 1.1 million tonnes in 2012. The annual wood pellet production in Japan was only about 34,000 tonnes in 2009, recent numbers are not available. Co-firing constitutes of about 65% of the Japanese pellet consumption and the rest is consumption in household sector. Imports of wood pellets to Japan have strongly increased in recent years. Most of the wood pellets are imported from British Columbia, Canada with minor amounts from China, Vietnam and New Zealand. Some sources predict that the Japanese wood pellet consumption would reach 8 million tonnes by 202063.

There are over 20 pellet plants in South Korea; all are very small and connected to woodworking industries, using their residues. Consumption of wood pellets in South Korea is increasing. In 2010 about 27,000 tonnes of wood pellets were consumed in South Korea. About 15,000 tonnes was produced domestically and rest imported mainly from China, Vietnam and Malaysia. The future market of wood pellets is expected to grow due to a renewable portfolio standard introduced by the Korean government. Some sources predict that the South Korean wood pellet consumption would reach 5 million tonnes by 202063.

The EU is most likely to remain globally the largest wood pellet consumer, but East Asia, namely Japan and South-Korea are showing signs of growth and may even surpass North-America by 2020. The increasing domestic consumption of pellets in China, Japan and South Korea will draw increasing amount of imports of wood pellets from Canada, namely British Columbia. Just recently, late 2013 first regular shipments of wood pellets to South-Korea began from British Columbia. In a longer time span increased consumption in South-Korea and Japan casts an effect on the pellet imports of the EU. East Asian demand strongly depends on policy developments in Japan and South Korea. How rapidly this demand will materialize will probably become more clear when more details on policy measures in both Japan and South Korea are expected. Regarding China very little useful information was available, and demand development is hard to predict. Demand in the US will probably remain limited to small scale use in households, and will not use pellets on a large scale for industrial purposes. Also the wood pellet consumption in residential sector is usually secondary source of heat. This makes the market volatile and highly dependent on other factors,

63 Wood Pellet Association of Canada
mainly the price development of currently cheaper substitute fuels: shale gas and heating oil.

3.1.2 Agricultural biomass

The global demand for food, fibre and fuel has become a matter of high political concern while competing intensively for limited land and other resources (e.g. water, infrastructure). An increasing demand is expected and projected to grow with some 50% by 2050 compared to 2011. Global industrial demand for wood fibre is expected to increase for all traditional forest products and this will impact future land use and increase pressure on land. In addition, wood fibre is also increasingly demanded for other uses than traditional forest products like, for example fast growing forest plantations will play a greater role in meeting increasing demand. Further, combined land utilization is increasingly valuable to meet different and growing demands for wood fibre (Holmgren 201264). The worldwide production of woody/ligno-cellulosic biomass in the agricultural sector is still relatively low. For example, the increase of production capacities from 2012 to 2013 was 22-fold lower than needed to reach 2DS targets in 2025.Error! Bookmark not defined.. The current situation suggests that the role of woody/ligno-cellulosic biomass will be much lower than expected in the IEA-DS2 scenario.

The role that agricultural biomass will play in the future of supply will not solely depend on the many technologies which exist nor on further investment to improve their efficiencies. It will also depend upon the ability to overcome the barriers that inhibit project development and constrain sufficient commercial investment (OECD, IEA 200765). Increasing the available supply of biomass in future could therefore depend on surplus of arable land, marginal and degraded lands, or plantation forests. However purpose grown energy crops are unlikely to become economic within the next decade without introducing direct supporting policies unless they can produce multi-products or demonstrate co-benefits such as acting as a hedge against future fuel supply risks (OECD, IEA 2007). The long term potential for agricultural biomass supply depends on land availability which depends on food sector development and factors limiting access to land, water and nature protection. The yields of chosen agricultural biomass are also influencing (WEC 201366).

The future demand will require a very high technological level of agricultural production. Crop yields due to different agricultural production system have a large impact on biomass potentials, but more knowledge on the expectation of learning and implementation of advanced technologies in agriculture will be necessary (Dornburg 200867).

Strong renewable energy targets being set at regional and national level (e.g. the European Renewable Energy Directive) are likely to lead to a significant increase in demand. This demand is likely to be met through increased use of residues and wastes, sugar, starch and oil crops, and increasingly, lingo-cellulosic crops. Under favourable conditions substantial growth is possible over the next 20 years (WEC

64 Holmgren, L. (2012): The global need for food, fibre and fuel. Kungl.skogs-och Lantbruksakademiens, Tiidstrift
67 Dornburg, V. et al. (2008): Biomass Assessment Assessment of global biomass potentials and their links to food, water, biodiversity, energy demand and economy: Inventory and analysis of existing studies. Performed within the framework of the Netherlands Research Programme on Scientific Assessment and Policy Analysis for Climate Change (WAB)
2013). To cover the global demand and to achieve global bioenergy targets in the longer term efforts need to be directed at increasing yields and modernising agriculture especially in regions such as Africa, Far East and Latin America. Avoiding land pressure and food insecurity the global supply should be encouraged using residues and wastes (WEC 2013).

3.1.3 Biogenic waste

Differently from many forms of solid biomass and some agricultural waste and residues, other biogenic wastes and residues cannot be considered international traded commodities, and are often non-traded or range limited. Thus the changes in supply and demand in global regions are unlikely to have major effects in the EU.

This section presents the information available on biogenic waste consumption beyond the EU. This limits the scope of the analysis to food waste and textile waste. A full assessment of the end uses (material and energy-related) of those streams is not possible due to lack of data, in particular in relation to countries like China.

Food Waste

Food waste production is strictly linked to per capita ratios and population size of each regions of the world. According to the Food Wastage Footprint (FWF) model developed by FAO, at global level the Asian region (including India and South East Asia) appears to be a major producer of food waste. In particular, in China food waste has steadily increased in the recent years ranging between 50% and 70% of the total municipal solid waste (MSW) generation of 352 Mt (or 440 kg/cap) in 2010. As food waste is not collected separately, it is mixed with other solid waste in MSW and eventually incinerated or landfilled (landfilling of food waste reached on average 56.6% in 2009).

Another major producer of food waste is the US, where food waste generated in 2012 reached more than 36 million tonnes (accounting for 28% of total MSW)\(^6\), with only a small portion (5%) diverted from landfills and incinerators for composting.\(^7\) A similar trend can be found in Canada, where an estimated $ 27 billion of food is wasted annually.\(^8\)

Textile waste

The US is one of the major producers of textile waste (around 9% of the total US MSW), and particularly of cotton waste.\(^9\) An estimated 14.3 million tonnes of textiles were generated in the US in 2012, accounting for approximately 5.7% of total MSW generation. In 2012, the US recovered an estimated 14.4% of textiles in clothing and footwear and 17.8% of items such as sheets and pillowcases for export of reprocessing.\(^10\) Between 1989 and 2007, the US exported nearly 7 billion pounds of

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72 EPA (2012)
used clothes, mainly to developing countries. Tanzania is one of the largest importers of textile waste from the US.\textsuperscript{74}

### 3.2 Biomass trade within the EU and globally

The main factor defining the suitability of bioenergy commodities to global trade is the energy content in relation to the required storage space. Figure 48 illustrates the characteristics of different biofuels in this context. Wood pellets, which is currently the most important internationally traded bioenergy commodity has about three times smaller space requirement per energy unit than logging residue chips, which are mostly traded locally. The energy content per volume in bio-oil is almost double to wood pellets; however the global markets are currently at an infant state. Straw and other agricultural biomass commodities have very low energy content and high space requirement. These biomass types cannot be traded long distances as such, but have potential as raw material of liquid biofuels.

**Figure 48** Storage space required by various fossil and renewable fuels related to energy content

![Storage space required by various fossil and renewable fuels related to energy content](source)

Source: Alakangas et al. 2000

\textsuperscript{74} The top export categories from the US to Tanzania include \$ 27 million for miscellaneous textile articles, among them textile waste. http://www.ustr.gov/countries-regions/africa/east-africa/tanzania
3.2.1 Wood biomass\textsuperscript{75,76,77}

**Roundwood**

Largest part of solid wood products trade to and from the EU is accounted by roundwood and sawnwood. The total trade of roundwood within the EU is about 45 million m\(^3\). The EU27 has been a net importer of industrial roundwood through the last decade. According to Eurostat, the total import volume of roundwood outside the EU27 reached 11.6 million m\(^3\) in 2011 while exports out from EU27 amounted to 6.7 million m\(^3\).

Softwood roundwood imports accounted for about 40% of the overall roundwood import volume to the EU in 2011. Russia, Ukraine and Belarus account for about two thirds of the non-EU softwood roundwood supply to the EU27. Hardwood roundwood imports from outside the EU27 area are also dominated by these three countries.

In 2011, China was the main destination for both softwood and hardwood roundwood exports from the EU27. According to Eurostat, Japan, India and Morocco were among the countries that imported over 100,000 m\(^3\) of both softwood and hardwood roundwood.

**Sawnwood**

Softwood dominates the EU27 sawnwood business in terms of volume. Germany is expected to increase exports outside the EU27 area, particularly to the US and China. Also Austria and the Czech Republic are expected to take advantage of the US housing market recovery.

The EU27 has traditionally been a net importer of hardwood sawnwood but this situation has been changing lately. In 2011, the EU27 net import volume fell to less than 1 million m\(^3\) and the overall balance is forecast to remain the same towards 2016. Sweden is by far the biggest exporter of sawnwood, followed by Finland, Austria, Romania and Germany, whereas Italy, the UK, France and the Netherlands are the biggest importers (Figure 49).

\textsuperscript{75} Indufor, Study on the Wood Raw Material Supply and Demand for the EU Wood Processing Industries
\textsuperscript{76} RISI International Pulwood Trade Review 2012
According to Eurostat, the EU27 imported 16.7 million m³ of sawnwood from outside the EU member countries. Softwood species made up about 53% of the total import volume. In 2011, Russia was by far the largest supplier of softwood sawnwood followed by Ukraine, Albania, Norway and Canada (Figure 50). The US was the largest source of hardwood sawnwood imports followed by Cameroon and Ukraine (Figure 51).
Countries in North Africa and the Middle East dominate as markets for the EU27 exports of softwood sawnwood outside the member countries (Figure 52). Japan has long been a traditional and important high-end market for Scandinavian and lately increasingly also for central European suppliers. Hardwood sawnwood exports are spread across a larger number of countries, with Asian countries well represented among the biggest importers (Figure 53). The economic and political situation in the North African and the Middle Eastern countries is of huge importance for the European sawnwood industries.
Figure 52  International destinations of softwood sawnwood exports by the EU27 (2011)

![Image of a pie chart showing the destinations of softwood sawnwood exports by the EU27 in 2011. The main export destinations are Egypt, Japan, Algeria, Saudi Arabia, Morocco, Norway, Israel, Switzerland, United Arab Emirates, Tunisia, and Others.]

Total Exports outside EU27: 16 million m³
Source: Eurostat, External Trade database

Figure 53  International destinations of hardwood sawnwood exports by the EU27 (2011)

![Image of a pie chart showing the destinations of hardwood sawnwood exports by the EU27 in 2011. The main export destinations are China, Egypt, Norway, Switzerland, Morocco, USA, Israel, Albania, India, Pakistan, and Others.]

Total Exports outside EU27: 3.2 million m³
Source: Eurostat, External Trade database

Wood Based Panels

Particleboard and MDF exports and imports occur mainly within the continent, although Europe is a net exporter as a whole. This trade deficit is forecast to decline gradually so that by 2016 the EU27 will be only a minor net importer.

OSB imports from outside the European Union are small compared to internal-trade. In 2011, exports from the European Union increased to China, Japan and the US with Russia, Turkey and Ukraine being the other main export destinations. However, the
total is still well below 1 million m³. Imports of OSB have fluctuated between 30 000 and 200 000 m³ and are sourced mainly from North America.

The EU27 has been a net importer of plywood during the last decade. The annual trade deficit has ranged between 2-4 million m³. Hardwood plywood imports especially from Russia have increased rapidly during the last decade. The EU27 as a whole is forecast to remain as a net plywood importer with Russia expected to remain a major contributor of extra-EU supply.

**Pulp**

Major pulp trade flows are presented in the Figure 54 (CEPI 2011). The total exports from CEPI were 2.3 million tonnes and imports 8.0 million tonnes. Some 80% of the exports were delivered outside of the CEPI member countries and 94% of the imports arrived from outside those countries.

It is foreseen that imports from South America will continue increasing as pulp mill investments, including those from EU-based companies continue there. About 18 million tonnes of extra pulp capacity is somewhere in the project pipeline for 2010’s. A capacity of five million tonnes is under construction and soon to be in production, even though not all planned projects will go ahead. Instead, the imports from the US are expected to decline, as the production capacity is adjusted according to the paper production capacity.

**Figure 54**  Pulp trade flows between CEPI countries and major global regions (2011)

Most of the pulp, 41% (over 3 million tonnes) were imported to the EU27 from Brazil in 2011, 18% of pulp imports were from North America (the US and Canada) and Chile is in third place with some 1.3 million tonnes of imports (Figure 55). This indicates the feasible transportability of pulp to Europe even from the Pacific coast of Latin America.
It is foreseen that imports from South America will continue increasing as pulp mill investments, including those from the EU-based companies continue there. About 18 million tonnes of extra pulp capacity is somewhere in the project pipeline for 2010’s. Capacity of five million tonnes is under construction and soon to be in production, even though not all planned projects will go ahead. Instead, the imports from the US are expected to decline, as the production capacity is adjusted according to the paper production capacity.

Figure 55 The main international sources of wood pulp imports by EU27 in 2011

Some 43% of the pulp exported from the EU was exported to China in 2011 (Figure 56). The exports to China increased from 800 000 tonnes in 2010 to 1.3 million tonnes in 2011. The exports to the other countries are minor. The export of pulp will increase, however the export of recovered paper will decrease because the internal EU demand is increasing.

It is expected that pulp exports to China will continue growing because of continuing increase of Chinese paper production and the decision of the Chinese government to close the most polluting pulp and paper mills. Especially NBSK pulp will stay competitive. A question remains as to how competitive the potential greenfield Russian Siberian NBSK mills will be. However, those mills are not anticipated to be commissioned before 2016. At the same time the recently announced Nordic softwood pulp capacity increases are expected to start production during 2016-2017.
The main international destinations of wood pulp exports by EU27 in 2011

Source: Eurostat, External Trade database

**Paper and Paperboard**

Global paper and paperboards consumption has experienced the highest growth rate in Asia while consumption is stable or even declining in North America and Europe. Paper and paperboards production has increased significantly in China, where the volume almost tripled between 2000 and 2011. Simultaneously, the growth rate of consumption is high especially in China.

The trade flows of paper and board are presented in the Figure 57 (CEPI 2011). The total exports from CEPI countries were 18 million tonnes and imports 4.6 million tonnes. 66.5% of the exports were delivered outside Europe, and 73% of the imports arrived from outside Europe.

Most of the paper is imported from the US. Norway follows as CEPI countries. In 2011 Brazil, Canada and China took the next places. The export from EU27 is larger than imports. For example more paper is exported to the US than imported from there. The biggest export destinations are the US, Turkey, Russia, China, Japan and Brazil. The US and Switzerland are unlikely to invest heavily in paper mills in the near future.
Figure 57  Paper and paperboard trade flows between CEPI countries and major global regions (2011)

Firewood

Most of the firewood is traded in domestic markets, however about 3.4 million m$^3$ of firewood was traded in the EU in 2012, mostly between neighbouring countries. Large scale trade of firewood requires special handling in bulk transport. It decreases the bulk (energy) density and makes long distances economically infeasible. Mostly trade is done in bagged form in nets, or stacked on pallets.

Wood chips

In the wood chips trade EU27 has followed the global increasing trend (Figure 58). The two major export routes of woodchips to the EU can be identified. Hardwood chips are exported with sea vessels to Spain and Portugal mainly from Uruguay, Brazil, Canada, Congo and Liberia. According to RISI the total Atlantic imports of woodchips to Spain and Portugal was about 2 million m$^3$. Another trade flow of wood chips originates mainly from Russia to Finland. About 2.2 million m$^3$ (2012) of chips was imported by Finland from Russia. These volumes do not separate the chips for pulp or wood based panel production and energy production. Minor volumes are traded from Russia, Belarus and Ukraine.
In 2013 the total traded volume of wood chips within the EU27 was about 11 million m³. It is estimated that less than 10% of the annually reported global wood chip trade volumes are energy-related. Similar to Global trend majority of the chip trade in the EU is primarily destined for pulp and paper production, with some trade for other uses such as fibre- and particleboards. Globally energy-related wood chip trade takes almost exclusively place within the EU between the member states or as exports to the EU27 region, where policies promoting the use of renewable energy have stimulated wood chip use in the district heating and CHP segment.

Wood chips for the EU residential market are primarily sourced locally. The international wood chip trade is exclusively driven by the industrial sector, where chips are combusted in dedicated district heating or CHP plants. Respective trade takes place in the form of virgin wood chips, or chips made of recovered wood. Official statistics indicate that trade of recovered wood chips dominate the EU-related trade in terms of volume.

In Europe two main markets for wood chips in energy production can be distinguished (Figure 59). The first is the wood chip trade between the countries around the Baltic Sea, where Sweden, Denmark and Finland and to some extent also Germany have been leading importers of wood chips from Baltic states and Russia. The second market is the southern market, which is mainly driven by wood chips use in medium scale CHP installations in Italy. Italy is sourcing major volumes of wood chips from neighbouring countries and Balkans.

The key constraint for international wood chip trade for energy is economic viability. Margins are primarily influenced by production and transport costs, but also prices in and exchange rates to target markets. Relatively low energy density, high moisture content and variable particle size and shape of wood chips are the main factor to limited geography of wood chips trade to energy purposes.
Production costs of wood chips depend heavily on feedstock prices. The key wood chip producing and exporting regions have a long tradition in export oriented forestry, but relatively undeveloped domestic wood processing, and/or pulp and paper industries. They benefit from the availability of low cost feedstock and residues, infrastructure, and experience. In Europe wood chip trade usually takes place directly between supplier and consumer. Combustion plants using exported wood chips are often located close to waterways, allowing for a relatively economic transport of the comparatively moist biofuel.

**Figure 59**  Bioenergy-related wood chip trade in Europe

Large scale international shipments of wood chips made of recovered wood are rare but have been known to occur. Still, globally the majority of recovered wood though appears to have been landfilled, combusted locally, or traded short distances, mainly between neighbouring countries. The key region for international wood waste trade is currently the EU, mainly due to legal and bioenergy policy frameworks and related financial incentives set across the individual member states.

Historically, Sweden has been one of the first states to attract large amounts of recovered wood. The trade of recycled wood has expanded to larger sphere involving several EU27 member states. Major trade flows of recovered wood chips are displayed in Figure 60. Top importing nations include Germany, Italy, and Belgium and the major exporters are clearly the Netherlands and the UK. The relatively balanced import-export relation of Belgium and Germany is largely related to national policy.
schemes which favour different streams of waste wood. The German renewable electricity feed-in scheme has provided strong incentives for the combustion of clean (non-treated) recovered wood.

Figure 60  Trade of recovered wood chips in Europe

![Trade of recovered wood chips in Europe](image)


Wood pellets

Wood pellets are, by far, the most important solid wood fuel traded internationally. The EU is the biggest producer and consumer of wood pellets in the world. Demand in the EU draws currently the largest trade flows of wood pellets from North-America and Russia (Figure 61).
Figure 61  Major global wood pellet trade routes (2013)

Source: Eurostat, Indufor data

Import of wood pellets to the EU from outside was about 3.2 million tonnes in 2012 and customs statistics show that the imports to the EU in 2013 increased to 5.7 million tonnes. The US and Canada export about 2.7 and 2.0 million tonnes of pellets to the EU respectively, Russia about 0.7 million tonnes/a. Most of the exports from North-America are going to UK, Netherlands, Belgium and Denmark. Russian exports are targeted to Sweden and Denmark. Global trade of wood pellets is dominated by industrial quality pellets.

In 2013 the wood pellet trade within the EU was about 5 million tonnes. Major pellet exporters are Latvia (1 million tonnes), Estonia (0.6 million tonnes), Portugal (0.5 million tonnes). Romania and Poland exported 0.3 and 0.2 million tonnes in 2012.

Two of the biggest importers within the EU internal markets are Denmark and Italy that imported both about 1.8 and 1.1 million tonnes respectively in 2013. Sweden, Austria and Germany import 0.42 million, 0.36 million and 0.32 million tonnes of pellets respectively.

The internal trade flows of wood pellets in the EU can be separated to two main regions. Continental European zone is dominated by the trade of residential wood pellets used in the residential heating segment. Another area, the Nordic zone, besides having strong domestic markets, imports both industrial and residential wood pellets from sources within and outside EU.

As illustrated in the Figure 62 the demand of residential wood pellet heating sector in Italy, Germany, Austria, Denmark, France and Sweden draws major volumes of residential wood pellets. The trade has generated and driven increasing household and residential heating use.

In continental market most of the residential wood pellets are marketed via retailer networks on a regional level. Only few biggest large scale producers, traders and networks operate independently on the national level. Most small and medium scale producers procure their raw material from wood processing industries in their vicinity and sell their products through a regional network of retailers. Often these companies
form networks that are selling pellets under well-established brand names. Networking helps smaller producers to enter the markets by providing access to wider logistical distribution system with sufficient transportation capacity.

Most of the residential wood pellets traded in the EU follow ENplus wood pellet standard which sets the characteristics for wood pellets in terms of technical characteristics and transparency of the whole supply chain. About 3.5 million tonnes of wood pellets consumed in the EU are ENplus certified.

In the Nordic wood pellet markets two main consumption hubs are Denmark and Sweden. Both draw trade of both residential and industrial wood pellets from Finland, Poland, the UK, the Baltic Countries and Portugal (Figure 62). Trade flows from Finland, Poland and the UK include residential wood pellets.

Total amount of wood pellets exported from Latvia, Estonia and Lithuania is about 1.8 million tonnes, (1 million tonnes, 0.6 million tonnes and 0.2 million tonnes respectively. During the last decade Riga in Latvia has been the major export harbour for Russian made industrial wood pellets. Thus, it is likely that these volumes presented by Eurostat include also industrial wood pellets of Russian origin. Wood pellets exported from Finland, Poland and the UK include mainly residential wood pellets consumed in the Danish and Swedish residential heating and district heating sector. Portugal has become one of the few major exporters of industrial wood pellets within the internal markets of the EU. Trade flows from Portugal are directed mainly to Denmark (0.3 million tonnes) and UK (0.1 million tonnes).
Export of wood pellets from extra EU sources involves mainly trade of industrial wood pellets. Three major exporting countries can be identified. The US and Canada have been the most important sources of industrial wood pellets over the last decade (Figure 63). The imports from North America have been increasing during the last years and so far peak volumes 2.8 million tonnes from The US and 1.9 million tonnes from Canada were recorded in 2013. North American exports are directed to the UK, Benelux, Denmark and a small part to Italy. The Atlantic trade of wood pellets is done mainly directly between the supplying company and the consumer. Large volumes are consumed rather centralized by 8 largest companies in the UK, the Netherlands, Belgium and Denmark (2012 estimated 85% of the industrial wood pellet consumption in the EU78). Regarding the North-American imports wood pellet consumers can rely on supply security, thus longer term supply contracts are common. This has improved the transparency of trade by improving price visibility and indexation.

Russia has also increased its significance in the EU industrial wood pellet export markets. During 2009-2013 Russian exports to the EU have almost doubled from 0.4 million tonnes to 0.7 million tonnes. Major countries importing Russian industrial wood pellets are Sweden and Denmark where pellets are combusted in coastal CHP plants. Due to volatile nature of wood pellet production in Russian mills, the export markets are not as stable or established as on the Atlantic side of the EU. Industrial wood pellet trade from Russia involves traders acting as middlemen. Due to supply

uncertainty long term supply contracts between the trader and consumer occur rarely and the trade is mostly done as spot basis.

**Figure 63**  Major external wood pellet import routes to EU (2013)

![Map of major external wood pellet import routes to EU (2013)](image)

Source: Eurostat

### 3.2.2 Agricultural biomass

Trade with residues from livestock is in general low due to the low value of this biomass fraction and its high water content. The production of ligno-cellulosic biomass is today rather low so that no trade statistics are available. Also trade with straw is low. Consequently, these biomass fractions are not reported, e.g., under FAOSTAT\(^79\). For these biomass types rather bioenergy products (bio-ethanol, biogas, pyrolysis oil, torrefied biomass) may be traded in future\(^80\).

Regarding woody biomass from short rotations produced biomass is very similar to products from forest land. Thus, it can be assumed that these biomass streams follow the same trade channels as forest biomass. The key constraint is economic viability. Already key producing countries/regions benefit from residues trade due to existing infrastructure and export orientation. The EU markets will be expected as a large driver for international woody biomass trade. The EU will be net importer and North America will be net exporter, especially for wood pellets (see chapter above) (Lamers et al. 2014).

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3.2.3 Biogenic waste

As discussed in section 2.3 above, the most obvious end uses of paper/cardboard waste are recycling, composting or incineration with energy recovery. Almost two third of the total volume of paper and cardboard waste is utilised in those activities. If intra- and extra-EU trade flows of recovered paper provide an indication on the traded volumes of waste paper which have undergone recycling and composting (as outlined below), this is not sufficient to determine the trade flows of this category of waste due to energy production.

The total traded volume of recovered paper within the EU27 amounts to 10.6 million tonnes in 2010 (Figure 64). In terms of exports from the EU, the total amount traded was around 9.38 million tonnes in 2010, 97% of goes to Asia (9.11 million tonnes), followed by a 2% to other European countries (206 000 tonnes) and by less than 1% to North America, Latin America and the rest of the world (63 000 tonnes) (see Figure 65).

Figure 64  Trade flows of recovered paper in 2010

The total imports of recovered paper amounts to 1.22 million tonnes in 2010. Most of the volumes come from other European countries (83.6% or approximately 1 million tonnes) or from North America (15.1% or 184,000 tonnes) (Figure 66).
4 Costs and prices of biomass

4.1 Costs of biomass supply

4.1.1 Wood biomass

Bioenergy projects must be economically viable for the different actors in the value chain. Woody biomass used for energy generation must be able to compete with other uses, e.g. wood based panels and at the same time the energy produced from biomass must be as cheap as or cheaper than energy produced from competing energy sources.

Main cost factors are similar for supply of wood for energy and industrial roundwood. Thus factors like harvesting and forwarding productivity, terrain and hauling distance as well as long distance transport affect the cost efficiency in similar manner. The biggest differences in harvesting wood to energy purposes are generally lower yield per harvested hectare and lower market price of harvested wood material.

The share of solid fuel feedstock, such as biomass, in the operation costs of a typical energy plant is approximately about 50%. Thus, the competitiveness of biomass-based energy generation strongly depends on the cost and quality of feedstock supply. In this chapter factors affecting supply cost structure of two different wood biomass types, forest chips and wood pellets is observed. These represent two different types of wood biomass commonly used in energy production.

- Forest chips are a primary wood energy source which is derived from fresh harvested wood raw material that has not had any previous use.

- Wood pellets are traditionally made of industrial by-products which are a secondary wood energy source, coming from industrial wood processing but has not been altered by any chemical process.

Understanding the underlying factors forming the total production costs of both types of products helps understanding their effect on the biomass availability and division between energetic and material use.

Costs of harvesting of firewood are not examined in this section. Firewood harvest is usually mixture of small scale commercial activity and independent consumer activity of harvesting small volumes of firewood to household use. There are no generalized supply chains that would enable reasonable comparison. Also markets are of very local character and transparent price information is very difficult to find.

Production costs of forest chips

The supply of forest chips can vary depending on the raw material type as the production of forest chips consists of a series of individual operations performed to process biomass into commercial fuel and transport it from the stand to the plant. The whole system is built around the chipping. The position of the chipper or crusher in the procurement chain mostly determines the state of biomass during transportation and,
therefore, whether subsequent machines are dependent on each other. Chipping may take place at the harvesting site, roadside or landing site, terminal storage or at the plant where the chips are eventually used. Table 5 presents the commonly utilized supply chains of forest chips in the EU.

### Table 5: Forest chip supply chains used in the EU27

<table>
<thead>
<tr>
<th>Supply Chain</th>
<th>Raw materials</th>
<th>Location</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Forest Stand</td>
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<tr>
<td><strong>1. Roadside Chipping</strong></td>
<td>Tops and Branches</td>
<td>Wood is forwarded to the roadside</td>
</tr>
<tr>
<td></td>
<td>Small size stemwood, Stumps</td>
<td>Wood is forwarded to the roadside</td>
</tr>
<tr>
<td><strong>2. Terminal Chipping</strong></td>
<td>Tops and Branches</td>
<td>Wood is forwarded to the roadside</td>
</tr>
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<td></td>
<td>Small size stemwood, Stumps, Pulpwood logs, Defect sawlogs</td>
<td>-</td>
</tr>
<tr>
<td><strong>3. Plant Chipping</strong></td>
<td>Tops and Branches</td>
<td>Wood is forwarded to the roadside. Tops and branches or small diameter stemwood can be bundled with purpose built machine</td>
</tr>
<tr>
<td></td>
<td>Small size stemwood, Stumps, Pulpwood logs</td>
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Source: Indufor

Several factors affect the total cost of biomass supply. Harvesting method and conditions such as terrain, average tree size and density, have effect on the productivity and production cost. Harvesting of tops and branches has the lowest cost since it involves only loading leftover material to the forwarder cargo space and hauling it to the roadside storage after final felling. When forest chip raw material is acquired from thinning operations in younger stands the tree size is a lot smaller than in harvesting operations in mid-aged or mature forest stand. This is the case in countries where demand of pulpwood from to material purposes is high. Smaller stem size means that lower accumulated volume per machine working hour. Because the price of the forest chip raw material is low, poor productivity has been the main restriction in procurement of forest chips from younger stands. Today purpose built
harvesters, using accumulating harvester heads capable of processing multiple stems simultaneously, are used in these harvesting sites. When forest chips are sourced from stands, with average stem size comparable to pulpwood, regular harvesters and forwarders can be used. Harvesting costs depend also on fuel and labour cost, which differ by country depending on the local level of fuel price and wages.

Location of chipping determines much of the costs of chipping, transport and required investment. Forest chip supply chains can be divided to centralized and decentralized depending on the location of the chipper. Centralized chipping operation and storing chips in terminal is a cost efficient option for large scale CHP plants. Decentralized supply chain such as roadside chipping can be applied as general supply chain for all sizes of plants.

Moisture content of forest chips is the most important single quality attribute of forest chips\(^\text{84}\). It affects heating value, storage properties, chipping and transport costs. Moisture in wood decreases energy content. This means that if moisture content of wood is increased more volume and consequently increased amount of truckloads of forest chips need to be supplied to heating plant to receive the target amount of energy. As an outcome the total cost and the resulted CO\(_2\) emissions from transport are increased. In a study by Acuna et al. (2012) total supply costs of forest chips in CHP plant in Finland was estimated up to 33\% lower with proper drying applied for forest chips raw material in the supply chain.

Figure 67 presents costs of forest chips supplied with various supply chains in different EU countries. By country the total supply cost varies by used raw material and chipper location. Also, in general the supply cost of tops and branches is lower than the supply of forest chips from roundwood, small-size whole trees or stems. No direct conclusions of the cost levels in different countries can be made, however they give a view on the cost level in cases, where the Nordic forest chip supply chains are adopted to various conditions in different parts of the EU.

In Spain long forwarding and transport distances and slower driving speed caused by mountainous terrain are expected to increase the unit costs. Also allowable load size for trucks is Spain is only 44 tonnes (64-76 tonnes in Finland). Transport is decreasing the cost efficiency.

In Scotland with decentralized space heating infrastructure, the district heating networks are considerably smaller. In the UK forest chips are supplied to disperse small district heating facilities using terminals. Also forest road network does not allow access to the forest during winter, because muddy roads do not sustain traffic. Terminals are thus required as storage points of forest chips over longer period of time.

Finland (and Sweden) has been a forerunner of forest chip use in the EU. Centralized and decentralized supply chains have been in operation already for decades. Therefore efficient utilization of all supply types has evolved in both countries. The Nordic supply chain of logging residues is the most cost competitive alternative among the reviewed supply chains. Supply of forest chips from roundwood is still costly in the Nordic countries because the supply is focusing to sites with small average stem size. Also labour and fuel costs are high in the EU standards.

In Poland most of the forest areas are located on sandy soils accessible almost through the year. Species composition in Poland does not favour use of tops and

\(^{84}\) Sikanen, L. 2011 Vesi polttoaineessa, merkitys ja hallinta. Presentation.
branches from final fellings as the forests are pine dominated, which has lower crown and branch biomass volume, meaning that energy content of harvest per hectare is reduced. In this case the supply chain was based on mechanized harvesting, although only 5% of total logging in Poland is done with a harvester. Manual chainsaw harvesting can be expected increase the cost.

Figure 67 Supply costs of forest chips of various supply chains in selected countries

Volume of tops and branches is relative to the harvested volume of sawlogs as both are sourced mainly from final felling site. As tops and branches are the cheapest raw material, ensuring the availability of sawlogs to sawmills enables more efficient utilization of forest chips from this “low cost” source. Potential of forest chips is largely unutilized in many countries. Additional harvest of wood for energy purposes means increased use of existing roads. This means that if the supplied forest chip volumes are increased, access to forest and good condition of road infrastructure needs to be ensured. Therefore investments to forest road infrastructure and increase in forest road maintenance costs can be expected.

In general the supply costs vary greatly depending on the forest conditions, transport infrastructure, used machinery and energy infrastructure. Same supply solutions cannot be applied to all countries but have to be developed in suitable forms through experience, case by case. Countries with wood supply developed around mechanized harvesting machinery can be expected to have good opportunities in quickly increasing volumes of forest chips. Entrepreneurs are able to use the existing machinery for harvesting regardless of final use (material/energy) of the wood. In countries with...
supply based on manual harvesting, major restructuring and investments to mechanized harvesting equipment will be needed.

**Production costs of wood pellets**

Production of wood pellets follows several processes from reception and storing of wood raw material to grinding and drying the wood biomass, and pelletizing it. In pelletizing process wood pellets are formed under high temperature and pressure, where the wood particles will fuse into a solid mass, forming a pellet. Ready pellets are cooled to normal temperature and sieved to remove crumbles and dust. Finally wood pellets are stored and packed to desired package size, ready to be transported to the customer.

Figure 68 shows the cost structure of wood pellet production in Germany, Sweden and Russia according to data collected by Indufor. The illustrated costs are based on data from actual wood pellet producers in respective countries. All reference mills are using industrial by-products as raw materials effect of change in feedstock base to fresh wood biomass is discussed further in this section.

**Figure 68   Wood pellet production costs in Germany, Sweden and Russia**

![Wood pellet production costs in Germany, Sweden and Russia](image)

Source: Indufor database

Raw material cost constitutes the major part of pellet production costs. The raw material is most costly in absolute and relative terms in Germany. In Sweden and where the competition of industrial by-products less evident the price is slightly lower. At the moment, scarcity of industrial by-products is not a problem in Russia. Sources are of plenty and the price of the feedstock at the pellet mill can be even zero plus transportation from the vendor sawmill.

The wood pellet production is not labour intensive as the cost of labour constitutes about 10% of total costs in the EU and even less in Russia. In Germany and Sweden energy and depreciation costs are also about 10% of total costs. In Russia the share
of depreciation is higher because of typically higher discount rate. Labour and energy costs are naturally linked to local wages and price level electricity.

Wood pellet manufacturing started integrated to sawmilling industry, where the idea was to refine cheap by-product at the site as value adding product. Wood pellet mills integrated to sawmills still exist but the increased demand has emerged independent pellet industry.

In Sweden wood pellet mills have utilized the industrial by-product resources efficiently integrated to the sawmilling industry. In Germany, pellet companies and mills exist mostly independent of large sawmilling industry. However, the connection of pellet and sawmilling industry is strong due to typically close distance between the mills. In Germany the competition for industrial by-products between the local wood based panels and pulp industry is evident. Pellet mills have so far been able to source raw material. However, since 2007 the by-product flows have had a general decreasing trend in both Sweden and Germany due to decreased sawmilling activity. In both countries producers are seeking opportunities to use small diameter roundwood as pellet raw material to respond to lower available volumes of industrial by-products and on the other hand increasing demand of wood pellets5.

As “easy” feedstock has been utilized, increased use of roundwood as wood pellet raw material is likely in the future. This means also increase in the wood pellet production costs. Roundwood may be more abundant resource but it may be more expensive especially compared to lower quality industrial residues. Also the use of fresh roundwood requires pellet mills to invest to debarking, chipping and additional drying machinery capacity. For this reason raw material, energy and depreciation costs can be expected to increase in the future. In a study by Ihalainen and Sikanen85 (2010) pellet production costs were compared between the use of industrial by-products and roundwood. Use of roundwood as raw material increased the total production costs almost 30%.

Russian wood pellet manufacturers have the advantage of utilizing cheap raw material sources from both industrial residues and roundwood. Nevertheless, success of Russian pellet manufacturers in the EU markets is dependent on their ability to respond to growing requirements in terms of wood pellet quality standards and sustainability requirements. Large energy companies are bound to strict sustainability criteria requiring wood sourced from FSC certified forests.

What is not shown in the figure is the cost of transportation logistics of wood pellets. The effect of this is particularly important for bulk distribution of wood pellets exported from Russia to the EU markets. Although the absolute production cost of wood pellets are smaller in Russia, the transportation cost to the consumer sets off the difference between European and Russian manufacturers. Especially small scale mills are forced to use traders to get their products to markets due to insufficient volumes for exporting. Wood pellet prices from several sources are discussed further in wood pellets price section.

4.1.2 Agricultural biomass

Residues may be desirable raw materials, because utilizing them does not require recovering the costs of production: they are already covered by food and feed production\textsuperscript{86}.

In comparison to other feedstocks, such as dedicated biofuel crops, residues typically have the lowest cost as e.g. straw and bagasse from sugar cane can be collected at harvest. However, feedstock costs for agricultural residues vary. They may be modest if agricultural residues can be collected and transported over short distances. Costs can even be negative for residues for which disposal fees can be avoided by using them for energy production. On the other hand, transport costs can be relatively very high if there are significant distances involved, as the energy density of biomass from this source is usually low. These costs are an important reason for agricultural residues often being used locally. Still, there can be significant commercial local markets. A problem with low-cost agricultural residue feedstocks is that the amount of feedstock available depends on the agricultural markets for the primary production goods, e.g. the availability of bagasse on the ethanol and sugar markets.

Manure, for example, is a scarce resource in some regions, while in others it is too abundant. Under the EU Nitrate Directive in Nitrate Vulnerable Zones farmers are obliged to pay for the disposal of excess manure (above 170 kg N/ha). It can be assumed that farmers with excess manure have to face costs to get it disposed. Within the “Biomass Futures” project it was assumed that in regions where the deposition of Nitrogen exceeds the value of 170 kg Nitrogen/ha manure would be available for bioenergy production at no cost for the feedstock. In regions with limited or no excess prices of around 40 Euro/ton were considered.

Costs of biomass supply increase when dedicated crops for energy use are produced. Yield and production costs data for Short Rotation Forestry (SRF) crops is mainly from trial plots and pilot production schemes. The few cost and revenue estimates available show significant variation. The variation in costs and yields may reflect varying planting conditions – establishing SRF on degraded land is likely to be more costly and lower yielding than planting on land of high productivity. Costs for SRF and grasses like miscanthus are relatively high for the establishment of the plantation but lower for maintenance and harvest\textsuperscript{87}.

Considering the value chain for bioenergy crops, four major cost items can be identified: land costs, labour costs, capital costs and fertilizer costs. Together they are the total cost of an agricultural production system. Labour cost consists of wages and labour input and can be defined as hectare based cost. Capital cost consists of inputs like machinery and prices (e.g. for machinery). Capital cost, land cost and labour cost are hectare based. Only fertilizer costs are yield based and consist of fertilizer prices and fertilizer input (Figure 69).


\textsuperscript{87} Hauk, S., Knoke, T., & Wittkopf, S. (2014). Economic evaluation of short rotation coppice systems for energy from biomass—A review. Renewable and Sustainable Energy Reviews, 29(0), 435–448. doi:http://dx.doi.org/10.1016/j.rser.2013.08.103
The cultivation of ligno-cellulosic crops has total capital expenditures of 143 €/ha for poplar, 156 €/ha for willow and 576 €/ha for miscanthus. Poplar and willow have the largest expenses in planting and plants (94% and 76%). Miscanthus cultivation is dominated with 64% by harvesting, field transport and storage (de Witt 2010). SRC costs around 2 500 Pound per hectare to establish but is eligible for a 50% planting grant through the Energy Crops Scheme.88

The production costs for agricultural residue stems from collection in the field, field transport and transport to an intermediate site or end-use site. De Witt calculated with cost data on agricultural residues between 1.1 and 6.5 €/GJ.88

The production costs at which biomass resources are available in Europe vary considerably, with significantly lower costs in Central and Eastern Europe than in Western Europe. This is due to lower land rent costs and labour costs for Central and Eastern Europe. The greater part of the first generation feedstock supply is available at production costs of 5–15 GJ/a compared to between 1.5 and 4.5 GJ/a for second generation feedstocks. Cost differences can be attributed to the relatively extensive production practices and high yields for second generation feedstocks. The majority of agricultural residues can be made available to costs between 1 and 4 GJ/a.

4.1.3 Biogenic waste

The utilisation of biogenic waste for energy production is economically feasible on the basis of cost. Considering the increasing competition between waste material for recovery, reuse and recycling and recovery of wastes and residues for energy use, these will be used for energy-related purposes only if the cost of undertaking such an operation is competitive against other material uses along the value chain.

Due to lack of available data on management costs of several biogenic waste categories (i.e. food waste, wood debris and textile), this section includes an

88 http://www.crops4energy.co.uk/short-rotation-coppice-src/
assessment of the collection and transport costs associated with some of the waste streams included in the biological fraction of municipal solid waste. These are paper and cardboard waste, green waste and sewage sludge.

**Biological fraction of municipal solid waste**

Elbersen et al (2012) report cost levels of the biological fraction of municipal solid waste only for the Netherlands in 2020. The same cost levels were applied to the rest of the EU countries.

An EU average of 2010’s costs associated with municipal solid waste amounts to 22.75 €/tonne.\(^89\)

**Paper and cardboard waste**

In 2010, an average EU-wide cost of low quality paper of 115€ / tonne is reported in Elbersen et al (2012)\(^90\). This translated into a price of 6.3€ / GJ of energy produced. To estimate the 2020 or 2030 costs of a tonne of paper and cardboard waste, Elbersen et al apply an inflation rate per year to the current prices.

**Green waste**

No specific costs are connected to the grassland cuttings, as there are already included in the normal management activities. The costs associated with transport and drying of road side verge grass for energy production is assumed to be around 10€/tonne of dry matter for the EU27. An inflation correction factor is applied per year in order to calculate 2020 and 2030 costs for transport and other activities associated with road side verge grass.\(^91\)

**Sewage sludge**

As for green waste, the cost of sewage sludge is assumed to be 0, except for transport and pre-treatment costs, which are estimated to be around 10€ / tonne of dry matter for the EU27. 2020 and 2030 costs are calculated by applying a yearly inflation rate.\(^92\)

### 4.2 Biomass market prices

#### 4.2.1 Wood biomass

As illustrated in chapter 2.2, wood biomass markets have been increasing notably during the last decade. The general price development of wood fuels has been stable in comparison to the world market prices of fossil fuels which have more fluctuating character. Predictability of wood fuel prices has partly played a role in the increasing demand, which has consequently influenced the steady increase of the wood fuel prices. Another main cause for the increase of wood fuels price is the increased demand caused by policy measures targeting the mitigation of greenhouse gas emissions. This chapter aims to present aspects that influence the formation of wood fuel prices also current trends of different wood fuels (forest chips, industrial by-products, recovered wood and wood pellets) in several markets are displayed.

**Wood fuel production costs and price formation**

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\(^89\) Elbersen et al (2012).
\(^90\) Elbersen et al (2012), Annex 4. Approach and sources used for estimating price levels of different biomass sources 2020 and 2030, p. 86.
\(^91\) Ibid.
\(^92\) Ibid.
Development of production costs is one principal short term driver of the wood fuel prices. This is caused by the aforementioned fact that the costs of feedstock procurement can consist up to 80% of the total costs of wood energy production. Traditionally the price of forest chips has likely been set by the cost of production. In some cases the market price paid for forest chips is too low to cover the cost of production. This has been the case e.g. in Finland where supply of forest chips from small size stemwood from young forest stands has not been profitable without state subsidies paid to cover the cost of harvesting and chipping. On the other hand the production of forest chips from tops and branches collected from final felling sites is profitable even without subsidizing the activity since the raw material is ready available on site as a by-product of harvesting of sawlogs and pulpwood.

Prices of forest chips have been steadily increasing in Finland, Sweden and Germany as forest chips has become a major fuel used in district heating and CHP applications. Industrial by-products were earlier widely used in energy production as such but as the competition of this raw material has increased, the interest of energy producers have turned to feedstock alternatives that are not as “easily” available. At the same time national level subsidies such as feed-in tariffs or market premiums have improved the energy producer’s wood paying capability casting an upward trend in forest chips prices. This means that the market price of forest chips is not anymore totally driven by production costs but increasingly by policies and subsidies.

Also small correlation in the price of oil and price of forest chips can be found. Largely mechanized production of forest chips require inputs of fossil diesel consumed in the harvesting process. This has a direct link to the production costs of forest chips.

**Relationships between wood fuel and fossil fuel prices**

In a long run high oil price acts as an incentive to use alternative fuels such as wood pellets which eventually increases the demand and drives the price upwards. This is a process that drives long term decisions in investment of new technology for combustion of alternative fuels. The most important link between wood and fossil fuel prices lies in the substitutability of these fuels. Linkage of wood fuel prices to alternative fuel prices is most evident in large scale use of wood in energy production. Co-firing of wood fuels typically occurs in two different large scale applications. In the UK, Benelux and Denmark industrial wood pellets are co-combusted with coal in power stations. In the Nordic countries, mixture of wood fuels such as forest chips and industrial by-products are combusted in CHP plants together with fossil coal and peat. These kinds of facilities are flexible to switch between alternative fuels depending on the price of respective fuel (and emission permits). This is supported by technological development in wood fuel sector. The expansion of torrefied wood pellet markets enables the production and use of wood pellets in a very similar way to coal in terms of combustion, logistics and storability.

**Wood fuel price connectivity to the development of forest industry sector**

Wood fuel market is connected to all sectors of the wood consuming industry as they are not only the producers of final products but also producers of by-products that can be allocated to several different material and energetic purposes. Especially market price of industrial by-products and recovered wood is more dependent on what would the competing users be willing to pay for the material. Consequently wood energy prices can influence or can be influenced by the price of wood as industrial raw material.
The availability of inexpensive raw material has been an essential factor contributing to the development of industrial scale wood energy utilization in countries with traditionally strong forest industry sector, such as Finland, Sweden and Germany. The roundwood consumption of sawmilling industries are contributing to the availability of industrial by-products as well as forest chips produced from tops and branches from final fellings. This also means that the development of wood fuel market is vulnerable to events especially in the sawmilling industry. The global economic downturn experienced during 2008-2009 cast strong recession to the construction sector. Sawmilling industries suffered from reduced demand were forced to cut down production. This led to substantial drop in availability of industrial by-products which eventually increased their prices notably.

**Wood fuel prices and international trade of wood fuels**

Increasing share of wood fuels, mainly wood pellets are being traded within Europe and between the continents. Usually, when trade of certain commodity increases, national markets become merged together and the supply and demand does not have to occur in the specific national market. The connection of national markets is visible in the development of market prices of bioenergy commodities. E.g. the prices of wood pellets in specific market segments have tendency to converge to common level and follow similar trends and differ only by the cost of transportation. In this sense there is a major difference between the markets of forest chips and markets of wood pellets. In forest chips markets, that have more national character, the price trends have been fluctuating in totally separate ways between some of the major consuming countries (Figure 70). On the other hand the prices of wood pellets in industrial markets are developing in similar manner and on roughly at the same level regardless of geography.

**Current wood fuel prices and trends**

The following section presents an indication of current market price of used wood fuels and trends for markets where data is available. In general the status of wood fuel price data in terms of availability and transparency in many countries is poor. Common price quotations and time series following the trends are in many ways at an infant state but they are developing as wood energy products are being transformed to globally traded commodities.

Prices are given as per energy unit, tonne or cubic meter depending on the unit which the trade is most commonly based on. In wood chips the energy content is the most crucial factor defining the quality of fuel, thus the price of forest chips is based on its energy content (MWh). Industrial by-products can be used in various segments, thus common volumetric measurement of cubic meters is used as the basis of trade. In wood pellets trade the commonly referred unit is tonnes. This unit is used because wood pellets are somewhat uniform commodity with standard density and heat value. Also in international trade transport tariffs are based on weight of transported goods.

Figure 70 shows the trend of forest chips prices in three major consuming countries, Finland, Sweden and Germany. Also coal prices are presented aside, because coal is the common fossil fuel used in district heating and CHP applications that is substituted by forest chips. Presented prices include taxes. Price of forest chips has been steadily increasing in all referred countries however the drivers vary depending on the country. Sweden applied the tax on fossil fuels already in 1991. This tax has been one of the main drivers in increasing the use of forest chips and wood pellets in Sweden. The effect of the tax making coal a very expensive fuel in comparison to forest chips for Swedish energy producers can be seen in the figure. In Finland coal has retained
competitiveness against wood fuels for longer time; however the energy tax levied on coal increased in 2011 increasing the price notably. The increased demand and slowly increasing forest chip prices are because of state subsidies provided to cover unit costs of forest chips production. Another factor increasing the competitiveness of forest chips is subsidies of biomass based electricity. In Germany the price of coal has remained at a lower level in comparison to forest chips. The competitiveness of forest chips is based on feed in tariff which is pair per kWh of produced electricity from biomass.

Figure 70  Price of forest chips in Finland, Sweden and Germany (delivered)

In Figure 71 prices of industrial by-products in three major producer and consumer countries Finland, Sweden and Germany are presented. The markets and pricing of industrial by-products differ notably between the countries. Prices for Finland and Sweden are delivered but the German price, according to EUWID, is at the mill (seller). This makes the direct comparison challenging; however the general trend of prices in these markets during the period has been increasing.

Finland and Sweden operate in closed market of industrial by-products. The level of integration in raw material sourcing between the sawmilling and pulp industry is high. Non-integrated sawmills often make contracts with wood procurement organizations of big integrated forest industry companies. Non-integrated sawmilling companies sell their by-products primarily to large integrated pulp producing companies and secondarily to wood pellet mills or energy use as such. In Germany the markets of industrial by-products are more active for several reasons. Sawmilling company structure is more diverse, the level of integration is low, paper industry is mostly using recycled paper and the facilities are evenly spread within the country making the average distance between supplier and buyer shorter. Also the demand is more versatile in Germany. In addition to pulp industry and energy consumption large wood based panels industry presents large demand.
Recently the market price has been most volatile in Germany where the competition of this raw material between the mentioned consumption segments is most evident. Prices of industrial by-products increased quickly in 2009-2010 during the financial crisis when German sawmills cut their production. Decline in production reduced the availability of industrial by-products thus increasing the price.

Swedish sawmilling industry was not as severely affected by the financial crisis and the market of industrial by-products continued through the period relatively stable. Sweden is not part of the Eurozone, thus the country was able to avoid sawmilling industry recession, due to favourable exchange rate development of Swedish crown. Sawnwood production dropped also in Finland during 2009; however the effect to the market price of industrial by-products was small. The reason for moderate price development is the integration of forest industry and resulted lack of competition of industrial by-products.

**Figure 71** Price of industrial by-products (excl. bark) in Finland, Sweden and Germany

![Price of industrial by-products (excl. bark) in Finland, Sweden and Germany](image)

Source: Statistics Finland, Indufor data, Skogsstyrelsen, EUWID

Figure 72 illustrates the prices and historical trends of wood pellets in several markets. Compilation of wood pellet price statistics was used to collect information of wood pellet prices. Different wood pellet markets following separate price levels and trends can be identified. Prices retrieved from Finland, Germany, Austria and PIX continental pellet price include price of wood pellets of residential quality. These pellets are of high quality manufactured from the best available raw materials (clean and dry industrial by-products). Three price indices PIX Nordic, Industrial pellets ARA and Industrial pellets FOB Baltic present the price level of industrial wood pellets in three markets. Acronym “ARA” refers to wood pellets shipped from North America to import ports in Amsterdam, Rotterdam or Antwerp. “FOB Baltic” refers to price of industrial wood pellets at shipping ports of Latvia and Lithuania. These wood pellets are produced either in Baltic States or Russia. This price does not include the sea transportation cost to the final consumer. PIX Nordic represents the industrial wood pellet price (CIF) in Nordic countries and Baltic States. This includes majorly price level of wood pellets shipped delivered to coastal CHP plants in Sweden and Finland.
Market prices for Sweden derived from Swedish Forest Agency (Skogsstyrelsen) present price level of domestic wood pellet markets. This includes both industrial and residential wood pellets. Apart from actual residential pellet consumption sector and large industrial CHP wood pellet combustion plants the third so-called mid quality grade is used in medium scale district heating plants. Thus the presented Swedish market price is set roughly in between the residential and industrial wood pellet market segments.

Prices of industrial and residential wood pellets are following separate development trends thus they need to be observed separately.

Figure 72  Price of wood pellets in several markets in the EU

As illustrated in Figure 73 the prices of industrial pellets have been developing roughly at the same level between two major industrial wood pellet trade routes North-America (ARA) and Russia (Industrial pellets FOB Baltic, PIX Nordic). Industrial wood pellet prices are set aside with coal price to visualize the level against the main substitute fuel used in CHP and co-generation plants. Measured by merely the market price coal is still the cheapest fuel, however policies and set subsidy measures (feed-in tariffs or market premiums) promoting the energy use of biomass improve the competitiveness of industrial wood pellets over coal. High taxes levied for coal in Sweden have similar effect on competitiveness of industrial wood pellets.

The market of industrial wood pellets is characterized by a handful of large pellet end-users consuming majority of traded pellets. According to Argus, nine largest wood pellet plants consumed approximately 85% of all industrial wood pellets within the European market.
In Figure 74 prices of residential wood pellets in several markets are presented aside with light fuel oil prices. Light fuel oil has traditionally been the fuel used in residential heating applications that pellet heating systems have been replacing. It can be seen that both in Finland and Germany the price of light fuel oil has been generally an increasing trend and notably volatile in comparison to the moderate increase of residential wood pellet prices. In Germany and Austria state has subsidised wood pellet combustion equipment investments in residential scale and small district heating segment. Investment support together with the predictability of residential wood pellet prices has driven the increasing demand of residential wood pellets in Germany, Austria, Sweden and Italy. Although the residential wood pellet price is at same level with other European markets, the residential wood pellet consumption in Finland is not functioning. The reason for this is the historically low taxation of light fuel oil, cheap electricity and appearance of competitive and in many cases more appealing technology to residential heating markets (geothermal heat, heat pumps). The consumption of residential wood pellets has been stagnated at level of about 70 000 tonnes/a since 2009.
The market for recovered wood is a relatively immature market that has been gaining significance during the last decade. Very few sources related to market prices of recovered wood are available. Figure 75 presents price of recovered wood in United Kingdom and Germany. EUWID publishes price of recovered wood in Germany delivered to user. German prices presented are average of all recovered wood quality classes. Price of recovered wood in UK is presented from statistics of British Letsrecycle.com website.

Germany is the biggest recovered wood market in the EU (see Figure 26). Small to very large private waste companies are responsible for collection waste and treatment recovered wood. Leading electricity companies and energy suppliers consume recovered wood in CHP plants. Local, municipal energy suppliers and private investors operate biomass power plants also. The local particle board industry use untreated recycled wood for particle board and use treated recovered wood chips for their own power plants. According to BAV and EUWID the German market for recovered wood is relatively balanced. Compared to supply, the demand has been slowly increasing throughout the period but there has not been shortages because of imports to domestic market. Increasing demand has caused the general price increase of recovered wood in Germany.

In the UK landfill taxes imposed to recovered wood and increasing haulage costs have been increasing. Also discussion about complete ban of wood sent to landfill has been ongoing, however local wood recycler’s notion is that large majority of utilizable good quality recycled wood is anyway recycled. In the UK the recycled wood market is dominated by a multitude of wood recycling companies around the country. In Figure 75, the average market price for the UK show the “gate fee” an individual must pay for bringing wood raw material to recycling facility. So far fees have been negative, but the best qualities of recovered wood have been attracting positive gate fees, price
paid for bringing wood to facility. During 2012-13 the gate fees have been increasing. The reason for this is the reduced demand from wood based panels industry. Several mills within the markets of UK wood recyclers have cut production or shut down through 2012-13.

Figure 75  Price of recovered wood in United Kingdom and Germany

Source: Letsrecycle.com, EUWID. (*) Price point, delivered at recovered wood recycling plant. (**) Price point, recovered wood treatment plant

4.2.2 Agricultural biomass

Prices for agricultural biomass sourced and consumed locally are difficult to obtain and no time series data on a comparable basis are available. Prices paid will depend on the energy content of the fuel, its moisture content and other properties that will impact the costs of handling or processing at the power plant and their impact on the efficiency of generation.

4.2.3 Biogenic waste

As observed above, conversely to wood and agricultural biomass, biogenic wastes cannot be considered as final commodities sold to end-users for either energy production or alternative material uses. The market price, net of costs for collection and transport, is thus assumed to be 0.

The price of any management activities associated with any biogenic waste categories is considered a cost and is discussed in section 4.1.3 above.

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5 Conclusions

General conclusions

Material and energy uses of the wood and agricultural biomass and biogenic waste are largely separate from each other. Essential use of wood is in material purposes. Interaction and dependencies between material and energy use is most evident within this sector. Agricultural biomass is first and foremost produced for food and feed. Material uses of biogenic waste are still much limited and strongly dependent on effective ways to decontaminate the waste. Thus, possibilities for and competition between energy- and material uses of the biomass types are quite separate between sectors.

Possible overlaps between the sectors could arise from the establishment of short rotation forestry for bioenergy on agricultural land, which could possibly decrease the demand of energy wood from wood biomass supply. Also, improvements in waste management could make biogenic waste, especially recovered wood, a more important source of feedstock for both material and energy production.

There are large differences within biomass production and utilization between the EU28 countries, as geographical conditions, infrastructure and population densities vary greatly. Germany and France are major producers of both wood biomass and agricultural biomass; otherwise there is a clear geographical division between the two types of biomass. Sweden and Finland stand out as producers of wood biomass, while Spain and Italy are large producers of agricultural biomass. Production of biogenic waste is related to the population of the countries, with Italy, France, the UK and Germany being the largest producers.

National and international trade is well established within wood biomass products, while almost non-existent within agricultural biomass and biogenic waste. Due to the bulkiness of the products, transport prices play a central role in all trade of biomass products.

Wood biomass

Material and energetic use of wood raw material from domestic sources in the EU will be increasingly interconnected. This is already the situation, as the different proportions of felled trees and consequent by-products of industrial processing are directed to various end uses, depending on the wood paying capability of local wood consuming industries. Although being low margin products, subsidies paid for energy that is produced using wood and other biomass have increased the wood paying capacity of energy producing industries throughout the EU.

Sawmills remain to be in a key position to keep the market of wood raw material running for both material and energy uses because sawlogs are the most valuable part of a tree and thus the most interesting from the producer’s point of view. Procurement of proportions with lesser value (pulpwood, tops and branches) is tightly integrated to the sawlogs supply. Consequently, better sawlogs availability improves also raw material acquisition possibilities of pulp and paper, woodworking and bioenergy industries.

Firewood consumption in small scale stoves and fireplaces remains popular in the EU. Indirectly, it can be deduced that this wood consuming sector is major. Due to lack of solid data on firewood consumption, it is difficult to determine to which extent firewood consumption replaces other possible end uses of the limited amount of wood available, however it is of a high importance since it is estimated to account for about 1/3 of total wood biomass used for energy.
Use of forest chips has increased in several countries and there is potential for further increase. However, several challenges need to be addressed as the supply of forest chips is expected to move to areas with poorer resources and longer transport distances. The supply of forest chips for energy is also highly dependent on public subsidies. The end product has low added value, and the profitability depends on how efficiently the production costs can be lowered by applying efficient harvesting technology and supply organization. In order to lower the supply costs, special development needs to be targeted especially on storage management, infrastructure and harvesting machinery development.

The pool of industrial by-products is almost completely utilized. Increasing competition of roundwood resources between the pulp, wood based panels industry and bioenergy use can be expected since the total sawnwood production is expected to increase only marginally. In this situation further expansion of domestic wood pellet industry and residential wood pellet heating sector is possible only by increasing the production expanding the raw material base to using roundwood as wood pellet raw material.

In consumption of industrial wood pellets, it is likely that the EU will become even more dependent on imports. Globally, the EU will remain the top consumer. Nevertheless, the expansion of wood pellet consumption in the Asian region is already directing trade flows, e.g. from Western Canada, away from Europe. Russia is expected to become more important for European energy companies’ wood pellet procurement; however issues related to ensuring sustainably produced wood raw material and supply security through established trade connections need to be addressed.

The success and technological development of pilot projects of wood based liquid biofuels production will define whether it will become a growing wood consuming industry. However, the production will likely be integrated to existing chemical pulp industry.

Recovered wood presents a potential raw material source for material uses and energy. Trade and markets are the most developed in the EU countries with dense population, established standardization and legislation defining the possible uses (material and energy) based on the level of contamination.

Competitiveness of wood fuels has traditionally been burdened by their low price and relatively high sourcing costs. This is due to the fact that the wood energy commodities are low margin products with limited marketability. In many cases the economic feasibility can be reached by applying subsidies aimed at covering production or investment costs or increasing price paid for the final product. The market prices of wood biomass commodities for energy have been generally increasing throughout the last decade due to increasing demand. Advantage in comparison to the fossil fuels characterized by fluctuating price trends is their stable price development.

It is likely that wood raw material price will increase further. Two possible pathways to respond to this challenge can be envisaged. In direct energy use of primary wood resources competitiveness can be increased by reducing the feedstock supply costs with development of technology, working methods, logistics and infrastructure. Industries concentrating on refining the higher value added wood energy commodities have probably less influence on the price of available raw material. In this case the profitability needs to be created by adding value to the final product with technological innovations and global markets.
Agricultural biomass

Agricultural biomass demand is sensitive not only to supply potentials, but also to total energy demand and competitiveness of alternative energy supply options. In the future, a rationalisation of agriculture, especially in developing countries, is necessary to satisfy and compensate the growing demand for food.

Bioenergy from agriculture is today mainly used for biofuels in the transport sector. The focus within this study was not on biofuels for transport, but considered woody/ligno-cellulosic biomass, cropping residues and residues from livestock. Biomass from ligno-cellulosic energy crops can contribute to primary energy supply in the short term in heat and electricity applications, in the long term for biofuels.

Perennial energy crops are an alternative to conventional forestry to increase biomass production. Short rotation coppice can fill the gap between the demand for biomass and the current supply. The cropping area of cellulosic energy crops has increased steadily but cellulosic energy crops are very unevenly distributed over the EU countries. It is assumed that in 2030 perennial crops cultivated in the EU would be 50 times as much as 2011. Cropping with perennials will remain underutilized domestic sources because at the domestic prices they can hardly compete with imported resources. Stricter sustainability criteria will increase the demand for residues, waste and perennials. This will create a larger demand for ligno-cellulosic materials which is likely to lead to larger utilization of domestic wastes and cropped biomass. Therefore the development and deployment of perennial crops (in particular in developing countries) are important in case of a bioenergy use in the long run. Furthermore, the supply systems must be adapted to local conditions, e.g., for specific agricultural, climatic, and socio-economic conditions.

Cropping residues are determined by crop type and yields. The quantity amount of crop residues that can be removed from the field without significantly affecting soil fertility is debated and depends largely on regional conditions. Therefore the potentials vary within EU-countries. Nevertheless, cropping residues are an attractive resource with high potentials for future use. Agricultural and forestry residues could fulfil more than half of the biomass demand, followed by wastes and perennial crops. A significant amount of agricultural residues can be expected to be available for energy purposes in 2020, most of them from cereal straw. Energy crops are expected to be able to meet the major part of the increasing biomass demand.

From a global point of view an increasing demand for agricultural resources enhanced the competition of land use. To cover the global demand and to achieve global bioenergy targets in the longer term efforts need to be directed at increasing yields and modernizing agriculture especially in regions such as Africa, Far East and Latin America. Avoiding land pressure and food insecurity the global supply should be encouraged using residues and wastes.

Biogenic waste

An overall figure of the current EU supply and demand of biogenic waste for energy production and material uses is not possible to estimate due to much uncertainty around data quality and the coverage of the biodegradable waste statistics. When available, estimates per type of biodegradable waste stream are provided.

The greatest amount of available waste comes from food waste and paper and cardboard waste. The availability of the different categories of waste is linked to the size of each Member State – for example, major producers of paper and cardboard waste are the UK, Germany, France and Italy.
Given the increasing recycling rates for most of municipal and food waste sub-categories taken into account in the present study, it is estimated that the availability of biogenic waste for energy production will be decreasing over time.

The competition between the use of the various streams of biogenic waste for material purposes or for energy production is increasingly apparent and depends on the profitability of either of those activities. Composting, as opposed to energy production, is a major material use of the biomass fraction of mixed municipal waste, as well as of food waste. In addition, recycling of paper and cardboard waste is prioritized in the EU waste hierarchy and currently virtually all waste and cardboard paper are reused for recycling.

A full assessment of intra- and extra-EU trade flows of the different biological fractions of municipal solid waste and of food waste is not possible due to lack of data. However, trade flows seem to be very limited, as not profitable, either because of the low energy content-ratio (i.e. food waste, green waste, dried sewage sludge) or because of the physical properties of some waste categories (i.e. wood debris is bulky) which make them non feasible for transport. Thus the changes in supply and demand of biogenic waste in other regions of the world are unlikely to have major effect in the EU.

Since biogenic waste would not constitute final commodity sold to end-users, all information available has been classified as a cost, instead of a price. The cost among the different categories of biogenic waste varies widely, but in several cases is identical for all Member States (i.e. paper and cardboard, green waste, and sewage sludge).
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Study on Impacts on Resource Efficiency of Future EU Demand for Bioenergy

Task 2: Analysis of impacts of biomass production on natural resources and the global environment
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1. Summary

Impacts of the energetic use of wood on natural resources and the global environment are manifold. While many studies have examined land use change emissions associated with biofuels, fewer studies can be found that assessed implications (mostly GHG emissions) of increasing the use of wood for biofuels and for heat and power compared to alternative uses of the wood.

The aim of the literature review is to provide an in-depth analysis of the potential impacts of the energetic use of wood, and its possible increase, on natural resources and the global environment, namely biodiversity, soils, water bodies, greenhouse gas emissions and indirect land use effects.

The literature review for environmental and economic impacts (both positive and negative) covers the impacts on biodiversity, soil, water, GHG-emissions, land use and indirect effects and economic impacts. A set of 40 references was considered relevant after categorization from an initial list of 202 references. Furthermore, nine references have been reviewed regarding measures and instruments related to the cascading use of biomass.

The main results from the literature review are:

- From a biodiversity perspective the review showed that two aspects are of high relevance: a) the protection of areas with high biodiversity value and b) sustainable extraction rates of dead wood, residues, stumps and old trees.
- The review showed that most soil impacts are very site specific and require respective soil conservation measures (e.g. restriction on residue and stump extraction)
- The identified impacts on water are of lower relevance compared to e.g. impacts on biodiversity and soil (focus on rain-fed systems).
- Strong impacts on greenhouse gas emissions from biomass production occur when areas of high carbon stock are converted to bioenergy plantations of low carbon stock, but also an increase of wood extraction, including whole tree harvest and residue extraction, can lower the carbon stock of forests.
- Indirect effects and also economic impacts are mainly related to competition between different biomass uses (energy, material) and occur for biomass resources that can potentially be deployed for different uses e.g. stem wood. Such effects are limited for the use of branches, stumps and residues.
- The most central issues and proposed methods for increasing cascading are the need for clear definitions of cascading use over the whole biomass lifecycle; imposition of taxes, subsidies and legal measures to promote cascading use; and cross-disciplinary dialogue for developing more efficient logistical and technological solutions in different cascading stages.
2. Introduction

The ‘Roadmap to a Resource Efficient Europe’\(^1\) and ‘Roadmap for moving to a competitive low carbon economy in 2050’\(^2\) of the European Commission identify land use and the food sector, beside the housing and mobility sectors, as key domains for effective restructuring and climate change mitigation. Relevant for the land use sector, the Resource Efficiency Roadmap requests e.g. the restoration of ecosystems and of biodiversity, an increase of soil carbon contents, and prevention of soil erosion. Also, the Resource Efficiency Roadmap refers indirectly to the land use sector by encouraging the substitution of carbon intensive materials e.g. in chemistry and construction by bio-products.

However, there is a challenge in regard of the overall outcome regarding net GHG emissions and efficient use of resources if individual policies and strategies impacting on land use, biomass production, trade and use are not integrated. Furthermore, impacts on other ecosystem services, competing sectors and triggered feedback mechanisms across sectors and economic actors is not appropriately quantified and understood. The poor understanding of these issues is due to the complex nature of global land use and due to the fact that the land use sector is closely connected to other sectors. Measures directly targeting this sector have implications on others and vice versa.

The impacts of biomass use on GHG emissions and associated land use and land use change are among the more researched biomass impacts. They were already studied in the 1990s (e.g., Leemans et al. 1996; Marland and Schlamadinger 1997) when direct land use change effects were also considered in life cycle assessments (LCA) studies. Most studies addressed land use change emissions associated with biofuels (e.g., Gibbs et al., 2008; Searchinger et al. 2008). However, some assessed also implications (mostly GHG emissions) of increasing the use of solid biomass for biofuels (Forström et al. 2012, Havlík et al 2011) and for heat and power (Cherubini 2010; Latta et al. 2013; Gerssen-Gondelach et al. 2014) compared to alternative uses of the wood (Böttcher et al. 2012; Matthews et al. 2014a). These impacts include trade-offs and synergies. The key challenge in the assessment of direct and indirect effects is the delineation of system boundaries and the development and application of appropriate methods and metrics to assess impacts within those.

Besides GHG emissions, other effects need to be considered when evaluating the impacts of biomass use and its expansion such as the potential loss of biodiversity and habitats or effects of cropland intensification and nutrient losses (IINAS/EFI/JR 2014). Some studies have explored the impact of biofuel production on biodiversity (Britz and Hertel 2009, Eggers et al. 2009, Hellmann and Verburg 2010). These impacts include trade-offs and synergies. There are many examples where existing land management is sub-optimal, resulting in various forms of desertification or degradation including wind and water erosion, sedimentation of rivers, rising groundwater levels, groundwater contamination, eutrophication of rivers and groundwater or loss of biodiversity. In several cases, the increased efficiency in biomass production may result in an improvement in overall land management (Smith et al. 2013).

The objective of this project (“Study on the Impacts on resource efficiency of future EU demand for bioenergy”) is to investigate and assess the resource efficiency and implications of different future scenarios of increased use of bioenergy for electricity

\(^1\) COM/2011/0571/final
\(^2\) COM/2011/0112/final
and heat in the EU, including impacts on natural resources and on the environment and also indirect impacts of increased use. For the purpose of this study, "biomass" is defined as all kinds of cellulosic material from existing forestry operations, new plantations, short rotation coppice, dedicated crops, plus organic residues or waste used as a material or for energy.

2.1. Aim and methodology of Task 2

The aim of the literature review is to provide an in-depth analysis of the potential impacts of biomass production, and its possible increase, on natural resources and the global environment. The review focuses on quality, applied methodological approaches, and coherence between studies. Also shortcomings and limits of existing studies are subject to the review. This literature review is not a stand-alone product. A central aim is to provide a scientific balanced base for further work under Task 3 (modelling) and Task 4 (analysis of impacts).

The literature review for environmental and economic impacts (both positive and negative) covers the impacts on biodiversity, soil, water, GHG-emissions, land use and indirect effects and economic impacts. Each impact category is sub-divided in detailed impacts, e.g. soil erosion, soil carbon loss, soil compaction, soil nutrient loss and soil salinization for the category soil (see details in Appendix 1). Relevant references are selected from a list of potentially suitable references. Each selected reference is screened for the mentioned impact categories as well as the cause of impact and the suggested response. In total 40 references out of a list of 202 references have been covered.

Beside the analysis on the above mentioned impacts this literature review also covers a review of measures and instruments promoting the cascading use of biomass. For this topic much less references are available compared to environmental and economic aspects. In total nine references have been covered in the review. The references have been screened for measures and instruments related to the cascading use of biomass.

2.2. Use of the assessment within the project

The main outcome of the literature review is an evaluation of the (positive and negative) impacts most relevant to the scope of the study. Based on this, a set of impacts to be incorporated into the modelling work carried out under Task 3 have been proposed. These results will be further considered when developing the methodological framework of the modelling work e.g. as constrains in scenarios (Task 3.1).

Furthermore under task 3.1, the outcome of the literature review is used to develop sustainability indicators that can be linked with model output and thus be considered in the analysis of the impacts under Task 4. Here quantitative indicators directly calculated in the model framework, qualitative indicators derived from model outputs and from the literature review are used.

2.3. Overview of the structure of the report

Each environmental and economic impact as well as cascading use of biomass is covered in a single section. Following a short introduction, impacts from the use of biomass are reviewed for each topic separately to understand:

- impacts of biomass production and its increase;
• impacts of conversion, transport and use of biomass.

The review also includes responses to the impacts suggested in the reviewed references.

Following this review, conclusions are drawn about which identified impacts should be covered in the modelling framework. Furthermore we indicate how these impacts could be implemented and which datasets might be suitable for this work.
3. Biodiversity

Habitat loss as a result of land-use change is the major threat to biodiversity, with over 80% of globally threatened birds, mammals, and amphibians affected wholly or in part by habitat loss. Other prominent factors causing the decline of biodiversity are habitat fragmentation and isolation, land-use intensification and overexploitation, species invasions, and adverse climate-change impacts (see overview in Hennenberg et al. 2010).

The use of biomass for energy purposes can be one driver causing loss of biodiversity linked primarily to direct and indirect land-use change and increasing intensity of land use. The increasing use of biomass is likely to increase this pressure, with the exception that the increase of biomass extraction is embedded in biodiversity protection measures. In consequence, regulations and international agreements in the context of the energetic use of biomass (e.g. RED 2008, GBEP 2011) as well as voluntary certification systems (e.g. FSC, PEFC, RSB) address the protection of biodiversity.

The screening of literature carried out in this project focussed on the following detailed impacts: loss of species, loss of ecosystems, damage of flora and fauna and loss of ecosystem functions.

3.1. Impacts from the use of biomass on biodiversity

3.1.1. Impacts of biomass production and its increase

An overview of impacts addressed by studies and identified in the in-depth review is summarised in Table 3-1. First of all, the loss of areas with high biodiversity value is mentioned as an important impact that can follow unsustainable biomass production. In consequence, the protection of valuable areas is of high importance, including existing protected areas as well as valuable areas without a protection status (GBEP 2011, OEKO/IFEU/CI 2010, Berndes et al. 2013, Gove et al. 2010; see possible response in Table 3-1). These areas shall be completely excluded from biomass production or the land use shall be adopted in a manner that the protection goal can be achieved.

Beside protection of areas with a high biodiversity value, sustainable cultivation practices are needed that increase or at least preserve habitat quality, especially for rare, threatened and endangered species. A central negative impact on biodiversity from forest management is due to a low amount of dead wood in intensively managed forest ecosystems as habitat features for saproxylic organisms. Negative impacts can be further caused by the removal of logging residues (fine and course woody debris), whole tree harvest and the extraction of large dead wood (Müller and Bütler 2010, Abbas et al. 2011, Bouget et al. 2012, Fernholz et al. 2009, Tuomasjukka et al. 2014, Baral and Malins 2013, Verkerk et al. 2011, Hart et al. 2013). Regarding possible responses, Müller and Bütler (2010) stress the importance of heterogeneity of dead wood for the protection of biodiversity. From their literature review they derived threshold values to guarantee a sufficient amount of dead-wood and dying trees with respect to the protection of biodiversity including all dead wood fractions (peak-dead wood-values at 20–30 m³ ha⁻¹ for boreal coniferous forests; 30–40 m³ ha⁻¹ for mixed montane forests; 30–50 m³ ha⁻¹ for lowland oak–beech forests; see Müller and Bütler 2010). Furthermore the extraction of rare dead wood fractions like large dead wood should be avoided (Fernholz et al. 2009), residue harvesting in stands with high ecological values should be excluded and large scale extrapolation should be avoided (Bouget et al. 2012; see also Tuomasjukka et al. 2014). Such aspects should be
included in site and resource specific management guidelines (Abbas et al. 2011, Hart et al. 2013, Baral and Malins 2013) or active measures against high biomass removal should be undertaken (Verkerk et al. 2011). Nevertheless, the production of forest biomass may affect the forest biodiversity positively (e.g. management of neglected forests; wood extraction to achieve nature protection goals).

The extraction of stumps can negatively impact biodiversity due to the loss of microhabitats found in stumps (Bouget et al. 2012, Moffat et al. 2011). In consequence, Bouget et al. (2012) advise as response to avoid large scale exportation of stumps as well a prohibition of stump extraction in areas with high ecological value. The identification of sensible areas should occur by a risk assessment on a site level (Moffat et al. 2011).

Old and dying trees show rare habitat features in managed forest (Bouget et al. 2012, Hart et al. 2013). Harvest of these trees should also be avoided, especially those of broad-leaved tree species (Bouget et al. 2012, see also Tuomasjukka et al. 2014).

Another aspect that was less prominent in the reviewed literature is the negative impact on biodiversity that can occur from invasive species, including tree species, cultivated for bioenergy use. These species should be avoided because they can spread out and can cause uncontrollable impacts outside of the production area (GBEP 2011).

The detailed impact “loss of ecosystem functions” was not explicitly mentioned in the reviewed references. However, it is well known that impacts like loss of species and ecosystems can directly result in a loss of ecosystem functions (e.g. Groom et al. 2006).

With regard to impacts of short rotation coppice (SRC) on biodiversity, the effects can be positive as well as negative. A differentiation among animal groups, previous land use, spatial structures and ecological conditions of SRCs is needed. For example, short rotation coppice, short-rotation forestry and Miscanthus appear to support a higher abundance and diversity of bird species than arable or improved grassland (Gove et al. 2010).

In addition, the respective landscape concerns need to be considered (Dimitriou et al. 2011). However, the cultivation of SRC on former intensively managed cropland is likely to show positive impacts on biodiversity while impacts tend to be negative on high biodiversity agricultural lands (Berndes et al. 2013).

<table>
<thead>
<tr>
<th>Cause of impact</th>
<th>Possible response</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Loss of ecosystems – Valuable area (including areas with high biodiversity value)</strong></td>
<td></td>
</tr>
<tr>
<td>Degradation of valuable areas, protected areas, fragmentation, missing buffer zones, use of invasive species (OEKO/IFEU/CI 2010)</td>
<td>Scheme for mapping relevant areas, prior use of uncritical unused-land and making use of biodiversity friendly cropping methods (e.g. next to protected areas) (OEKO/IFEU/CI 2010)</td>
</tr>
<tr>
<td>Conversion of areas of high biodiversity value or critical ecosystems to areas of bioenergy production (GBEP 2011)</td>
<td>Not specified</td>
</tr>
<tr>
<td>Deforestation (Forestry Commission Scotland 2009)</td>
<td>Creation of forest habitat networks and new native woodlands (Forestry Commission Scotland 2009)</td>
</tr>
<tr>
<td>Outcome</td>
<td>Recommendation</td>
</tr>
<tr>
<td>------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Replacement of native woodland or other biodiversity-rich habitats by energy crops (Gove et al. 2010)</td>
<td>Not specified</td>
</tr>
<tr>
<td>High volumes of timber and biomass harvested in more intensive forest management systems (Hart et al. 2013)</td>
<td>Not specified</td>
</tr>
<tr>
<td>Loss of biodiversity due to SRC cultivation if land already has a high biodiversity level (Berndes et al. 2013)</td>
<td>No SRC on high biodiversity agricultural lands (Berndes et al. 2013)</td>
</tr>
<tr>
<td>Short-rotation forestry and Miscanthus more likely to be colonized by species of disturbed or edge habitats, whereas woodland specialists are unlikely to establish without deliberate encouragement (Gove et al. 2010)</td>
<td>Re-introduction of traditional forestry management techniques, such as coppicing, and better use of our forestry resources (Gove et al. 2010)</td>
</tr>
<tr>
<td>Biomass crops such as SRC, short-rotation forestry and Miscanthus appear to support a higher abundance and diversity of bird species than arable or improved grassland (Gove et al. 2010)</td>
<td>No specification</td>
</tr>
</tbody>
</table>

**Loss of species – Stumps**

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stump harvest as stumps show often microhabitats for rare species (Bouget et al. 2012);</td>
<td>No stump harvesting in stands with high ecological values, avoid large scale extrapolation (Bouget et al. 2012)</td>
</tr>
<tr>
<td>Loss of species that depend on dead wood and microhabitats in stumps (Moffat et al. 2011)</td>
<td>Careful assessment of risk at a site (Moffat et al. 2011)</td>
</tr>
</tbody>
</table>

**Loss of species – Dead wood / Residues**

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absence of a sufficient amount of dead wood / dying trees as dead and dying trees have been shown to be a key habitat feature for a broad range of saproxylic organisms (Müller and Bütler 2010)</td>
<td>Guarantee an amount of dead-wood /dying trees above threshold value. (summary: peak-dead wood-values at 20–30 m³ ha⁻¹ for boreal coniferous forests, 30–40 m³ ha⁻¹ for mixed montane forests, and 30–50 m³ ha⁻¹ for lowland oak–beech forests. Beside the amount of dead wood its heterogeneity is of importance (Müller and Bütler 2010)</td>
</tr>
<tr>
<td>The removal of coarse and fine woody debris has an influence on maintaining ecosystem wildlife and biodiversity habitat resources (Abbas et al. 2011)</td>
<td>Site and resource specific management guidelines (Abbas et al. 2011)</td>
</tr>
<tr>
<td>Loss of habitats for deadwood specialists by removal of logging residues (fine and course woody debris) and whole tree harvest (Bouget et al. 2012)</td>
<td>No residue harvesting in stands with high ecological values, avoid large scale extrapolation (Bouget et al. 2012)</td>
</tr>
<tr>
<td>Loss of large dead wood (Fernholz et al. 2009)</td>
<td>No harvest of large dead trees (Fernholz et al. 2009)</td>
</tr>
<tr>
<td>The lack of dead and decaying wood is threatening many forest species and renewable energy targets are increasing that threat (negative effects on beetles, shrubs, structural diversity of tree, mosses, liverworts; positive effects on diversity of trees and small mammals) (Tuomasjukka et al. 2014)</td>
<td>Concentrate conservation efforts on areas where biodiversity still rich; care to be taken with energy wood harvesting near nature reserves, retain old living and dead trees especially deciduous oak, lime and aspen (Tuomasjukka et al. 2014)</td>
</tr>
<tr>
<td>Removal of forest residues (Baral and Malins 2013)</td>
<td>Adoption of best harvesting practices. A certain portion of residues should be left behind to ensure the adequate species abundance and diversity(Baral and Malins 2013)</td>
</tr>
</tbody>
</table>
Extracting forest biomass for energy production may result in loss of deadwood and hence biodiversity (Verkerk et al. 2011) 

Undertaking active measures taken against high biomass removal (Verkerk et al. 2011) 

Harvesting and extraction of forest residues and dead wood (Hart et al. 2013) 

Protection or management of forest with the purpose of constraining harvesting activities (Hart et al. 2013) 

### Loss of species – Habitat trees 

<table>
<thead>
<tr>
<th>Description</th>
<th>Implications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harvest of old / dead / dying trees that are habitats for deadwood specialists (Bouget et al. 2012)</td>
<td>No harvest of habitat trees, especially of broad leave trees (Bouget et al. 2012)</td>
</tr>
<tr>
<td>Selection and specialisation of forest tree species to fewer types (Hart et al. 2013)</td>
<td>Not specified</td>
</tr>
</tbody>
</table>

### Biodiversity – Damage of flora and fauna 

<table>
<thead>
<tr>
<th>Description</th>
<th>Implications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Due to invasive species (GBEP 2011)</td>
<td>Not specified</td>
</tr>
<tr>
<td>Miscanthus crop plants provided less insect food than wheat crop plants (Bellamy et al. 2009)</td>
<td>Management for wildlife (Bellamy et al. 2009)</td>
</tr>
<tr>
<td>Modifications to stubble heights and straw management in-situ which could reduce cover for small farmland birds and increase their predation risk (IEEP et al. 2010)</td>
<td>Increased planting of cover crops as part of an optimised crop rotation that provide alternative winter fodder ground for birds (IEEP et al. 2010)</td>
</tr>
</tbody>
</table>

#### 3.1.2. Impacts of conversion, transport and use of biomass

The selected references did not address impacts on biodiversity from the conversion, transport and use of biomass. This can be interpreted as the fact that such impacts are of minor importance compared to impacts occurring from biomass production. Impacts on biodiversity from conversion, transport and use of biomass often occur as “co-impacts” to other aspects like pollution of waterbodies or soil degradation.

#### 3.2. Proposals to address biodiversity impacts in the modelling framework

From a biodiversity perspective the review showed that two aspects are of high relevance and it is proposed to cover them in in the modelling framework:

1. The protection of areas with high biodiversity value  
2. Sustainable extraction rates of dead wood, residues, stumps and old trees

The first aspect could be implemented by the exclusion of already known valuable areas like protected areas (e.g. World Database on Protected Areas), primary forests (e.g. Forest Intact Landscape) and peatland areas (Harmonized World Soil Database, GLC 2000) from biomass production. Furthermore, the overlay of maps on the distribution of rare and threatened species from different species groups can be used to derive areas of high biodiversity value that are currently not protected (e.g. UNEP-WCMC biodiversity atlas; compare Table 3-2). These areas may also be excluded from biomass production. Mapping initiatives for rare and endangered species (e.g. Key Biodiversity Areas, Important Bird Areas, Important Plant Areas, Alliance for Zero Extinction), however, appear not to be easily usable in this project as they are not globally available and they are not freely available.
Sustainable extraction rates (point 2) for dead wood, residues, stumps and old trees should to be specific to forest types and regions. A differentiation between boreal, temperate, sub-tropical and tropical forests appears reasonable. The models applied by IIASA differentiate between stem wood, branches and stumps. Harvesting rates of these fractions should be set to a level as to assure a sufficient amount of dead wood. Given that adverse effects are clearly site and management specific in nature, these can be minimized through site-specific forest guidelines and best practices in forest management. These already exist in a number of EU Member States (as well as in third countries) and include for instance the type and amount of logging residues that should be left in the forest for biodiversity reasons (guidelines in Sweden suggest a 20% retention level, in Finland 30% and in the US state of Minnesota 20%).

The challenge is the selection of suitable thresholds that can be used in the model work. Thresholds for the extraction of dead wood could follow the results from Müller and Bütler (2010), e.g. leaving 30 m$^3$ ha$^{-1}$ stem wood as dead wood and old trees in boreal coniferous forests. Less concrete responses found in the literature like the avoidance of large scale exportation of stumps (Bouget et al. 2012) need to be translated in reasonable thresholds, e.g. a maximum of 10% stump extraction.

Negative impacts from invasive species are difficult to address in models as the impacts will not occur on the production area. However, the yields implemented in IIASA models are based on native species for each region. This means that the models assume no cultivation of invasive species that may show higher productivity compared to native once.

Similarly, the cultivation of genetic modified organisms (GMO) may cause negative impacts on biodiversity outside of the cultivation area. GMO may show higher yields or may require less inputs compared to non-GMO that, e.g., may result in lower GHG-emissions in an LCA. However, this assessment is out of the scope of the applied models.

<table>
<thead>
<tr>
<th>Area type</th>
<th>Dataset to be used</th>
<th>Specifications</th>
<th>Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protected areas</td>
<td>World database on protected area NATURA 2000</td>
<td>Category I-IV: No biomass extraction Category V-VI: Forestry allowed; normal land use on existing arable land and grassland</td>
<td></td>
</tr>
<tr>
<td>Primary forest</td>
<td>Intact forest landscape</td>
<td>No use and no conversion allowed of intact forest landscapes Link to corruption index for countries not respecting the rule?</td>
<td></td>
</tr>
<tr>
<td>Peat land</td>
<td>Harmonized world soil database GLC 2000</td>
<td>Category Histosol: no use</td>
<td></td>
</tr>
<tr>
<td>Area of high biodiversity value (including grassland and forests)</td>
<td>UNEP-UCMC biodiversity atlas</td>
<td>Selection depending on the number of endangered species from mammals, amphibians, birds, etc. on site; Restriction of site can be set like for protected areas, meaning no conversion, no use, use with yield restrictions.</td>
<td></td>
</tr>
</tbody>
</table>

These proposals are based on results from OEKO/IFEU/CI (2010). The suitability of datasets will be evaluated in more detail under Task 3 of this project.
4. Soil

The fertility of soil plays a key role in the potential and capacity of land for agricultural and forestry use, and soil degradation is the main impact that threatens these opportunities (UNEP 2014). Furthermore, soil performs numerous environmental functions such as storing, filtering and transformation of substances (nutrients, contaminants and organic carbon) and serving as a habitat for species.

The use of biomass may affect the degradation status of the soil, positively (e.g. increase of soil carbon) or negatively (increase of soil erosion). The protection of soil is already embedded in legislation (e.g. cross compliance regulation within the EU) and is part of standards like Forest Stewardship Council (FSC), Programme for the Endorsement of Forest Certification (PEFC) and Roundtable on Sustainable Biofuels (RSB) as well as the Global Bioenergy Partnership (GBEP) indicator.

Soil degradation can be caused by inappropriate land management – that can be avoided by soil protection measures (e.g. WOCAT 2007) – or by natural disturbance. Main factors causing soil degradation are soil erosion, soil carbon loss, compaction, nutrient loss, salinization (OEKO/IFEU/CI 2010), and these are covered as detailed impact categories in this report.

4.1. Impacts from the use of biomass on soil

4.1.1. Impacts of biomass production and its increase

Most negative impacts on soil from biomass use mentioned in the reviewed references are a result of unsuitable land management during production or harvesting of biomass (see Table 4-1).

Soil erosion mainly occurs at unsuitable sites (e.g. steep slopes; OEKO/IFEU/CI 2010, Moffat et al. 2011) or after strong disturbance such as exposing bare soil to water and wind after deforestation (Forestry Commission Scotland 2009, Turbe et al. 2010), less surface cover after residue extraction (Alexopoulou et al. 2010, IEEP et al. 2010) and especially after deep tilling and stump harvest (Fernholz et al. 2009, Turbe et al. 2010).

Soil carbon and soil nutrient loss are often directly associated with the loss of upper soil layers by soil erosion. Furthermore, the loss and gain of soil carbon strongly depends on cultivation measures. Intensive soil treatments in general increase the mineralisation of soil carbon (OEKO/IFEU/CI 2010, Alexopoulos et al. 2010), and soil disturbance from stump extraction can have strong effects (Moffat et al. 2011). The extraction of forest or agricultural residues (OEKO/IFEU/CI 2010, Alexopoulos et al. 2010, Hart et al. 2013, GBEP 2011) reduces the rebuilding of soil carbon. However, the cultivation of short rotation coppice can increase C sequestration in the soil when grown on agricultural soils previously grown with annual crops (Dimitriou et al. 2011). This should also be the case for other perennial species.

Soil nutrient loss is mainly associated with the extraction rate of biomass and can reduce soil fertility mainly in case of pure soils (Bouget et al. 2012, Fernholz et al. 2009, Hart et al. 2013, Tuomasjukka et al. 2014, Aherne et al. 2011, Baral and Malins 2013). In forests the removal of wood parts containing high contents of nutrients, e.g. logging residues (fine and coarse woody debris) and whole tree harvest are of high importance (Bouget et al. 2012). Tuomasjukka et al. (2014) state that minor increases in harvesting of residues may causes major increase in nutrient loss from a site. Nutrient loss with stumps is of lower relevance, but the removal of nutrient-rich
soil attached to the tree root plates can show strong impacts (Moffat et al. 2011). Furthermore nutrient load in run-off water can increase after root and stump extraction (Moffat et al. 2011).

Soil compaction is mainly caused by inappropriate use of machinery on vulnerable soils or under wet conditions (OEKO/IFEU/CI 2010, Hart et al. 2013, Turbe et al. 2010). Soil compaction can occur in a similar manner on forest or agricultural land. Salinization is mainly a result of inappropriate irrigation, often occurring in arid regions on arable land (OEKO/IFEU/CI 2010, Turbe et al. 2010). Most forest land is not irrigated and salinization is unlikely. Further impacts are the disturbance of soil structure by stump extraction (Moffat et al. 2011) and the reduction of soil functionality (including upper mentioned aspects) by the extraction of residues like straw on agricultural sites (IEEP et al. 2010).

The responses suggested in the reviewed references on impacts on soil erosion, nutrient loss and carbon loss are rather similar (see Table 4-1). Agricultural cultivation and harvest of tree and forest residues should be adapted to site conditions (categorising risk classes) and suitable soil protection measures should be applied according to a sound risk assessment. Appropriate soil protection measures will vary depending on the local and given soils character, but include, e.g., reduced tillage, cap on biomass and residue extraction rate, surface cover, green cover over the winter period, mulching, interception of rainfall and rooting systems. In many cases a soil protection measure addresses several impacts, e.g. mulching reduces the erosion risk, improves the soil carbon content and favours the nutrient cycle.

With regards to stumps and forest residues Fernholz et al. (2009) propose to forbid residue harvest on rocky, dry, poor soils and open swamps and stump harvest in addition on steep slopes and from riparian areas. On other harvest sites stumps with a diameter larger 15cm should not be extracted and no more than 30% of residues should be harvested (Fernholz et al. 2009).

Looking at soil nutrient loss, site-adapted extraction rates and avoiding of large-scale harvests are proposed (Bouget et al. (2012), and needles and leaves should stay on site (Aherne et al. 2011). However, intensive harvesting does not necessarily lead to reduced soil nutrient stocks as effects are site specific (Tuomasjukka et al. 2014). The application of wood ash may also compensate for the nutrient losses (Hart et al. 2013).

Table 4-1 Cause of impact on soil from biomass production and possible response found in literature

<table>
<thead>
<tr>
<th>Cause of impact</th>
<th>Possible response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil erosion</td>
<td>Insufficient land management (step slops, no soil protection measures applied) (OEKO/IFEU/CI 2010)</td>
</tr>
<tr>
<td></td>
<td>Soil protection measures, e.g. soil cover, perennial crops, row cultures, wind breaks and quota of residue use (OEKO/IFEU/CI 2010)</td>
</tr>
<tr>
<td></td>
<td>Increase of soil erosion on slopes due to soil disturbance (Moffat et al. 2011)</td>
</tr>
<tr>
<td></td>
<td>Careful assessment of risk at a site, categorizing soil types in risk classes (Moffat et al. 2011)</td>
</tr>
<tr>
<td></td>
<td>Soil disturbance due to stump harvest (Fernholz et al. 2009)</td>
</tr>
<tr>
<td></td>
<td>Stumps should not be harvested on steep slopes, from riparian areas and on rocky, dry, poor soils and open swamps. No extraction of stumps with a diameter larger than 15cm (Fernholz et al. 2009)</td>
</tr>
<tr>
<td></td>
<td>Unsuitable cropping management activities and crop characteristics, including residue extraction (Alexopoulou et al. 2010, IEEP et al. 2010)</td>
</tr>
<tr>
<td></td>
<td>Soil protection measures (interception of rainfall, surface cover, rooting system, particularly green cover over the winter period, leave residues on the soil) (Alexopoulou et al. 2010)</td>
</tr>
<tr>
<td><strong>Deforestation (Forestry Commission Scotland 2009)</strong></td>
<td>Creation of forest habitat networks and new native woodlands (Forestry Commission Scotland 2009)</td>
</tr>
<tr>
<td>-----------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Deforestation, exposing bare soil to water and wind, the use of deep tillage (Tuomasjukka et al. 2014)</td>
<td>No specification</td>
</tr>
</tbody>
</table>

### Soil carbon loss

<table>
<thead>
<tr>
<th>Insufficient land management (high biomass extraction rate, intensive soil treatments) (OEKO/IFEU/CI 2010, Alexopoulos et al. 2010)</th>
<th>Soil protection measures, e.g. reduced tillage, cap on biomass and residue extraction rate, surface cover, mulching, interception of rainfall, rooting system (OEKO/IFEU/CI 2010)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase of carbon loss due to increased mineralisation of carbon after soil disturbance due to stump extraction (Moffat et al. 2011)</td>
<td>Careful assessment of risk at a site, e.g. categorizing soil types in risk classes (Moffat et al. 2011)</td>
</tr>
<tr>
<td>Negative or positive soil C balance of bioenergy feedstock (Don et al. 2012)</td>
<td>Plant and soil specifics should be compared to previous use of land (Don et al. 2012)</td>
</tr>
<tr>
<td>Loss of soil carbon due to intense biomass extraction and/or cultivation or missing of soil protection measures (GBEP 2011)</td>
<td>Application of soil conservation measures, depending on soil degradation risk (GBEP 2011)</td>
</tr>
<tr>
<td>Depletion of soil organic carbon because of extraction of forest residues on sites with shallow soils (Hart et al. 2013)</td>
<td>Not specified</td>
</tr>
<tr>
<td>An increased C sequestration can be expected when SRC is grown on agricultural soils previously grown with conventional crops. However, the initial soil properties are responsible for the extent of C storage (Dimitriou et al. 2011)</td>
<td>Not specified</td>
</tr>
</tbody>
</table>

### Soil nutrient loss

<table>
<thead>
<tr>
<th>Removal of wood parts containing high contents of nutrients, e.g. logging residues (fine and coarse woody debris) and whole tree harvest (Bouget et al. 2012)</th>
<th>Site-adopted extraction rate, avoid large-scale harvest (categorizing soil types in risk classes) (Bouget et al. 2012)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Removal of nutrient-rich soil attached to the tree root plates; nutrient loss with stumps occurs, but is much lower compared to branches and steam wood; nutrient load in run-off water after root/stump extraction (Moffat et al. 2011)</td>
<td>Careful assessment of risk at a site (Moffat et al. 2011)</td>
</tr>
<tr>
<td>Extraction of nutrients by residue harvest (Fernholz et al. 2009)</td>
<td>No residue harvest on rocky, dry, poor soils and open swamps, and 30% of residues must be left on other harvest sites (Fernholz et al. 2009)</td>
</tr>
<tr>
<td>Depletion of nutrients because of extraction of forest residues on sites with shallow soils (Hart et al. 2013)</td>
<td>Application of wood ash to compensate for the nutrient losses (Hart et al. 2013)</td>
</tr>
<tr>
<td>Intensive harvesting will lead to decrease in soil nutrient status if not compensated for by management measures (Aherne et al. 2011)</td>
<td>Needles and leaves should stay on site, fertilisation of N and K and others as appropriate to ensure sustained forest growth (Aherne et al. 2011)</td>
</tr>
<tr>
<td>Removal of forest biomass decreases site nutrient stocks affecting e.g. the nitrogen cycling. Minor increase in harvesting residues may causes major increase in nutrient loss from a site (Tuomasjukka et al. 2014)</td>
<td>Intensive harvesting does not necessarily lead to reduced soil nutrient stocks. Effects are site specific (Tuomasjukka et al. 2014)</td>
</tr>
<tr>
<td>Loss of soil nutrients (removal of biomass) (Baral and Malins 2013)</td>
<td>Nitrogen fixation, atmospheric deposition or additional use of chemical fertilizers, organic manure, or ash (Baral and Malins 2013)</td>
</tr>
</tbody>
</table>
Soil compaction

In appropriate use of machinery depending on soil type and soil humidity (OEKO/IFEU/CI 2010)  
soil protection measures, e.g. crop choice (yield mass, rooting system), adapted machinery (weight, tires), considering weather conditions (OEKO/IFEU/CI 2010)

Use of heavy machinery for extracting biomass or trampling (particularly in wet soil, e.g. caused by poor drainage) (Hart et al. 2013, Turbe et al. 2010)  
Not specified

Soil salinisation

Inappropriate irrigation (OEKO/IFEU/CI 2010, Turbe et al. 2010)  
Irrigation measures, e.g. no irrigation on sensitive soils, use of water with low salt content for irrigation, use effective drainage systems (OEKO/IFEU/CI 2010, Turbe et al. 2010)

Other soil impacts

Disturbance of soil structure by stump extraction (Moffat et al. 2011)  
Careful assessment of risk at a site (Moffat et al. 2011)

Negative impacts from wood removal (Abbas et al. 2011)  
Retaining or leaving tree foliage and leaving up to 30% of residues in the field (Abbas et al. 2011)

Reduction of soil functionality due to the extraction of straw from agricultural areas (IEEP et al. 2010)  
Ploughing-in of cut straw following the cereal harvest to help maintain soil functionality (IEEP et al. 2010)

4.1.2. Conversion, transport and use of biomass

Impacts from conversion, transport and use of biomass on soil were not mentioned in the references covered in the literature review. However, soil contamination by pollutants from these processes may occur locally e.g. in case of non-routine operation.

4.2. Proposals to address soil impacts in the modelling framework

The review showed that most soil impacts are very site specific and require respective soil conservation measures. The amount of biomass extraction can be part of the soil conservation measure (e.g. mulching with straw, retaining nutrient cycle by leaving branches and leaves on site). Other soil conservation methods increase the possible extraction rate and create production costs (e.g. fertilisation with ash). Some soil conservation measures may only cause costs that are not directly visible in yields (e.g. adaption of machinery, windbreaks). Finally, specific soil conservation measures may lead to a lowering of the future yield developments (e.g. adoption of crop rotation to allow straw extraction).

From a modelling perspective the challenge is firstly to identify requirements that might be covered by area related restrictions in the model work:

1. Identification of exclusion areas where (i) no production is allowed at all and (ii) where no residue or stump extraction should occur (e.g. depending on steep slopes, poor soils (low soil organic content, low content of nutrients), wet soils)
2. Restriction of residue and stump extraction on all remaining areas
3. Lowering the development of yields (agriculture and intense forestry), i.e. assuming a lower annual yield-increase rate assuming stronger soil protection measures

A short overview of possible data sets that may be used for the implementation of soil restrictions in the model work are listed in Table 4-2.
Secondly, additional conservation measures of soils and their impact on production costs could be added and reflected upon in the economic model.

### Table 4-2  List of dataset to address sustainability impacts on soil

<table>
<thead>
<tr>
<th>Area type</th>
<th>Dataset to be used</th>
<th>SpecificationsStudy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biodiversity - loss of ecosystems</td>
<td>Global evaluation data sets for slope classes &quot;Global 30 Arc Second Elevation Data&quot; as used by G4M for estimating forest growth.</td>
<td>No biomass extraction on slopes &gt; 30%. No residue and stump extraction on slopes &gt; 15%.</td>
</tr>
<tr>
<td>Steep slopes</td>
<td>European soil database as harmonized for EU. Harmonized world soil database based on &quot;Soil map of the world&quot;.</td>
<td>Maximum 30% extraction of residues and stump on all sites. For EU, no extraction of residues and stump on land with stones &gt; 25% and Very fine texture. Globally, no extraction of residues and stump on land classified as stony.</td>
</tr>
</tbody>
</table>
5. Water and water pollution

The unsustainable management of freshwater resources is a key global environmental challenge to achieve human wellbeing (UN 2012, WWAP 2014) as well as the protection of ecosystems that depend on sufficient and clean water (CBD 2009). Freshwater is already scarce in some regions of the world, and existing freshwater resources are under heavy threat from overexploitation due to growing population and changing diets, pollution, energy demand and climate change. The agricultural sector in particular is responsible for about 70% of freshwater withdrawal worldwide (WWAP 2014).

The use of biomass for bioenergy can impact on freshwater resources mainly by an over-use of water resources, lowering of water table, and the pollution of water bodies (e.g. OEKO/IFEU/CI 2010).

5.1. Impacts from the use of biomass on water and water pollution

5.1.1. Impacts of biomass production and its increase

For biomass pathways under the focus of this study (solid biomass, short rotation coppice, lignocellulosic biomass, agricultural residues, etc.) impacts on freshwater are assessed to be much lower compared to impacts from arable crops for biofuels. Nevertheless, authors of the studies in this literature review highlight several impacts on water resources from the use of biomass that might be of interest within the model work.

The overuse of water resources and impacts on water tables (see Table 5-1) can occur from a high use of water for biomass cultivation (OEKO/IFEU/CI 2010, GBEP 2011), namely by irrigation in areas with water stress or by cultivating energy crops with high water demands (Alexopoulos et al. 2010). For example the evapotranspiration from short rotation coppice with willow and poplar is in most cases significantly higher than arable crops, but lower than conventional forests (Dimitriou et al. 2011, Don et al. 2012). In water scarce regions or regions with existing high water use a switchover to short rotation coppice may strengthen the water scarcity. To avoid such negative impacts of the cultivation of bioenergy crops on the local hydrological balance, authors of the reviewed reference suggest to consider plant species specifics when choosing species in arid and water scarce regions (Dimitriou et al. 2011) as well as mitigation options for irrigation (OEKO/IFEU/CI 2010). However, most bioenergy crops and especially forests grow under rainfed conditions and irrigation is of low relevance.

The main source of water pollution from agriculture and forestry is the use of fertiliser and pesticides (OEKO/IFEU/CI 2010, UNEP 2011, Alexopoulos et al. 2010, GBEP 2011, Baral and Malins 2013, Langeveld et al. 2012). Furthermore, high nutrient loads in run-off water can occur after stump extraction (Moffat et al. 2011), forest site preparation (Baral and Malins 2013) and intensive logging and residue extraction (Hart et al. 2013, Baral and Malins 2013). Possible responses include the reduced application of chemicals and adequate use of waste water from municipals and industries for irrigation (OEKO/IFEU/CI 2010) and innovative forms of integrated production (UNEP 2011) as well as careful assessment of risks at a site in case of stump extraction (Moffat et al. 2011).

Short rotation coppice is generally considered to improve the water quality relative to conventional agricultural crops due to the less intense management practices of SRC.
It is suggested to use short rotation coppice in intensively managed agricultural areas to improve the current water quality (Dimitriou et al. 2011).

An increased logging of forests can impact hydrological processes in a region (e.g. increased water run-off, retention and reduced water infiltration; Abbas et al. 2011, Tuomasjukka et al. 2014), and changes in lake water chemistry due to changes in water run-off chemistry can occur (Aherne et al. 2011). Tuomasjukka et al. (2014) reports a measurable and substantial negative response of intensive residue extraction in acid sensitive catchments in the boreal zone in medium term. Also high extraction rate of residues (e.g. straw removal) can decrease water filtration and increase evaporation (IEEP 2010). These impacts, however, may be addressed by management treatments considering local water cycle situations (Abbas et al. 2011) and by leaving a sufficient amount of leaves and residues in the forest (Aherne et al. 2011, IEEP 2010).

Table 5-1  Cause of impact on water from biomass production and possible response found in literature

<table>
<thead>
<tr>
<th>Cause of impact</th>
<th>Possible response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overuse of water resources and impact on water tables</td>
<td>Mitigation options in case of overuse of water (e.g. upgrading of soil moisture capacity, improvement of irrigation and water use efficiency, reducing water demand at other locations, water storage)(OEKO/IFEU/CI 2010)</td>
</tr>
<tr>
<td>Irrigation in areas with water stress (OEKO/IFEU/CI 2010)</td>
<td>Mitigation options in case of overuse of water (e.g. upgrading of soil moisture capacity, improvement of irrigation and water use efficiency, reducing water demand at other locations, water storage)(OEKO/IFEU/CI 2010)</td>
</tr>
<tr>
<td>High use of water for bioenergy production (cultivation) (GBEP 2011)</td>
<td>No specification</td>
</tr>
<tr>
<td>High water demand of selected energy crops (Alexopoulos et al. 2010)</td>
<td>No specification</td>
</tr>
<tr>
<td>Surface runoff and impact on groundwater recharge (Langeveld et al. 2012)</td>
<td>No specification</td>
</tr>
<tr>
<td>Reduce downstream water availability (Berndes et al. 2013)</td>
<td>No specification</td>
</tr>
<tr>
<td>Evapotranspiration from SRC fields with willow and poplar is in most cases significantly higher than arable crops but lower than conventional forest (site-specific variation possible) (Dimitriou et al. 2011)</td>
<td>Plant species specifics should be considered when choosing species, especially in arid regions (Dimitriou et al. 2011)</td>
</tr>
<tr>
<td>Increased use of water in comparison to agricultural crops (e.g. a 5% and 10% higher water consumption for Miscanthus and willow compared with wheat and permanent grassland). SRC have deeper roots than agricultural crops that enables them to use and deplete deeper groundwater resources, although this could be a disadvantage by affecting the local hydrological balance (Don et al. 2012)</td>
<td>No specification</td>
</tr>
<tr>
<td>Water pollution – land use</td>
<td>Mitigation options, e.g. reduced application of chemicals and adequate use of waste water for irrigation (OEKO/IFEU/CI 2010)</td>
</tr>
<tr>
<td>Washout/contamination from agrochemicals in case of high loads of nutrients and pesticides) (OEKO/IFEU/CI 2010)</td>
<td>Mitigation options, e.g. reduced application of chemicals and adequate use of waste water for irrigation (OEKO/IFEU/CI 2010)</td>
</tr>
<tr>
<td>Agricultural and forestry activities: The main sources of pollution are related to the use of pesticides and fertilizers (UNEP 2011)</td>
<td>Innovative forms of integrated production will prove the best way to avoid and mitigate impacts (UNEP 2011)</td>
</tr>
</tbody>
</table>
### High loadings of nutrients (N, P, K) and pesticides in water bodies (Alexopoulos et al. 2010, GBEP 2011, Baral and Malins 2013, Langeveld et al. 2012)

Not specified

### Nutrient load in run-off water after stump extraction can affect water bodies (Moffat et al. 2011)

Careful assessment of risk at a site (Moffat et al. 2011)

### Forest management activities (site preparation, harvesting) (Baral and Malins 2013)

Not specified

### Detrimental harvesting patterns (intensive logging, residue extraction) (Hart et al. 2013)

Not specified

### SRC is generally considered to improve the water quality relative to conventional agricultural crops in a given area due to the management practices of SRC (weed control only during the establishment phase, tillage only before the establishment phase, and lower inorganic fertilization than other crops) (Dimitriou et al. 2011)

Several authors suggest the use of SRC in intensively managed agricultural areas to improve the current water quality and meet EU obligations in terms of water quality expressed in the Water Framework (Dimitriou et al. 2011)

### Water – other aspects

| Hydrological process are impacted by tree removal: Reduced interception and reduced moisture storage results in more runoff in small streams and increased water yield; litter storage of water is impacted by changes in the amount of litter on-site; temporarily eliminating transpiration increases baseflow and soil moisture; reduced infiltration increases overland flow and storm flow, whereas increased infiltration decreases overland flow and increases base flow (Abbas et al. 2011) | A number of forest management guidelines have been developed to address these points. However, a number of them are very site specific and would be difficult to implement in a model. Furthermore, most hydrology guidelines recommend riparian areas, ditches, filter strips and water body protection. One though is that North American guidelines specify the avoidance of stump harvesting for utilization, except in woodland conversion sites (Abbas et al. 2011) |
| Increased demand for biomass for energy is increasing pressure on forests. Changes in harvesting levels has an influence on soil and lake water chemistry (Aherne et al. 2011) | Measures like: Needles and leaves to stay on site; fertilisation of N&K; ensure sustained forest growth (Aherne et al. 2011) |
| Decreasing water filtration and increasing evaporation due to high extraction rate of residues, e.g. straw removal (IEEP 2010) | Leaving cut residues on the surface of the soil (IEEP 2010) |
| Forest harvest influences interception, retention, cycling of water (delivery rates to surface waters and dynamics of aquatic systems) (Tuomasjukka et al. 2014) | Not specified |
| A measurable and substantial negative response of intensive residue extraction has been recorded in acid sensitive catchments in boreal zone in medium term (Tuomasjukka et al. 2014) | Not specified |

### 5.1.2. Conversion, transport and use of biomass

Main impacts conversion, transport and use of biomass on water mentioned in the reviewed references refer to the pollution of waterbodies from processed waste water and non-routine operation (OEKO/IFEU/CI 2010, GBEP 2011, UNEP 2011). Technological improvements on waste water treatment and the selection of uncritical location of plants are proposed to response to these impacts (OEKO/IFEU/CI 2010, UNEP 2011). Furthermore, a high use of water for bioenergy production may cause an overuse of water resources (GBEP 2011).
### Table 5-2 Cause of impact on water from conversion, transport and use of biomass and possible response found in literature

<table>
<thead>
<tr>
<th>Cause of impact</th>
<th>Possible response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overuse of water resources</td>
<td></td>
</tr>
<tr>
<td>High use of water for bioenergy production (conversion) (GBEP 2011)</td>
<td>No specification</td>
</tr>
<tr>
<td>Water pollution – conversion</td>
<td></td>
</tr>
<tr>
<td>Insufficient cleaning of process water / non-routine operation (OEKO/IFEU/CI 2010)</td>
<td>Mitigation options, e.g. improved waste water treatment and uncritical location of plants (OEKO/IFEU/CI 2010)</td>
</tr>
<tr>
<td>High loads of pollutants (manly organic substances) in waste water of bioenergy conversion plants (GBEP 2011)</td>
<td>Not specified</td>
</tr>
<tr>
<td>Agricultural and forestry activities: co-products (e.g. vinasse) from the industrial pathways of some feedstocks (UNEP 2011)</td>
<td>Future technologies, probably associated with bio-refineries, could incorporate better water quality management (UNEP 2011)</td>
</tr>
</tbody>
</table>

### 5.2. Proposals to address water impacts in the modelling framework

As mentioned above the identified impacts on water are of lower relevance under the scope of the project compared to e.g. impacts on biodiversity and soil, thus the implementation of impacts on water should be followed with lower priority.

Nevertheless, the most relevant impacts on water that might be considered in the model work are:

1. Avoid overuse of freshwater resources in water scarce regions
2. Avoid pollution of waterbodies from the application of fertilizer and pesticides
3. Avoid pollution of waterbodies from process waste water

The overuse of freshwater resources may be addressed by restrictions on irrigation for bioenergy crops in water scarce regions (see Table 5-3) as well as a cap on areas that could be used for short rotation coppice or other bioenergy crops characterised by high transpiration rates. Even regrowth of forests might be critical in such water scarce regions due to the even higher transpiration rate compared to short rotation coppice.

### Table 5-3 List of dataset to address sustainability impacts on water

<table>
<thead>
<tr>
<th>Area type</th>
<th>Dataset to be used</th>
<th>SpecificationsStudy</th>
</tr>
</thead>
</table>
| Biodiversity - loss of ecosystems | GLOBIOM endogenously estimated areas with high level of water scarcity. | In water scarce regions:  
- No irrigation (mainly agriculture)  
- Cap on the area used for short rotation copies |

The pollution of water bodies caused by fertilizer and pesticides could be mitigated by the reduction of their application. This could partly be achieved by optimising e.g. fertiliser application, but also a reduction of yields is likely in case of the reduction of inputs. The latter could be implemented in the model work by lowering the assumed yield development. Furthermore the reduction of nutrient loads in run-off water could
be addressed by mitigation options such as the restriction of residue and stump extraction rates already named for the protection of soil (see Section 4.2).

A reduction of the risk of water pollution from waste water would require higher investments in bioenergy conversion plants. However, in the modelling framework the demand of bioenergy is exogenously defined and the issue should as such be dealt with by POLES/PRIMES energy system models.
6. Greenhouse gas emissions

The reduction of greenhouse gas emissions (GHG) compared to fossil fuels is one important aim for the use of bioenergy (along with energy security and rural competitiveness and job creation), and GHG reductions from bioenergy compared to fossil fuels can be either positive or negative. Greenhouse gas emissions along bioenergy pathways are strongly dependent on each step along the production chain from land use to conversion, transport and use of biomass. Emissions from land use can be especially high in case of land use change (e.g. ploughing up grassland), and emissions from conversion, transport and use are influenced by parameters such as efficiency, transport distance and the avoidance of emission sources for methane and nitrous oxide in the process steps. Furthermore, the payback times when using forest products for bioenergy range from 0 to almost 500 years, depending on the reference (i.e. what is substituted e.g. coal), time horizon, site and species, etc. (Agostini et al. 2013). The review carried out focuses on three aspects: GHG emissions (incl. substitution effects compared to fossil fuels), change of carbon stock, and change of disturbance pattern.

6.1. Direct impacts from the use of biomass on greenhouse gas emissions

6.1.1. Impacts of biomass production and its increase

Significant negative impacts on greenhouse gas emissions from biomass production occur when areas of high carbon stock are converted to bioenergy plantations of low carbon stock (Hart et al. 2013, OEKO/IFEU/CI 2010, Forestry Commission Scotland 2009), but also an increase of wood extraction, including whole tree harvest and residue extraction, can lower the carbon stock of forests (Zanchi et al. 2012, Hart et al. 2013, Tuomasjukka et al. 2014, see Table 6-1). However, there are cases where long-term active forest management can increase biomass and timber production while still safeguarding the forest carbon stock at the landscape level (Berndes et al. 2013). Examples of such improvements range from the promotion of regeneration and silvicultural management to enhancing forest growth (through improved timing of pre-commercial cutting, thinning efforts, fertilization, etc.). Managing forests for products (energy and/or materials) can also determine higher GHG savings than suspending the management (Matthews et al 2014b), and an increase in woodfuel production may be occur after natural disturbances such as storms (Agostini et al. 2013).

Generation of bioenergy using stumps and roots may release more greenhouse gases into the atmosphere than are saved by their substitution for fossil fuels (Moffat et al. 2011). Also Vanhala et al. (2013) states that stump harvesting may decrease the soil carbon stock. However, empirical research on the magnitude of emissions from the use of stumps and roots in comparison to fossil fuels (positive or negative) is limited (Vanhala et al. 2013).

Furthermore, there is a debate concerning the timing of net GHG savings that occurs when biomass is used to replace fossil fuels. The core of this issue is that there is a time delay between emissions when woody biomass is burned and subsequent regrowth of the terrestrial C stock – the so-called "ecosystem carbon payback time". In particular when forests with long rotation periods are being used for energy purposes, there can be noted a strong temporal imbalance in the C dynamics between the time when the C is released into the atmosphere and later sequestrated again back into the forest (Zanchi et al. 2012, Berndes et al. 2013, EEA 2013a). However, under some forest use scenarios, the same argument applies when harvesting
residues and stumps for energetic use, inducing a direct emission of carbon in comparison to the slow decomposition in the field (Vanhala et al. 2013). The implication of this issue varies significantly when looking at a stand level or landscape level, and if a short or a long term time scale is considered (Berndes et al. 2013).

For agricultural residues ADAS (2008) states that straw incorporation is an inefficient method of sequestering carbon and that the removal of straw for burning would have an adverse effect on greenhouse gas emissions.

The possible responses found in the reviewed references can be grouped into two main aspects. Firstly, areas of high carbon stock should not be converted to production areas with lower carbon stock (OEKO/IFEU/CI 2010, Forestry Commission Scotland 2009). Secondly, a GHG-accounting method along the full production chain for forestry products should also cover the carbon sequestration rate of forests and the carbon being released when the mass of fuel is burned (Zanchi et al. 2012, Berndes et al. 2013), including changes in soil carbon (Vanhala et al. 2013). Threshold values for the reduction of GHG emissions in comparison to fossil fuels are of importance for the implementation in regulations like the RED (OEKO/IFEU/CI 2010).

**Table 6-1  Cause of impact on greenhouse-gas emissions from biomass production and possible response found in literature**

<table>
<thead>
<tr>
<th>Cause of impact</th>
<th>Possible response</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHG-emissions (incl. substitution effects compared to fossil fuels)</td>
<td></td>
</tr>
<tr>
<td>High GHG-emissions along bioenergy-pathway (OEKO/IFEU/CI 2010)</td>
<td>Threshold for GHG-reduction of bioenergy, based on GHG-methodology (live-cycle analysis) including CO₂-fixation, substitution of fossils, emissions from farming (fertilizer, pesticides, fuel), emissions from direct and indirect land-use change (OEKO/IFEU/CI 2010)</td>
</tr>
<tr>
<td><strong>UK example:</strong> (a) in a 40 year timeframe, CO₂ emissions are lower for suspended management forest than for forest managed for bioenergy only (b) managing the forest for products determines higher GHG savings than suspending the management (c) result depends on reference (what is substituted), time horizon, site and species, etc. (Matthews et al 2014b)</td>
<td>Not specified</td>
</tr>
<tr>
<td>Harvested material left in situ to decompose (including chipped wood) (ADAS 2008)</td>
<td>Not specified</td>
</tr>
<tr>
<td>Deforestation (Forestry Commission Scotland 2009)</td>
<td>Not specified</td>
</tr>
<tr>
<td>Removal of straw for burning would have an adverse effect on greenhouse gas emissions; straw incorporation is, however, an inefficient method of sequestering carbon (ADAS (2008))</td>
<td>Not specified</td>
</tr>
<tr>
<td><strong>GHG – Change of carbon stock and carbon depth</strong></td>
<td></td>
</tr>
<tr>
<td>Loss of carbon due to conversion of land with high carbon stock (OEKO/IFEU/CI 2010)</td>
<td>Exclusion of areas of high carbon stock (OEKO/IFEU/CI 2010)</td>
</tr>
<tr>
<td>Conversion of high carbon stocks forests to bioenergy plantations of low carbon stock (Hart et al. 2013)</td>
<td>Not specified</td>
</tr>
<tr>
<td>Increased harvesting intensity can reduce the level of carbon sequestered in particular forest stands (Hart et al. 2013)</td>
<td>Not specified</td>
</tr>
</tbody>
</table>
Generation of bioenergy using stumps and roots may release more greenhouse gases into the atmosphere than are saved by their substitution for fossil fuels (Moffat et al. 2011)

Careful assessment of risk at a site, e.g. categorizing some soil types in risk classes (Moffat et al. 2011)

Stump harvesting may decrease the soil carbon stock. However, empirical research on the magnitude of these emissions are rare (Vanhala et al. 2012)

Consider emissions from soil when harvesting of stump takes place (Vanhala et al. 2012)

Harvesting of residues and stumps and using them directly for energy induces a direct emission of carbon in comparison to the slow decomposition in the field (Vanhala et al. 2012)

Timing of carbon from decomposition of harvesting residues could possibly be considered in terms of a slow change in the soil carbon pool (Vanhala et al. 2012)

Burning biomass for energy is not carbon neutral as:
(a) there is a time delay between emissions and subsequent regrowth when woody biomass is burned;
(b) current harvesting levels might result in lowering the forest C stock (Zanchi et al. 2012)

An accounting approach could possibly be used to cover the carbon sequestration rate of forests and the carbon being released when the mass of fuel is burned (Zanchi et al. 2012)

Whole tree harvesting reduces soil C compared to stem only. Effects seen more frequently on forest floor than in mineral soil (Tuomasjukka et al. 2014)

Considerable variation in the observed response to harvesting of logging residues in soil and tree C (Tuomasjukka et al. 2014)

Growth enhancing measures (e.g. fertilization) and site preparation may increase productivity but may also lead to faster decomposition of soil organic matter (Berndes et al. 2013)

Not specified

Intensification in forest management has shown that stand management can increase C stock and biomass and timber production (Berndes et al. 2013)

Not specified

**GHG – Change of disturbance pattern**

An increase in woodfuel production may be attained with natural disturbances (Agostini et al. 2013)

Not specified

6.1.2. Conversion, transport and use of biomass

Single production steps along a bioenergy production chain may be responsible for high greenhouse gas emissions (ÖKO/IFEU/CI 2010, see Table 6-2). For example, emissions of methane and nitrous oxide and other trace gases may occur during anaerobic digestion of bio-waste and use of biogas (EC JRC-IES 2011) as well as from manure management (FAO 2013). Water use in processing can also contribute to GHG emissions, for example in wastewater treatment in the palm oil industry (UNEP 2011).

GHG calculation methods need to cover all possible emissions. The challenge is then to identify critical process steps and to optimize them towards low GHG emissions. The sum of emissions should be compared with threshold values for the reduction of GHG emissions (ÖKO/IFEU/CI 2010).
6.2. **Proposals to address impacts on greenhouse gas emissions in the modelling framework**

From a greenhouse-gas emission perspective it is of high importance to address the following aspects:

- No conversion of areas of high carbon stock
- No overuse of forests, i.e. extraction rate is not above regrowth
- Time delay between emissions and subsequent regrowth, both for energy and materials
- Threshold for the supply chain GHG-emission reduction compared to fossil sources

The conversion of areas with high carbon stock needs to be addressed in the model work. Most relevant land categories are forests, wetlands and peatland. These categories are sufficiently covered in global datasets like GLC 2000, HWSD, GLWD and UNEP-WCMC carbon atlas (see Table 6-3).

Regarding an overuse of forests, the G4M model applied by IIASA for estimating the forest harvesting potential in consideration to site conditions such that the harvest rates, including stem wood, branches and stumps, are below the regrowth rate. Only sustainable forest harvest levels are considered within the modelling framework that will be applied. Also information concerning extraction rates as specified in Section 3.2 (biodiversity) may be considered.

The literature review highlights that time lags between growth and use of forest biomass can influence the GHG-balance of a bioenergy pathway. Here both are possible: (1) the CO2-emission when burning wood occurs earlier than the CO2-sequestration by the followed re-growth and (2) the material use of wood may fix CO2 even longer than the re-growth would last (see also IPCC methodology on Harvested Wood Products, HWP). In the IIASA modelling framework, a landscape level approach
is taken when it comes to CO$_2$-emissions related to harvest of wood, change in forest age structural dynamics, and change in forest rotation periods. This means that overall forest landscape changes does impact GHG-emissions, but individual harvests and associated pay-back times are not considered. IPCC methodology concerning HWP pools are also fully accounted for in terms of in the framework that will be applied.

Finally, a threshold on the reduction of GHG-emissions could possibly be implemented in the modelling work to enable the exclusion of bioenergy pathways that do not match the reduction goal of, e.g., 60%. This aspect could be implemented as exclusion rule in the economic tool of the model.

**Table 6-3  List of dataset to address sustainability impacts on greenhouse gas emissions**

<table>
<thead>
<tr>
<th>Area type</th>
<th>Dataset to be used</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biodiversity - loss of ecosystems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High carbon stock - forests</td>
<td>Global Land Cover 2010 (GLC 2010)</td>
<td>Land covered by forest types</td>
</tr>
<tr>
<td>High carbon stock - wetlands</td>
<td>Global lake and wetland database (GLWD)</td>
<td>Location of wetlands</td>
</tr>
<tr>
<td></td>
<td>Global Land Cover 2010 (GLC 2010)</td>
<td></td>
</tr>
<tr>
<td>High carbon stock – peatland</td>
<td>Harmonized World Soil Database (HWSD)</td>
<td>Location of peatland (histosol)</td>
</tr>
<tr>
<td>High carbon stock</td>
<td>UNEP-WCMC carbon atlas</td>
<td>Location of area with high carbon stock</td>
</tr>
</tbody>
</table>
7. Indirect land use effects and economic impacts

Changes in land use are often the reason for impacts of the use of biomass on natural resources and the environment. Direct impacts from land-use change are already covered in the sections above, e.g. the conversion of areas of high biodiversity value (Chapter 3.1), increased soil erosion due to stump harvest (Chapter 4.1) and increased use of water by short rotation coppice in comparison to agricultural crops (Chapter 5.1). However, these direct land use impacts are in general under the control of the operator producing bioenergy and can be efficiently addressed by regulations and certification schemes.

In contrast, indirect effects and related impacts are mostly out of the control of bioenergy operators. Indirect effects occur mainly as consequence of the displacement of a former activity to fulfil a demand. In case that the former demand still exists, meeting this demand may case impacts elsewhere. The prominent example of indirect effects is indirect land use change (iLUC), i.e. impacts from land use change after displacing a former crop (including residues) by bioenergy production (see overview in Agostini et al. 2013). Though rarely reported indirect effects may also occur for the use of other resources like water and other activities like a reduced use of wood as materials due to an increased use for bioenergy.

Due to the interaction of global markets, the increased use of biomass resources can impact different biomass uses as well as other sectors. Such impacts are mainly driven by the competition for resources – that is often the driver for indirect effects mentioned above. Interaction takes place through, e.g., the supply and demand of biomass, costs and prices, trade pattern, technical development, changes in gross domestic product and environmental restrictions, and such aspects are typically covered in economic models. Within this project, economic aspects are already covered in-depth in the review of Task 1. Under this Task the covered references are in addition screened for the competition with other uses, increase of revenue, and supply cost at the power plant.

7.1. Impacts from the use of biomass

7.1.1. Impacts of biomass production and its increase

The main cause for indirect land-use change found in the reviewed references is the competition for land resulting in the displacement of a former land use, e.g. for food or feed production, by the production of biomass for bioenergy (OEKO/IFEU/CI 2010, Agostini et al. 2013, see Table 7-1). It is important to notice that displacement can not only occur for products (e.g. rape seed) and co-products (press cake of rape seed as feed), but also for residues if they are used for a specific purpose and the demand still exists (e.g. forest residues used for pulp and paper).

Furthermore the increased demand for land can result in a general intensification of land use – on bioenergy production areas as well as on other agricultural and forestry areas, for example the intensification of cereal cultivation (IEEP et al. 2010) or moving near natural forest towards intensive short rotation biomass production systems (Hart et al. 2013). Also an overuse of forest resources, i.e. increasing the wood-extraction rate above the wood regrowth rate (GBEP 2011), can be an indirect effect caused by an increased demand for bioenergy.
The overall reason for indirect land use change induced by the use of bioenergy is the increased biomass demand and the related production and competition for land resources. In consequence, the authors of the covered references suggest responses that release the pressure on the production of biomass and land already in use. This could be achieved by focusing biomass production on currently unused land (OEKO/IFEU/CI 2010), increase the use of unused wastes and residues (Hart et al. 2013), and the intensification of land use (e.g. increased and improved management, fertilization, suppression of natural disturbances like wild fires; Agostini et al. 2013). Furthermore, the iLUC effect should be visible in the calculation of greenhouse gas emissions from bioenergy, i.e. by including an iLUC factor (OEKO/IFEU/CI 2010).

Most economic impacts of biomass production identified in literature review are related to competition. The main driver is that the future increased use of wood for bio-energy and the bio-economy will put pressure on the use of wood in the EU, and even a gap between the supply and demand of wood can be expected (Indufor 2013). Already today about 10% of total traded wood chip volumes are allocated to bioenergy production (IEA 2012: Lamers, Junginger et al.). Furthermore, the growing demand of wood pellets in the EU is driving the pellet manufacturers to enlarge the feedstock base, adapting new logistics and transportation infrastructures, refining pellets (torrefaction; IEA 2011, see Table 7-1). This pressure is expected to result in the displacement of wood products from existing uses (materials and energy; Agostini et al. 2013). For example, the forest chip production can shift from the use of tops and branches towards an increasing use of stem wood and stumps (Diaz Yanez et al. 2013), and the optimisation of wood chip supply chains may lead to a shift from material use towards energy use (e.g. Spain; Anttila et al. 2011). Another economic impact is an intensification of forest management due to increased revenue for forest owners. This can be intensified by incentives for wood use (energy or other uses) (Agostini et al. 2013). Another relevant aspect might be the costs of land depending on the production pressure.

Table 7-1  Indirect effects and land-use impacts and economic impacts from biomass production and possible response found in literature

<table>
<thead>
<tr>
<th>Cause of impact</th>
<th>Possible response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indirect land-use change and competition with other land use</td>
<td>Utilisation of unused land for bioenergy and including iLUC factor in GHG-calculation are discussed (OEKO/IFEU/CI 2010)</td>
</tr>
<tr>
<td>Displacement of former land-use (OEKO/IFEU/CI 2010)</td>
<td></td>
</tr>
<tr>
<td>Movement away from near natural forests towards intensive</td>
<td>Use of wastes and residues as biomass to avoid land use change (Hart et al. 2013)</td>
</tr>
<tr>
<td>Movement away from near natural forests towards intensive short rotation biomass</td>
<td></td>
</tr>
<tr>
<td>Expansion of production of straw (e.g. ploughing up of biodiversity-rich</td>
<td>Not specified</td>
</tr>
<tr>
<td>Competition for land cases indirect land use change, iLUC) (Agostini et al.</td>
<td>Management intensification, e.g. increased and improved management, fertilization, natural disturbances suppression etc. (Agostini et al. 2013)</td>
</tr>
<tr>
<td>Potential intensification or expansion of cereal cultivation (IEEP et al. 2010)</td>
<td>Not specified</td>
</tr>
</tbody>
</table>

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### Overuse of forests

<table>
<thead>
<tr>
<th>Description</th>
<th>Not specified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood-extraction rate is above the wood regrowth rate, depending on forest type and site conditions (GBEP 2011)</td>
<td>Not specified</td>
</tr>
</tbody>
</table>

### Competition with other uses

<table>
<thead>
<tr>
<th>Description</th>
<th>Not specified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displacement of wood for products (or indirect Wood Use Change, iWUC) (Agostini et al. 2013)</td>
<td>Not specified</td>
</tr>
<tr>
<td>Displacement of wood from other energy sectors (or indirect Fuel Use Change, iFUC) (Agostini et al. 2013)</td>
<td>Not specified</td>
</tr>
<tr>
<td>Restriction for stump extraction (Abbas et al. 2011)</td>
<td>Not specified</td>
</tr>
<tr>
<td>The future increased use of wood for bio-energy and the bio-economy will put pressure on the use of wood in the EU. A gap between the supply and demand can be expected (Indufor 2013)</td>
<td>Not specified</td>
</tr>
<tr>
<td>Currently the bulk of the forest chips in the EU are produced from tops and branches, however shift towards increasing use of stem wood and stumps is expected as the demand grows (Diaz Yanez et al. 2013)</td>
<td>Not specified</td>
</tr>
<tr>
<td>In the global wood chip trade the current policies to reduce GHG emissions are driving the global trade of wood chips of pulp production to be replaced with chips to bioenergy production. It is estimated that app. 10% of total traded wood chip volumes are allocated to bioenergy production (IEA 2012: Lamers, Junginger et al.)</td>
<td>Not specified</td>
</tr>
<tr>
<td>Adopting Nordic forest chip supply chains to Spanish conditions can provide a feasible basis of utilizing the potential raw material in Spain to run heat energy business, whereas the local demand of wood for particle board production is declining (P. Anttila et al. 2011)</td>
<td>Not specified</td>
</tr>
</tbody>
</table>

### Increase of revenue

<table>
<thead>
<tr>
<th>Description</th>
<th>Not specified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased revenue for forest owners due to incentives for wood use (energy or other uses) casing an intensification of forest management (Agostini et al. 2013)</td>
<td>Not specified</td>
</tr>
</tbody>
</table>

### Increased demand

<table>
<thead>
<tr>
<th>Description</th>
<th>Not specified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Growing demand of wood pellets in EU are driving the pellet manufacturers to enlarge the feedstock base, adapting new logistics and transportation infrastructures, refining pellets (torrefaction) (IEA 2011)</td>
<td>Not specified</td>
</tr>
</tbody>
</table>

#### 7.1.2. Conversion, transport and use of biomass

Along the production chain Asikainen et al. (2011) highlight that a high mechanization rate of wood harvesting (Scotland 90%, Poland 5%) lowers the supply costs, but small-scale heating systems and high wood chip quality requirements increase the supply costs (Scotland). In case that subsidies (feed in tariffs of market premiums) are only targeted for short span of time, delays to major investments in large wood pellet heating plants may occur since the investors do not have certainty of long term productivity of the projects (IEA 2013: Ikonen T., Asikainen A. et al.).
Table 7-2  Economic impacts on conversion, transport and use of biomass

<table>
<thead>
<tr>
<th>Cause of impact</th>
<th>Suggested response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply cost at the Power plant</td>
<td></td>
</tr>
<tr>
<td>High mechanization rate of wood harvesting (Scotland 90%, Poland 5%) lowers the</td>
<td></td>
</tr>
<tr>
<td>supply costs. Small-scale heating systems and high wood chip quality requirement</td>
<td></td>
</tr>
<tr>
<td>increases the costs (Scotland) (Asikainen et al. 2011)</td>
<td>Not specified</td>
</tr>
<tr>
<td>Delay in investments</td>
<td></td>
</tr>
<tr>
<td>Subsidies (feed in tariffs of market premiums) are only targeted for short span</td>
<td></td>
</tr>
<tr>
<td>of time. This has caused delays to major investments in large wood pellet heating</td>
<td></td>
</tr>
<tr>
<td>plants since the investors do not have certainty of long term productivity of the</td>
<td></td>
</tr>
<tr>
<td>projects (IEA 2013: Ikonen T., Asikainen A. et al.)</td>
<td>Not specified</td>
</tr>
</tbody>
</table>

7.2. Proposals to address indirect effects and other land-use impacts in the modelling framework

Indirect effects and also economic impacts are mainly related to competition between different biomass uses (energy, material) and occur for biomass resources that can potentially be deployed for different uses e.g. stem wood. Such effects are limited for the use of branches, stumps and residues. The construction of the model framework in combination with a suitable set of scenarios should address effects that occur from this circumstance.

In October 2012 the European Commission adopted a proposal establishing an approach to minimize possible ILUC impacts of biofuels consumed in the EU. This includes a cap on the contribution that first generation food crops-based biofuels can make towards the national target of 10% renewable energy target in transport by 2020. The Commission proposal does, however, not include feedstock-specific ILUC factors due to the uncertainties associated to the modelling. Such uncertainties also apply to biomass for heat and power. These points shall be reflected in the modelling framework.

The GLOBIOM modelling framework allows for assessing direct and indirect land use change impacts of increasing bioenergy demand. Baseline developments concerning land use for new plantations and development of agricultural land can be directly compared to scenarios with changed assumptions. Of relevance appear mainly the efficient use of residues and wastes (see also cascading use in Section 8) and an increase of yields higher than in the baseline. These points may be addressed in the used economic model (GLOBIOM).

Due to the situation that an increase of the pressure on the use of wood is likely, it is important to notice that the economic tool in the model framework (GLOBIOM) already covers competition between different uses of wood (energy use, material use including cascading; see Section 8). The approach that will be applied covers both competition for forest biomass types (steam, branches, and stumps) and potential uses (energy, different material) within the economic framework. In this manner, price induced shifts, including incentives, are possible as well as fully represented endogenously within the framework that will be applied. Also increasing land prices as well as price


Due to the lack of an agreed methodology, indirect land use change was also not included in the GHG calculation of the Product Environmental Footprint (PEF), under the Commission's Recommendation 2013/179/EU.
induced forestry intensification may be included within the model framework and the analysis.
8. Cascading use of biomass

Biomass is widely used in the EU in the forestry and agricultural sectors, most importantly for food, feed and material production. It is also an important renewable resource for heat and energy production. However, the growing demand for biomass calls for considerations so that resource competition does not lead to adverse negative impacts due to scarce available biomass resources. Potential competition risks can be addressed by sustainably increasing the mobilisation of forest and agriculture feedstock, or by implementing innovative ways to improve the efficient use of the biomass resources as available. Both approaches may potentially address and mitigate the above-mentioned risks. This section will focus on the second approach through improvements in the cascading use of biomass.

Cascading use of biomass refers to re-use and recycling of biomass products so that “biomass is processed into a bio-based final product and this final product is used at least once more either for materials or energy” (Essel et al. 2014). The cascading principles have long traditions of deployment especially in the forest industries, where the pulp and paper industries as well as sawmill industries have well-established chains of using the biomass for different purposes in different stages of its lifecycle. A typical example of a cascading chain is the use of roundwood in paper production, where the cellulose fibres can be used for paper recovered as recycled paper several times, and thereafter the paper sludge can be pressed into paper bricks and, finally, used as an energy feedstock.

Cascading, especially in the form of recycling and re-using, is already widely used within the biomass sector. However, examples of explicitly using cascading to reduce environmental impacts of industries, or improving the effectiveness of the cascading chain, are mostly limited to more theoretical research projects.

Political interest in cascading use of biomass has increased considerably in recent years at the EU level, given that it complements goals to increase resource efficiency and the increasing interest in the bioeconomy (COM 2012) and bioenergy (e.g. COM 2013).

In this literature review, the focus is on measures and instruments affecting prospects for cascading use in the EU. In order to specify aspects to take into account in the future scenario analysis, the literature is also scanned for possible indicators of cascading use and its environmental effects. Finally, the possible ways to implement policy measures into the scenario models are examined.

8.1. Defining cascading use

Comparing different studies on cascading use is complicated by the fact that there has not been a clear consensus on the definition of cascading use of biomass. A number of definitions of the term have been presented, focusing on various benefits for cascade use (e.g. economic, environmental, and industrial), various industrial sectors are involved (e.g. wood-processing, recycling, and energy sector), and aim of the study (e.g. theoretical evaluation or practical implementation). A short overview of the large range of definitions that have been provided will be given here.

Essel et al. (2014) offer the definition above, focusing on the material use of biomass at least at one point of the biomass life cycle. COM (2013) uses a more explicit definition for a cascading chain, with product-use being prioritized before re-use, recycling, bioenergy and disposal in a decreasing order of preference. While the concept of cascading overlaps with for example concepts of circular economy and the
waste hierarchy, it is sometimes also used to refer to very complex systems of main and by-products (Essel et al. 2014).

Cascading use is referred to as single-stage if a product made of virgin wood is discarded and then directly used for energy (the biomass is used only for a single purpose, and then for energy). If there are two or more material uses for the biomass before its energy use (for example, discarded wooden furniture chipped and pressed into particleboards), cascading is said to be multi-stage (Essel et al. 2014). Odegard et al. (2012) differentiate biomass cascading chains also with respect to the dimensions in time, value and function – often all three elements are incorporated for the best environmental result. Cascading in time refers to increasing the lifespan of biomass by leaving as many future uses open as possible, as in paper recycling. Cascading in value refers to prioritizing the alternative uses of the biomass with respect to their value. Cascading in function refers to co-production of biomass products, so that the biomass stream is used for different types of products in order to promote as much functional use as possible.

Modelling cascading use first requires an understanding of the possible and existing biomass flows (Odegard et al. 2012, Mantau et al. 2010). In order to quantify the cascading use, indicators or proxies are needed. Mantau (2012) developed a detailed wood flow chart to calculate cascade factors for different cascading chains (Table 8-1). A cascade factor describes the relation between all wood resources (roundwood and other wood resources), and the resources from roundwood. This makes it possible to calculate the input-output relation of wood for certain parts of the wood value chain (Mantau 2012), or for the whole chain of woody biomass use, as done by Indufor (2013). The cascade factor provides thus a useful indicator for comparisons of the extent of cascading between different value chains and also over time.

Table 8-1 An example of the calculation of cascade factors

<table>
<thead>
<tr>
<th>Utilization of wood biomass</th>
<th>Total volume (M m³)</th>
<th>Cascade factor</th>
<th>Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Roundwood resources</td>
<td>577.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B Residues in wood products</td>
<td>72.9</td>
<td>1.13</td>
<td>(A+B)/A</td>
</tr>
<tr>
<td>C Residues in energy</td>
<td>103.4</td>
<td>1.18</td>
<td>(A+C)/A</td>
</tr>
<tr>
<td>D Recycling in products</td>
<td>130.2</td>
<td>1.23</td>
<td>(A+D)/A</td>
</tr>
<tr>
<td>E Recovery in energy</td>
<td>24.4</td>
<td>1.04</td>
<td>(A+E)/A</td>
</tr>
<tr>
<td>F Residue cascades</td>
<td>176.3</td>
<td>1.31</td>
<td>(A+B+C)/A</td>
</tr>
<tr>
<td>G Recycling + recovery cascades</td>
<td>154.6</td>
<td>1.27</td>
<td>(A+D+E)/A</td>
</tr>
<tr>
<td>H Cascades in products</td>
<td>203.0</td>
<td>1.35</td>
<td>(A+B+D)/A</td>
</tr>
<tr>
<td>I Residues + recycling in energy</td>
<td>127.9</td>
<td>1.22</td>
<td>(A+C+E)/A</td>
</tr>
<tr>
<td>J Total cascades</td>
<td>330.9</td>
<td>1.57</td>
<td>(A+H+I)/A</td>
</tr>
</tbody>
</table>

Adopted from: Mantau (2012); the numerical values for total volume and cascade factors are illustrative only.

In the reviewed literature, central issues used for comparing the impacts of cascading use are land use, CO2 emission reductions, and costs and energy demand of production (Dornburg and Faaij 2005, Sathre and Gustavsson 2006). Usually the reference system is chosen so that it produces the same material or energy functions. However, if several different or alternative functions are produced through the
cascading chain, the systems may become too complex to compare reliably. Therefore, Dornburg and Faaij (2005) emphasize the importance of comparing every single biomass chain with a single reference system.

Production costs and energy needed for production are relatively straightforward to calculate. The whole value chain needs to be taken into account: the different amounts of energy to produce, transport and process virgin and recovered wood, as well as the differences in by-product quantities (Sathre and Gustavsson 2006). The quantification of land use and CO2 emissions is not as easy, as these may occur at very different time points in alternative biomass production and cascading chains. For example, the rotation period – the time that the land is needed for one production cycle – in conventional forestry may be 100 years, whereas it in short rotation energy crops it is only a few years. On the material side, the time point when sequestrated carbon is released is also very different: for fuelwood it is almost directly after harvest, for paper maybe in a few weeks after production, and for building material possibly more than a hundred years after harvest. That is, the negative climate effects of CO2 emissions also occur at very different time points. One possibility to account for the different time horizons is to calculate the CO2 reductions of different land uses, and discount the monetary value of CO2 emissions at different points in time to the present day (Dornburg and Faaij 2005).

A clear definition of cascading use is of particular importance when aiming to increase cascading use through political instruments. Each of the definition as specified above has advantages and disadvantages in terms of the part of the system that they are able to cover and accurately represent. As expressed by AEBIOM et al. (2013) and Essel et al. (2014), narrowing the definition to multi-stage cascading implies hard restrictions on the biomass-using industries and may be impossible for many value chains. If single-stage cascading is also accepted within the term, more of the already existing product value chains may be counted in as utilizing the cascading principle.

### 8.2. Possible measures and instruments

There are several possible policy instruments that could be used to promote cascading use of biomass. Table 8-2 provides an overview of the instruments that have been suggested in the reviewed literature. The most central issues are the need for clear definitions of cascading use over the whole biomass lifecycle; imposition of taxes, subsidies and legal measures to promote cascading use; and cross-disciplinary and intergovernmental dialogue for developing more efficient logistical and technological solutions in different cascading stages. As noted by Haberl and Geissler (2000), notable gains in the total energy balance could be achieved by also utilizing the currently unused biomass residues in energy production. However, this is likely to require considerable investments in waste collection and treatment facilities.

<table>
<thead>
<tr>
<th>Measures</th>
<th>Instruments</th>
</tr>
</thead>
<tbody>
<tr>
<td>New paradigm of resource value (Sirkin et al. 1994)</td>
<td>Taking total utility into account when assigning the product prices, also reflecting the resource quality and potential utility, and not solely market prices of the resources. This includes special valuation of vital resource qualities (qualities that cannot be replaced, such as food biomass quality), over non-vital (e.g. biomass for energy, where there are many alternatives)</td>
</tr>
<tr>
<td>Improvement of resource efficiency (Sirkin et al. 1994)</td>
<td>Policies for promoting product durability; effective re-collection and distribution systems for used and reclaimed materials; co-production and co-design</td>
</tr>
</tbody>
</table>
Balancing consumption with replenishment (Sirkin et al. 1994) | Policy measures encouraging the development of methods for efficient resource regeneration and replenishment; production methods and product design with exploitable replenishable and renewable sources

Promoting cascadable design (Sirkin et al. 1994) | Formulating standard requirements for interchangeability; standard requirements for the utilisation of substances and materials; replacement equivalent deposit systems or introduction of resource compensation cost into the price of products; imposition of levies on products which cannot be cascaded or disassembled

Defining the criteria of the cascade (Keegan and Kretschmer 2013) | Taking entire life-cycles into account; water use efficiency and impacts on natural resources (including biodiversity); social considerations (supply security, and economic viability); waste prevention

Enhanced use of ecodesign to ensure technical feasibility of cascading use (Keegan and Kretschmer 2013) | Research and development.

Solving the logistical challenges of cascading use (Keegan and Kretschmer 2013) | Encouraging interdisciplinary research and strong links between sectors; strengthening the operation of waste collection and separation

Solving related policy challenges (Keegan and Kretschmer 2013) | Coordinated policies across government ministries (industry, agriculture, environment, research)

Financial measures (Keegan and Kretschmer 2013, Odegard et al. 2012) | Imposition of taxes on the use of virgin raw material, subsidizing energy sector for cascading use of biomass

Policy and/or legal measures (Odegard et al. 2012) | Recycling targets, landfill bans, adjusting laws that complicate the alternative uses of biogenic waste

Example from Austria: Utilizing the unused biomass residues for energy generation could contribute 6% (76 PJ) of the energy consumption (Haberl and Geissler 2000) | Account for combustion of woody wastes (from housing, agriculture) and straw from grain production; and utilizing wet municipal organic wastes, animal dung, organic residue from plant production as biogas

International agreement on limited biomass availability (IEA Bioenergy 2009) | Maximizing biomass conversion efficiency by minimizing raw material requirements while strengthening the economic position of agriculture, forestry, chemical and energy sectors.

Develop multi-disciplinary partnerships to foster R&D and deployment of new technologies (IEA Bioenergy 2009) | Bring together key stakeholders from different market sectors (agriculture and forestry, transportation fuels, chemicals, energy...)

8.3. Proposals to address cascading use in the modelling framework

Within this project, we propose first to analyse the extent of cascading in the different bioenergy scenarios using cascade factors presented in Table 8-2 (Mantau 2012, Indufor 2013). At this first stage, we will assess the potential use of the above-mentioned indicators within the modelling framework and how they could be applied to provide insight to the model development over time. The indicators will then be monitored to show how cascading evolves over time, both in total and in different parts of the value chain. The indicators will at first strictly be used as a monitoring tool to analyse and inform how change in cascading may occur over time, and how different scenarios may impact the applied indicators. This in turn allows also an analysis of the differences between the scenarios in overall land use change and related CO₂ emissions in relation to cascading use.
Within a second stage, policy measures identified in this review as particularly important for increasing cascade use will be assessed in terms of their potential impact on the cascade indicators developed in the first stage. The policy measures for cascading use touch on different aspects of the wood cascade chain, and are expected to affect the cascade indicators differently. The main underlying storylines may focus on (i) improved waste recovery through policy targets, i.e. maximise recycling of solid wood and (ii) imposing taxes on the energy use of virgin raw material. These envisioned policies measured are of particular interest as they are expected to have direct implications for the cascade indicators to be used and on the other environmental and economy indicators that are to be monitored.
9. Conclusions

Impacts of biomass use on natural resources and the global environment are manifold. The project attempts to cover the most relevant impacts in the model framework (Task 3) and assesses them in the subsequent analysis of impacts (Task 4). The literature review carried out in the project gives a comprehensive overview of the current knowledge on possible impacts on biodiversity, soil, water bodies, greenhouse gas emissions and indirect effects and other land-use impacts, including some aspects on economic impacts. Each impact category was divided into detailed impacts, e.g. soil erosion, soil carbon loss, soil compaction, soil nutrient loss and soil salinization for the category soil. A set of 40 references was considered relevant after categorization from an initial list of 202 references. The selected references were then analyzed for detailed impacts that were reported, as well as the causes of impacts and the responses suggested by the literature. Despite the complexity of the issue, the project tried to also identify important aspects regarding responses to impacts reported in the reviewed literature that have the potential to help reduce negative impacts (see summary in Table 9-1).

The use of biomass for energy purposes can potentially be a driver of loss of biodiversity, linked primarily to direct and indirect land-use change and increasing intensity of land use. The increasing use of biomass is likely to increase this pressure. The screening of literature carried out in this project focused on the following detailed impacts: loss of species, loss of ecosystems, damage of flora and fauna and loss of ecosystem functions. From a biodiversity perspective the review showed that two aspects are of high relevance: a) the protection of areas with high biodiversity value and b) sustainable extraction rates of dead wood, residues, stumps and old trees.

The review showed that most soil impacts are very site specific and require respective soil conservation measures. For sensitive areas measures may include the exclusion of areas from production and the restriction of residue and stump extraction (Table 9-1). However, the amount of biomass extraction can be part of the soil conservation measure (e.g. mulching with straw, retaining nutrient cycle by leaving branches and leaves on site) and lead to win-win situations. Other soil conservation methods increase the possible extraction rate but entail higher production costs (e.g. fertilization with ash). Some soil conservation measures may also only cause costs and not necessarily contribute to improved yields (e.g. adoption of machinery, windbreaks). Finally, specific soil conservation measures may lead to a lowering of yields compared to the option without measures (e.g. adoption of crop rotation to allow straw extraction). It is therefore necessary to favour win-win measures that contribute to soil conservation while positively impacting biomass production.

The identified impacts on water are of lower relevance compared to e.g. impacts on biodiversity and soil. This is due to the focus of the literature review on systems producing solid biomass that are largely rain-fed systems. The most relevant potential negative impacts on water are a) overuse of freshwater resources in water scarce regions, b) pollution of waterbodies from the application of fertilizer and pesticides, and c) pollution of waterbodies from process waste water (Table 9-1). However, there can also be positive impacts of biomass production systems, e.g. on ground water supply.

Strong impacts on greenhouse gas emissions from biomass production occur when areas of high carbon stock are converted to bioenergy plantations of low carbon stock, but also an increase of wood extraction, including whole tree harvest and residue extraction, can lower the carbon stock of forests (Table 9-1). However, there are
cases where long-term active forest management can increase biomass and timber production while still safeguarding the forest carbon stock at the landscape level. Examples of such improvements range from the promotion of regeneration and silvicultural management to enhancing forest growth (through improved timing of pre-commercial cutting, thinning efforts, fertilization, etc.). When including substitution effects on GHG emissions within the energy and industry sector, managing forests for products and services (energy and/or materials) can also determine higher GHG savings than suspending the management.

Table 9-1  Important points identified from the reviewed literature to reduce negative impacts from biomass use on the environment

<table>
<thead>
<tr>
<th>Environmental aspect</th>
<th>Details</th>
</tr>
</thead>
</table>
| Biodiversity          | - The protection of areas with high biodiversity value  
                        - Sustainable extraction rates of dead wood, residues, stumps and old trees |
| Soil                  | - Identification of exclusion areas where (i) no production at all is allowed at all and (ii) where no residue or stump extraction should occur (e.g. depending on steep slopes, poor soils, wet soils)  
                        - Restriction of residue and stump extraction on all remaining areas  
                        - Lowering the development of yields, i.e. assuming a lower annual yield-increase rate assuming stronger soil protection measures |
| Waterbodies           | - Avoid overuse of freshwater resources in water scarce regions  
                        - Avoid pollution of waterbodies from the application of fertilizer and pesticides  
                        - Avoid pollution of waterbodies from process waste water |
| Greenhouse gas emissions | - No conversion of areas of high carbon stock  
                        - No overuse of forests  
                        - Time lag of forest growth and wood use, both for energy and materials  
                        - Threshold for the GHG-emission reduction compared to fossil sources |

**Indirect effects** (for all environmental impacts) occur mainly as a consequence of the displacement of a former activity to fulfil a demand. In case that the former demand still exists, meeting this demand may case impacts elsewhere, especially as further biomass production will tend to extend into less fertile soils (hence requiring more inputs such as fertilizers and/or water) and/or into areas with higher ecological value. Results from the literature review on indirect effects and on economic impacts showed that both aspects are mainly related to competition between different biomass uses (energy, material) for biomass resources such as stem, branches, stumps and residues.

Finally a literature review was carried out for the **cascading use** of biomass, focusing on measures and instruments to incentivize it. The most central issues and proposed methods for increasing cascading mentioned in the covered studies are the need for clear definitions of cascading use over the whole biomass lifecycle; imposition of taxes, subsidies and legal measures to promote cascading use; and cross-disciplinary dialogue for developing more efficient logistical and technological solutions in different cascading stages.
10. References

Please note that the references are split in two reference lists (see details in Appendix 1):

- References that are cited in the text of this study and/or used in the in-depth literature review (Section 10.1)
- Further references that have been considered in the pre-selection of the literature review (Section 10.2)

10.1. References cited in the report and used in the in-depth literature review


ADAS (2008). Addressing the land use issues for non-food crops, in response to increasing fuel and energy generation opportunities. NNFCC project 08-004, ADAS, Hereford.


EEA (European Environmental Agency) (2013a). Review of the EU bioenergy potential from a resource efficiency perspective. Background report to EEA study; Copenhagen.


Fernholz K et al. (2009). Energy from Woody Biomass: A Review of Harvesting Guidelines and a Discussion of Related Challenges; Dovetail Partners, Inc.. Prepared for the Pinocet Institute for Conservation. Minneapolis MN.


Gheewala, S., Yeh, S., Fingerman, K., Diaz-Chavez, R., Moraes, M., Fehrenbach, H., ... Wani, S. (2011). The bioenergy and water nexus. UNEP.


10.2. Further references considered in the pre-selection of the literature review


Birdlife International (2011). Meeting Europe’s renewable energy targets in harmony with nature. The RSPB, Sandy, UK.


DBFZ (Deutsche Biomasseforschungszentrum), Oeko-Institut (2011). Environmental impacts of the use of agricultural residues for advanced biofuel production, commissioned by WWF; unpublished.

DECC (Department of Energy & Climate Change) and Defra (Department for Environment, Food and Rural Affairs) (2011) Anaerobic Digestion Strategy and Action Plan - A commitment to increasing energy from waste through Anaerobic Digestion. DECC and Defra, London, UK.


EEA (European Environmental Agency) (2013b). EU bioenergy potential from a resource efficiency perspective; Copenhagen.


FSC (Forest Stewardship Council) (2012). FSC International Standard. FSC Principles and Criteria for Forest Stewardship; FSC-STD-01-001 (version 5-0) EN


Hinge, J. (2009). Elaboration of a platform for increasing straw combustion in Sweden based on Danish experiences. Danish Technological Institute; Project No.: E06e641. Sponsored by Värme forsk.


ISO (International Standardization Organization ) undated. TC 248 Project committee: Sustainability criteria for bioenergy (under prepatation).


Melville, N. (2010). Developing Reed as a Wetland Product in the Humberhead Levels. RPSB, July 2010


PI (Partners for Innovation BV) (2011). Sustainability requirements for biofuels and biomass for energy in EU and US regulatory frameworks; prepared for NL Agency; Amsterdam


Roundtable on Sustainable Biomaterials (2013). RSB principles & criteria for sustainable biofuel production. RSB-STD-01-001 (Version 2.0)


VITO (Flemish Institute for Technological Research) (Ed.) 2011: BIOBENCH - Benchmarking biomass sustainability criteria for energy purposes; study carried out in cooperation with Oeko-Institut, TU Vienna, Utrecht University, ETA Florence, and REC under the authority of the EC DG ENER under contract ENER/C1/495-2009/SI2.572581, Mol.


WWF (World-Wide Fund for Nature) (2012). WWF's recommendations for sustainability criteria for forest based biomass used in electricity, heating and cooling in Europe. WWF, Brussels
11. Appendix 1: Methodology

11.1. Impact on the environment

During the last two decades a vast number of scientific studies addressing the sustainability of bioenergy have been published. The challenge of this literature review is to identify those studies that are of relevance for the modelling under Task 3 and the impact assessment under Task 4. We developed a three-step approach to fulfil this challenge:

Step 1: List of available studies
Based on the knowledge of the involved project partners on existing literature we generated a list of references that address impacts of biomass production and conversion on natural resources and the global environment. In total we covered more than 202 references with a specific focus on review studies. All references are listed in the Appendix. General information on the references, e.g. focus of the study, geographical range and type of land use, is collected in an Excel file that will be delivered as appendix of this report.

Step 2: Pre-selection
Due to time constraints we carried out a pre-selection of those references to be considered in an in-depth review. Studies were selected for in-depth review if they fulfilled the following requirement: “Are concrete indicators covered within the study (not only principles, e.g. soil protection is needed, but information on how soil protection shall be addressed, e.g. listing soil conservation measures)”. In total, 40 studies were selected for an in-depth review that provided information on more concrete indicators. The list in the Appendix identifies studies selected for in-depth review.

Step 3: In-depth review
For the selected studies an in-depth review was carried out. We categorised the studies to make results of the review more comparable across studies and to make sure the review is sufficiently representative (see Table 11-1). The following categories were covered in all reviews to achieve a systematic analysis across all selected references:

- **Type of biomass.** Describes the type of biomass feedstock regarding its origin (agriculture or forestry) and cultivation method.

- **Type of ecosystem.** Describes the type of ecosystem used for and natural conditions of biomass production differentiating tropical, sub-tropical, temperate and boreal forest and agriculture ecosystems.

- **Type of study.** Describes the type of research undertaken leading to the results presented by the study. Types of studies under review are: Model; Empirical; Review /Synthesis

- **Pressure / driver.** Describes the pressures and drivers of impacts addressed by the study. Categories are: (increase of) biomass production; conversion /transport /use of biomass; (general)

- **Impact.** Describes the impact of biomass production or use analysed in the study. We differentiate between: Biodiversity; Soil; Water and water pollution; GHG- emissions; Land-use impacts; Economic impacts; Others
**Impact detail.** Describes the impact in detail regarding concrete indicators affected by biomass use and production:

- **Biodiversity.** Loss of species; Loss of ecosystems; Damage of flora and fauna; Loss of ecosystem functions; Others
- **Soil.** Soil erosion; Soil carbon loss; Soil compaction; Soil nutrient loss; Soil salinization; Others
- **Water.** Over-use of water resources; Impact on water table; Water pollution; Others
- **GHG emissions (incl. substitution effects).** Change of carbon stock; Change of disturbance pattern; Others
- **Land-use impacts.** Indirect land-use change; Competition with other land use; Ploughing of grasslands; Overuse of forests; Others
- **Economic impacts.** Increase of revenue; Competition with other uses; Supply cost at the Power plant; Others

<table>
<thead>
<tr>
<th>Category name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>agr_all</td>
<td>All agricultural systems</td>
</tr>
<tr>
<td>agr_short rotation</td>
<td>Agricultural systems providing lignocellulosic biomass from Short Rotation Coppice systems</td>
</tr>
<tr>
<td>agr_grasses</td>
<td>Agricultural systems providing grasses</td>
</tr>
<tr>
<td>agr_lignocellulosic species</td>
<td>Agricultural systems providing lignocellulosic biomass</td>
</tr>
<tr>
<td>agr-animal byproducts</td>
<td>Agricultural systems providing biomass as a by-product of animal production</td>
</tr>
<tr>
<td>agr_residues</td>
<td>Agricultural systems providing biomass as residue of agricultural crop production</td>
</tr>
<tr>
<td>for_all</td>
<td>All forestry systems</td>
</tr>
<tr>
<td>for_round wood</td>
<td>Forestry systems providing biomass from round wood</td>
</tr>
<tr>
<td>for_residues_all</td>
<td>Forestry systems providing biomass from primary and secondary residues</td>
</tr>
<tr>
<td>for_residues_stumps</td>
<td>Forestry systems providing biomass from primary residues based on stump extraction</td>
</tr>
<tr>
<td>for_residues_branches</td>
<td>Forestry systems providing biomass from primary residues based on branch extraction</td>
</tr>
<tr>
<td>for_dead wood</td>
<td>Forestry systems providing biomass from primary residues based on dead wood extraction</td>
</tr>
<tr>
<td>waste_all</td>
<td>All waste categories</td>
</tr>
<tr>
<td>waste_food waste</td>
<td>Biomass from food waste</td>
</tr>
<tr>
<td>waste_biological fraction MSW</td>
<td>Biomass from the biological fraction of Municipal Solid Waste (i.e. households)</td>
</tr>
</tbody>
</table>

The relevant references were further screened for information describing:

- **Cause of impact** (e.g., inappropriate management, degradation etc.)
- **Suggested response** (e.g., thresholds, default values, measures etc.)
• **Suggestions on incorporating impact in modeling** (e.g. datasets, procedures, etc.)

In case that a reference covered different categories, a new entry was produced to cover this specific information. This means that a single reference may occur several times in the in-depth review list for different aspects. The information gathered from selected studies is presented in a summary table and further described in the text.

**11.2. Cascading use**

Similar to the review on impacts on the environment relevant references are collected for the topic of cascade use. The selected references were screened for information on measures and instruments addressing explicitly the cascade use of biomass. On purpose a wide definition of cascade use was adopted in the beginning as many studies as possible. This definition describes cascade use of biomass products that are at least once recycled, reused or recovered for either material, chemical or energy use. Due to the fact that publications on cascade use are rare, no pre-selection procedure was needed and all found references were covered in the review. In total nine studies were selected for an analysis.
Study on impacts on resource efficiency of future EU demand for bioenergy

Task 3: Modelling of impacts of an increased EU bioenergy demand on biomass production, use and prices
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Glossary

Anaerobic digestion
Anaerobic digestion is a biological process making it possible to degrade organic matter, in absence of oxygen, by producing biogas and sludge. The organic matter is degraded partially by the combined action of several types of micro-organisms.

Bioenergy
Energy produced from biomass sources excluding biofuels.

Biofuels
Transportation fuels made from biomass; such as biodiesel, bioethanol and biogas. *First-generation biofuels* refer to fuels derived from food crops, such as grains, sugar beet and oil seeds. They are relatively easy to manufacture, and thus the main type of biofuels produced today. *Second-generation, or advanced, biofuels* are produced from non-food biomass such as ligno-cellulosic materials or biogenic waste. They are considered superior to first-generation biofuels especially in terms of their social and environmental impact; however, their production is much more complicated and commercial production methods are still under development.

Biogenic waste
According to Article 3(4) of the Waste Framework Directive (2008/98/CE), biogenic waste is ‘biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises and comparable waste from food processing plants.’

Biomass
“Biodegradable fraction of products, waste and residues from biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste”. (Renewable Energy Directive (article 2).

Bio-oil
Also known as pyrolysis oil is a liquid produced from pyrolysis. It has a calorific value of 17.5 MJ/kg and an energy density of 20-30 GJ/m3. Bio-oil can be combusted for power in boiler, stationary engines and turbines, or upgraded for transport fuel.

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

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

CHP
Combined Heat and Power production

Co-firing
Co-firing is a primary application of combusting industrial wood pellets aside with pulverized coal in older coal power plants. Typically co-firing enables 5-15% mixture of wood pellets combusted with coal in order to minimize investment costs, process
modification and, most of all, overall process efficiency. However, with equipment modernization 40% share of wood pellets is possible.

**Composting**
Composting is a process by which organic matter is degraded by a microbial population consisting of bacteria and fungi consuming oxygen and producing CO₂, water, compost or humus and heat (exothermic).

**CSR**
Corporate Social Responsibility

**EU**
European Union

**FAO**
Food and Agriculture Organization of the United Nations

**Food waste**
According to the proposal for a Directive amending the Waste Framework Directive, food waste is ‘food including inedible parts from the food supply chain, not including food diverted to material uses such as bio-based products, animal feed or sent for redistribution.’

**Forest**
The FAO FRA definition is used when classifying land as forest, not including land that has trees on it but is predominantly under agricultural or urban land use (FAO 2012). **Protected forests** (as defined by WDPA Consortium 2004) are excluded from the analysis and no conversion or use of protected forest is allowed. Forest that is not protected is considered as forests available for wood supply. Forests include natural and semi-natural forests, as well as forest plantations.

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

**Forest chips**
Forest chips are fresh wood chips made directly of wood that is harvested from the forest, used for energy production, and has not had any previous use (as opposed to wood chips from industrial by-products). There are several raw material types of forest chips:
- Tops and branches removed from trees during final felling
- Sawlogs that are rejected being unsuitable for material purposes due to decay etc.
- Delimbed small size stems or un-delimbed small-size trees from thinnings
- Pulpwood size logs allocated to energy production from thinning or final felling
- Tree stumps.

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2 WDPA Consortium, 2004: World Database on Protected Areas. Copyright World Conservation Union (IUCN) and UNEP-World Conservation Monitoring Centre (UNEP-WCMC)
Forest residues
Forest residues are sometimes referred to separately from forest chips. Forest residues are typically leftover branches, stumps and stem tops from logging operations – thinning or final felling, chipped and mostly used for energy production. Forest residues are gathered from the logging site and forwarded to the roadside to be loaded on truck for long distance transport.

FSC
Forest Stewardship Council

Fuelwood (firewood)
Fuelwood is roundwood being used as fuel for such purposes as cooking, heating or power production. It includes wood harvested from main stems, branches and other parts of trees (where these are harvested for fuel) and wood that is used for the production of charcoal (e.g. in pit kilns and portable ovens), wood pellets and other agglomerates. The volume of roundwood used in charcoal production is estimated by using a factor of 6.0 to convert from the weight (mt) of charcoal produced to the solid volume (m³) of roundwood used in production. It also includes wood chips to be used for fuel that are made directly (i.e. in the forest) from roundwood. (FAOSTAT) In this project, the household and industrial uses of fuelwood are sometimes separated and referred to, respectively, as firewood and roundwood for energy.

Hardwood
Hardwood generally refers to all deciduous woods derived from trees classified botanically as Angiospermae, e.g. Acer spp., Dipterocarpus spp., Entandrophragma spp., Eucalyptus spp., Fagus spp., Populus spp., Quercus spp., Shorea spp., Swietonia spp., Tectona spp., etc. Sometimes referred to as broadleaves. (FAOSTAT)

ICT
Information and communications technology

Industrial By-Products
Industrial by-products include industrial chips, sawdust, shavings, trimmings and bark. They are supplied as by-products available in proportions from the processes of wood products industry, mainly sawmilling but also wood based panels and joinery production. Industrial by-products have to be clean and they are not altered by any chemical process. They are important raw materials for pulp, wood based panels (Particleboard, MDF/HDF) and wood pellet production as well as in bioenergy production as such.

Landfill
Directive 1999/31/EC on the landfill of waste defines landfill as a waste disposal site for the deposit of the waste onto or into land (i.e. underground), including internal waste disposal sites, and a permanent site (i.e. more than one year) which is used for temporary storage of waste.

m³ o.b.
Volume of roundwood in cubic meters measured over bark.

Mechanical pulp
Wood pulp obtained by grinding or milling: coniferous or non-coniferous rounds, quarters, billets, etc into fibres or through refining coniferous or non-coniferous chips. Also called groundwood pulp and refiner pulp. It may be bleached or unbleached. It excludes exploded and defibrated pulp, and includes chemi-mechanical and thermo-mechanical pulp. (FAOSTAT)
MDF/HDF
Medium-Density Fibreboard (MDF) is a wood-based panel made of fibres bonded together with resin. When density exceeds 0.8 g/cm³, it may also be referred to as “High-Density Fibreboard” (HDF). It is reported in cubic metres solid volume. The board is relatively homogeneous throughout its thickness without distinctive surface and core layers. Therefore the processing qualities are better than with solid wood and particleboard. (FAOSTAT)

Mtoe
Million tonnes of oil equivalent. One tonne of oil equivalent (toe) refers to the amount of energy released by burning one tonne of crude oil.

NREAP
National Renewable Energy Action Plan

OSB
Oriented Strand Board is a structural board in which layers of narrow wafers are layered alternately at right angles in order to give the board greater elastomechanical properties. The wafers, which resemble small pieces of veneer, are coated with e.g. waterproof phenolic resin glue, interleaved together in mats and then bonded together under heat and pressure. The resulting product is a solid, uniform building panel having high strength and water resistance. It is reported in cubic metres solid volume. (FAOSTAT)

Other industrial roundwood, other wood products
Roundwood used for tanning, distillation, match blocks, gazogenes, poles, piling, posts, pitprops, etc. (FAOSTAT)

Other natural vegetation (other natural land)
Other natural land is a land use category as used in GLOBIOM that includes a mixture of land that cannot be properly classified such as unused cropland (if not fallow) or grassland, including natural grasslands.

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

Perennial ligno-cellulosic biomass
Perennial ligno-cellulosic biomass covers biomass from species such as miscanthus and reed canary grass that can be established and used to produce biomass for energy purposes.

Plywood
Plywood is a panel consisting of an assembly of veneer sheets bonded together with the direction of the grain in alternate plies generally at right angles. The veneer sheets are usually placed symmetrically on both sides of a central ply or core that may itself be made from a veneer sheet or another material. It excludes laminated construction materials (e.g. glulam), where the grain of the veneer sheets generally runs in the same direction. It is reported in cubic metres solid volume. (FAOSTAT)
**Production capacity**
Production capacity is the volume of products that can be generated by a production plant or enterprise in a given time period by using current machinery. Several factors e.g. lack of raw materials can cause the actual production to remain below the maximum production capacity.

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

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

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

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

**Residential Wood Pellets**
Residential wood pellets are manufactured from clean by-products of sawmilling industry (sawdust, chips, and shavings); according to strict standards in terms of size, shape, cleanliness and moisture content (i.e. EN 14961). They are used in small scale wood pellet heating applications requiring uniform quality of fuel.

**Residue-to-crop ratio**
Describes the ratio of the amount of residues resulting from crop production and the amount of crops produced.

**Roundwood**
Roundwood is an aggregate comprising of felled or otherwise harvested and removed wood, with or without bark. It includes sawlogs and veneer logs; pulpwod, round and split; other industrial roundwood, and also branches, roots, stumps and burls (where these are harvested). It is reported in cubic metres solid volume.
Roundwood for energy
Roundwood that is directly used for energy production in small or large conversion facilities. This category does not include the wood biomass obtained from industrial by-products, nor firewood (household use of energy for fuel), nor forest residues. As such, the category accounts for stem wood that is of industrial roundwood quality and could be used for material purposes by the forest-based sector but that is instead being used for energy production.

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

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

Sewage sludge
According to Article 2(a) of the Directive on sewage sludge used in agriculture (86/278/EEC) sludge is 'i) residual sludge from sewage plants treating domestic or urban waste waters and from other sewage plants treating waste waters of a composition similar to domestic and urban waste waters; ii) residual sludge from septic tanks and other similar installations for the treatment of sewage; iii) residual sludge from sewage plants other than those referred to in i) and ii).’

SRC
See Short Rotation Coppice

Short Rotation Coppice
Short rotation coppices are formed by tree plantations established and managed under an intensive, short-rotation regime on agricultural land. They can be established with quickly growing species such as poplar and willow, and managed under a coppice system in a two-to-five-year rotation.

Softwood
Softwood generally refers to all coniferous woods derived from trees classified botanically as Gymnospermae, e.g. Abies spp., Araucaria spp., Cedrus spp., Chamaecyparis spp., Cupressus spp., Larix spp., Picea spp., Pinus spp., Thuja spp., Tsuga spp., etc. (FAOSTAT)

Solid wood equivalent
Solid wood equivalent (SWE) represents the volume of roundwood that is contained in a given amount of wood material. Typically, pulp and pellets are measured and reported in tons. In this report, 1 ton of mechanical or chemical pulp=2.22 m³ SWE, and 1 ton of pellets=2.5 m³ SWE. In addition, fibreboard is more dense than roundwood, and following, 0.7 m³ of fibreboard=1 m³ SWE in this report.
Textile waste
Textile waste consists of all kinds of textile and leather material which are discarded. This includes used packaging, worn clothes and used textiles, and waste from fibre/leather preparation and processing, as well as separately collected textile and leather.

Torrefaction
Torrefaction is a pre-treatment technology where the biomass is slowly heated to 240-300 °C in the absence of oxygen. The treatment degrades the biomass into a coal-like product without major fibrous structure, making it easy to grind. The torrefied biomass has a calorific value of 19-23 MJ/kg and a high energy density. Torrefied wood pellets are sometimes called “black pellets” or “pelletized biocoal”.

Used and unused forest
Unused forests do currently not contribute to wood supply, based on economic decision rules in the model. However, they may still be a source for collection and production of non-wood goods (e.g. food, wild game, ornamental plants). Forests that are used in a certain period to meet the wood demand, so-called used forests, are modelled to be managed for woody biomass production. This implies a certain rotation time, thinning events and final harvest.

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

Waste
The Waste Framework Directive (2008/98/EC) defines waste ‘any substance or object which the holder discards or intends or is required to discard’.

(Waste) prevention
According to Article 3(12) of the Waste Framework Directive (2008/98/EC) prevention means ‘measures taken before a substance material or product has become waste, that reduce a) the quantity of waste [...]; b) the adverse impacts of the generated waste on the environment and human health; or c) the content of harmful substances in materials and products.’

Wood Based Panels
This product category is an aggregate comprising veneer sheets, plywood, particle board, and fibreboard. It is reported in cubic metres solid volume. (FAOSTAT)

Wood chips
Wood chips are wood that has been reduced to small pieces and can be used for material production or as a fuel. For pulping, particle board and/or fibreboard production, the chips need to be without bark, for fuel use the wood chips may contain bark.
Wood pellets
Wood pellets are refined wood fuels traditionally made of clean industrial by-products of the mechanical wood industry, mainly wood chips, sawdust and/or shavings. Wood pellets are cylinder shaped and their diameter varies between 6 - 8 mm and length between 10 - 30 mm. The heat value of one kilogram of pellets correspond almost half a litre of light fuel oil. Unlike other wood based commodities (sawnwood, wood based panels) the production, consumption or traded volumes of wood pellets are usually reported in tonnes. In trade of wood pellets price reference is commonly set per tonne of pellets.
Foreword

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 date, 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\(^3\) used in the 2014 EU Impact Assessment\(^4\). The analysis focuses on biomass use for heat and electricity, hence excluding biofuels.

The information and views set out in this report are those of the author(s).
1. Introduction and the use of prospective scenarios

The starting point for the study is the EU 2020 climate and energy targets and the proposed EU 2030 framework and targets. In this context, the baseline of this study will be specified as close as possible to that of the EU Reference Scenario\(^3\) used in the 2014 EU Impact Assessment\(^4\) (hereafter referred to as the “2014 IA report”). The GHG emission reduction scenario of this study will follow the GHG 40 EE scenario specified in the same IA. Furthermore, this study uses the same modelling framework (e.g. GLOBIOM\(^5\) and G4M\(^6\)) for analysing the land use implications as the Commission reports, which improves consistency and comparability between the reports.

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 model computes market equilibrium for agricultural and forest products by allocating land use among production activities to maximize 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 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 is modelled following spatial equilibrium approach, which means that the trade flows are balanced out between different specific geographical regions. This allows tracing of bilateral trade flows between individual regions. A more detailed description of the model frameworks that are applied for this project is provided in Chapter 4 and Annex II.

In this study, biofuels are left outside the analysis of the results. Biomass used for the production of biofuels for the transport sector is still included in the modelling framework, and the full range of biofuel feedstocks and technological pathways available for production of 1\(^{st}\) and 2\(^{nd}\) generation biofuels are considered. Demand projections for biofuels will be the same as in the scenarios of the 2014 IA report. However, when discussing various different uses of biomass within this project, we include all other uses of biomass except for biofuel. Furthermore, the use of harvesting residues and waste related biomass feedstocks is also being left out in this Task report. As that of the use of biomass for the production of biofuel for the transport sector, the use of agricultural residues and waste related biomass feedstocks is considered within the modelling framework and their demand projections are fixed to that of the scenarios of the 2014 IA report. A more detailed description of how this is done is provided in Annex I.

In this project, a baseline scenario was first constructed to project future development as a continuation of on-going trends and historical developments. The scenario as such depicts a development trajectory wherein current policies remain unchanged, no new policies come into play, and no major changes from past trends occur. In addition


\(^6\) Gusti M. An algorithm for simulation of forest management decisions in the global forest model. Artificial Intelligence (2010a) N4:45-49.
to the baseline scenario, a number of policy scenarios were produced to highlight alternative future development and analyse their implications. Each policy scenario is built around a clear storyline and will focus on a single particular issue or aspect of the bioenergy markets. To allow a clear identification of the consequences and trade-offs related to the policy developments analysed, change in assumptions in a policy scenario only affects a part of the modelling framework being used. With this construction, differences in outcomes between the baseline and a policy scenario can be directly attributed to the issue that the policy scenario is reflecting.

The impacts of different scenarios were evaluated on 2030 and 2050 time horizons. Comparisons among scenario projections estimate how policy scenarios impact indicators such as regional production of different types of biomass, forest management strategies, international trade of biomass between countries/regions, and use of biomass resources in relevant sectors (e.g. energy, building, wood-processing industry).

The modelling efforts will also focus on evaluating the environmental and natural resource implications of the policy scenarios. This will be performed in a two-stage approach where scenario-specific results will first be analysed in order to quantify the impacts on aspects such as biodiversity, soil, land use (including direct and indirect land use change), overall greenhouse gas (GHG)-balance in the LULUCF (land use, land use change and forestry) sector, and forest carbon stocks (see report from Task 4). In a second stage, and depending on the modelling results obtained in the first step, a set of constraints will be imposed in the model in order to limit the environmental impacts that appeared the most salient ones in the results of the 1st stage of the modelling (this will therefore mimic the introduction of sustainability criteria related to these impacts). Thereafter, the analysis of the impact specific indicators will be re-run.
2. Baseline and policy scenarios – overview

The analysis of this study is based on the 2020 climate and energy package by the Commission and framed within the context of EU targets for renewable energy targets for 2030 and 2050. For this purpose, the Baseline and Emission Reduction Scenario were specified as close as possible to that of the reference and GHG40/EE scenarios used in reports for the Commission\textsuperscript{3,4}. Furthermore, this study uses the same modelling framework (e.g. GLOBIOM) for analysing the land use implications as the Commission reports, which improves consistency and comparability between the reports. Underlying scenario-specific development for the Rest of the World (RoW) has been updated to take into account the recent GECO 2015\textsuperscript{7} analyses. Further adjustments in terms of scenarios, assumptions, and model constructions between this project and that of the 2014 IA\textsuperscript{4} are detailed in Chapter 4 and under scenario descriptions in Chapters 5 and 6.

To analyse the impact of increasing EU bioenergy demand and developments in the (RoW), the following baseline and policy scenarios will be applied and analysed within the project (see also Table 1):

- **Baseline Scenario**: Assumes a continuation of current trends of bioenergy demand. This scenario follows the most recent Reference Scenario for EU\textsuperscript{3} with some adjustments. The main deviations from the EU Reference Scenario are: (I) updating the data concerning the current production and use of biomass based on results from Task 1 (see Chapter 2.2), (II) not applying pre-described feedstock-specific bio energy demands projection, instead allowing for substitutions between feedstock categories and selecting the feedstock’s to be used for energy purposes based on land use competition, (III) applying scenario-specific development of bioenergy demand and social-economic drivers in RoW according to GECO 2015 baseline (see Chapter 4.3).

- **EU Emission Reduction Scenario**: Explores the possible consequences of an increasing bioenergy demand, in line with the proposed EU decarbonisation objectives for 2030/2050\textsuperscript{4}.

- **Constant EU Bioenergy Demand Scenario**: Explores the implication of bioenergy demand first increasing as in the EU Emission Reduction Scenario, and then stabilizing after 2020\textsuperscript{4}.

- **Increased RoW Bioenergy Demand Scenario**: Assumes increasing bioenergy demand levels in the EU as in the EU Emission Reduction Scenario, as well as increased bioenergy demand for the RoW as described in the GECO 2015 Global Mitigation Scenario\textsuperscript{7}.

- **Increased EU Biomass Import Scenario**: Examines the implications of a higher level of biomass imports to EU from RoW for meeting the proposed EU decarbonisation objectives for 2030/2050. Also, the scenario assumes a higher biomass demand level than the baseline scenario, in line with the EU Emission Reduction Scenario.

Table 1. Overview of the main differences between the baseline and policy scenarios.

<table>
<thead>
<tr>
<th>Main model parameters</th>
<th>Bioenergy demand in EU28</th>
<th>Bioenergy demand in RoW</th>
<th>Biomass import to EU28</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline</strong></td>
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<tr>
<td><strong>Baseline Scenario</strong></td>
<td>As in EU Reference Scenario</td>
<td>As in GECO Baseline Scenario</td>
<td>Estimated by model</td>
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<td><strong>Policy scenarios</strong></td>
<td></td>
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<tr>
<td><strong>EU Emission Reduction Scenario</strong></td>
<td>As in GHG40/EE (increased level in 2050 compared to baseline)</td>
<td>As in baseline</td>
<td>Estimated by model</td>
</tr>
<tr>
<td><strong>Constant EU Bioenergy Demand Scenario</strong></td>
<td>As in GHG40/EE until year 2020, then constant</td>
<td>As in baseline</td>
<td>Estimated by model</td>
</tr>
<tr>
<td><strong>Increased RoW Bioenergy Demand Scenario</strong></td>
<td>As in GHG40/EE</td>
<td>As in GECO Global Mitigation Scenario (increased level compared to baseline)</td>
<td>Estimated by model</td>
</tr>
<tr>
<td><strong>Increased EU Biomass Import Scenario</strong></td>
<td>As in GHG40/EE</td>
<td>As in baseline</td>
<td>Enhanced import (estimated by model)</td>
</tr>
</tbody>
</table>
3. Summary of the key findings

3.1 Baseline scenario

The Baseline scenario of this project 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. It is based on the EU Reference Scenario of the 2014 Impact Assessment (Commission 2014) for the EU, and the GECO2015 baseline for rest of the world (RoW). Updates have been made on the set of biomass feedstocks and forest industry representation, but the aim has been to keep the Baseline of this study and that of the EU Reference Scenario as comparable as possible.

The results show a clear increase of wood used for both material and energy production between 2010 and 2050 in the Baseline scenario. On the bioenergy side, considerably larger amount of wood biomass is needed for energy production already in 2030, compared to the 2010 level. While the firewood used for domestic heating is expected to gradually decrease as a result of shifting to district heating and more advanced technologies for power production and improvements in energy efficiency, other feedstocks for energy production are seen to increase notably. Half of the total biomass for heat and power production in 2010 is retrieved from industrial by-products of wood material industries (sawdust, wood chips, bark and black liquor), and its share 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 main increase in the total volume of industrial by-products is expected to come from sawnwood production, which increases by almost 50% between 2010 and 2050.

EU pellet imports almost double between 2010 and 2030, from 10 Mm$^3$ to 19 Mm$^3$, and continue to increase, albeit with a slower rate, reaching 23 Mm$^3$ in 2050. The current main trade partners, USA, Canada and the area of the former Soviet Union continue as important pellet trade partners. Additionally, EU imports of wood pellets from Latin America and South-East Asia (Indonesia) increase significantly by 2050.

In terms of land use on the EU28 level, SRC is projected to become a major source of biomass for bioenergy, increasing from negligible amounts in 2010 to 44 million m$^3$ in 2030, and further to 60 million m$^3$ in 2050, which is 14% of all woody biomass used for heat and power production in 2050, and more than 50% of the total increase of woody biomass use for energy from 2010 to 2050. An additional impact to that of the development of SRC, is that of a large intensification in the use of EU forests. The forest harvest level in the Baseline scenario is seen to increase from 556 million m$^3$ to 616 million m$^3$ (11%) between 2010 and 2030, and reaches a harvest level of 648 million m$^3$ by 2050 (17% higher than in 2010).

Also the EU net import of roundwood increases, from 25 Mm$^3$ in 2010 to 33 Mm$^3$ in 2030 and 47 Mm$^3$ in 2050. This development results mainly from increased production of woody materials, most profoundly sawnwood but also boards and pulp. The increase in the material sector is driven by the population and GDP projections in the EU and RoW, which lead to growing EU consumption of woody materials and EU

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8 Pellet trade is here presented in volume of solid wood equivalent (SWE) to enable comparison with the other feedstocks. In reality, pellet trade is reported in tons.
exports of especially sawnwood. **The rapid increase of bioenergy demand between 2010 and 2030 is seen to also lead to some roundwood used directly for bioenergy; by 2050 the use of stemwood for energy is instead replaced by increasing SRC and pellet imports.**

### 3.2 Policy scenarios

In addition to the Baseline scenario, four policy scenarios were developed. Each of these scenarios focus on a particular issue in bioenergy demand and trade of biomass. The main findings of these scenarios are highlighted here.

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 use of imported pellets** (52 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 directly 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 9% increase to the Baseline results for that year.

**Constant EU Bioenergy Demand scenario** investigates the effects of a policies that increase the EU bioenergy demand similarly until 2020, but stay constant thereafter. As the population and GDP development is still projected to continue as in Baseline, there are only small differences between this scenario and the Baseline on the material production side. However, there is a clear difference in the composition of feedstocks used for energy production. Most importantly, there is only little pressure to produce SRC for energy. The policies until 2020 require an increase in the production of SRC, but thereafter the bioenergy demand can be increasingly satisfied through other feedstocks. Pellet imports increase as well until 2020, but remain almost constant thereafter. **No roundwood is used directly for energy in this scenario.** The development of heat and power technologies are projected to stagnate in this scenario, resulting in a higher level of firewood used for domestic heating than in the Baseline. Compared to the Baseline scenario, there is more particleboard production and less sawnwood production in this scenario. As the demand for industrial by-products from sawmills (chips and sawdust) for bioenergy production is lower, the profitability of sawmills decreases, leading into less production. On the other hand, particleboard production using this feedstock for material production becomes more profitable. Overall, the harvest level in the EU in 2050 is 15 million m$^3$ (2.3%) lower than in the Baseline.

The third policy scenario, **Increased 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 other scenarios. Indeed, the results show that with an increased RoW bioenergy increase, 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**
The fourth policy scenario, **Increased EU Biomass Import scenario**, investigates the impact of increasing EU reliance to imported biomass resources to see how domestic production reacts to decreased trade costs. Consequently, EU net import of roundwood grows to 71 Mm$^3$ by 2050 (22% increase compared to the EU Emission Reduction scenario), and EU net import of pellets grows to 218 Mm$^3$ (more than four times the amount foreseen in the EU Emission Reduction scenario). Here, the production of pellets in North America and especially USA will not be enough to satisfy the pellet demand in the EU: instead, Latin America and South-East Asia grow into important pellet suppliers, alongside with Canada and the former Soviet Union. 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. While the material production level in the EU grows slightly (especially particleboard and chemical pulp production), the harvest level is only 624 Mm$^3$ in 2050, an 11% decrease to the EU Emission Reduction scenario and a 3.7% decrease to the Baseline scenario.

### 3.3 Analysis of model assumptions

In addition to the analysis of the various scenarios, central modelling assumptions were assessed in the case of the EU Emission Reduction scenario. The analysis highlights the increasing future connectivity between the use of SRC, pellets, and forest-based industrial by-products. In particular, the analysis highlighted a **high substitution effect between SRC production and pellets import as of 2030 and 2050**. In other words, it is expected that if SRC production decreases, 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, the model predicts that 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 as of 2050. 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 to increase the cascading use of wood were evaluated. The analysis shows that **an increasing use of recovered 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**. On the other hand, while a tax directly related to the energy use of virgin use of wood would nominally 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.
4. Models

4.1 Overview of the applied integrated framework

At the center of the analysis for this study are two modeling tools that are developed and run by IIASA: an economic land use model GLOBIOM\(^9\) that will be utilized together with a detailed forestry sector model G4M\(^{10}\).

GLOBIOM is an economic model that jointly covers the forest, agricultural, livestock, and bioenergy sectors, allowing it to consider a range of direct and indirect causes of biomass use. The wood demand estimated by GLOBIOM is used as input in G4M, a detailed agent-based forestry model that models the impact of wood demand in terms of forestry activities (afforestation, deforestation, and forest management) and the resulting biomass and carbon stocks. In essence, G4M is a geographically explicit model which in combination with GLOBIOM helps to evaluate changes in national silvicultural forest practices related to changing demand and price information.

Both GLOBIOM and G4M rely on input data that describe production, trade, and demand in a base year, which are used to calibrate the model. In this study, the data provided in Task 1 will be used as such input data, allowing us to i) gain knowledge about the current "state of play" of biomass use so that differences over time and between scenarios can be assessed and ii) ensure that the models are well calibrated to produce robust results.

The information between the GLOBIOM and G4M models is circulated between modeling levels (economic land use and detailed forest sector models) iteratively. The baseline development and all scenarios will be built on flows of data and information in a specific order that is summarized below:

- Prior to the baseline calculation, GLOBIOM receives data from G4M on forest management parameters (e.g., forest increment, harvesting costs, management intensification possibilities), forest area, protected areas, initial NPV of agricultural land, initial wood prices;
- Similarly, EPIC\(^{11}\) delivers potential yields of a large variety of crops that can be grown for food, feed, and bioenergy production;
- After baseline calculations in GLOBIOM that include global competition of world regions and EU countries for different commodities, the model returns to G4M total timber production (domestic), and land and wood prices;
- G4M then computes change in forest area (e.g., afforestation/ deforestation/ intensification) and carbon stock.

With this set up, the G4M model serves also as a downscaling tool from the economic land use model to provide detailed analysis of impacts on forest carbon stock changes and other GHG emissions. This ensures that important details of specific sector characteristics are included in projections and in the analysis of the scenarios. On the other hand, it's the role of GLOBIOM to put biomass uses into competition with each other (e.g. competing between forest based industries and the bioenergy sector) and with other ecosystem services. GLOBIOM also ensures a consistent embedding of the analysis in global scenarios.

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\(^9\) See also: www.iiasa.ac.at/GLOBIOM

\(^{10}\) See also: www.iiasa.ac.at/G4M

\(^{11}\) See also: www.iiasa.ac.at/EPIC
4.2 Input data from Task 1

In this study, year 2010 is used as a starting point for the analysis. The GLOBIOM description of 2010 was complemented with data and analysis derived from Task 1. This data involves relevant international statistics (e.g., EUROSTAT, FAO, JWEE), national reporting, and other publicly available databases. This chapter provides an overview of the key information from Task 1 that was integrated into GLOBIOM within this study.

Initial capacities of forest based industries

GLOBIOM covers the production of the following forest industrial products: chemical pulp, mechanical pulp, sawnwood, plywood, fiberboard, and wood pellets. On a global scale, initial capacities of the forest industries producing these commodities are based on the production quantities from FAOSTAT. That is, production capacities for 2010 are assumed to be equivalent to production for the same year and no unused capacities are considered to be available. More detailed data concerning the production capacities of the forest based industries as collected in Task 1 was applied to provide more detailed information on the EU level. Still, no overcapacity was assumed for EU, in order to provide consistency with the global assumptions.

Household fuelwood (firewood) consumption

Production of fuelwood is a large cause of harvesting operations within the EU as well as globally. GLOBIOM covers household fuelwood, and initial national consumption levels are specified based on FAOSTAT figures. However, fuelwood consumption is generally considered highly uncertain as all sources of consumption do not show up in statistics, and as reporting is not consistently applied on a global level. To improve the estimate of the fuelwood consumption level for EU and refine the representation of how forests are being used in this study, we applied the numbers estimated in Task 1 for EU27, which are based on data from the Joint Wood Energy Enquiry (JWEE) and National Statistics. For countries outside of EU, FAOSTAT numbers were used. There is also recent development of private households shifting to pellet consumption replacing the traditional collected firewood. Such a shift in consumption patterns and its direct and indirect effects are not taken into account within the framework of this project.

Collecting of forest residues and forest chips

Collecting of forest residues (e.g. leftover branches, stumps and stem tops from logging operations) and producing forest chips on the logging site is becoming a large source of wood for energy production in a number of countries. However, not all countries collect and report national information about the production and consumption of forest chips, making consistent global information sources scarce. For this study, we applied the estimates as provided in Task 1 based on the compilation of national statistics and JWEE reporting. That is, harvesting of forest chips within GLOBIOM was baselined for 2010 according to the estimates provided in the Task 1 report. With this approach, the major consumer countries of forest chips within EU27 are represented as accurately as possible. For countries which were not covered in the Task 1 report, expert estimates of harvesting of forest chips were used.

Production of industrial by-products

The GLOBIOM model covers the production of four main types of by-products from the forest-based processing industry: sawdust, bark, wood chips, and black liquor. Data concerning the supply and consumption of these commodities was reported in Task 1 and applied here to provide a baseline for 2010. The data was used to define a baseline of the national supply of each by-product as well as consumption for the various end-use segments. That is, the national input-output coefficients of the...
industrial processing technologies where adapted to fit with the data reported in Task 1.

No learning in terms of technical conversion technologies (input-output coefficients) was applied across the range of forest based industrial production technologies.

**Recovered wood**

GLOBIOM has been extended within the project to cover recovered wood (e.g. wood from used packaging material, scrap timber from building sites, wood from demolition projects) used for production of wood based panels and/or energy purposes. Data concerning the availability and consumption of recovered wood as collected within Task 1 was applied to provide a baseline for 2010. The national-specific share concerning the use of recovered wood between forest-based industries and the energy sector as specified in the Task 1 report was also applied into GLOBIOM. For all countries for which no national specific data could be provided within Task 1, average availability and consumption numbers were applied based on expert estimates.

However, it is worth to notice here that there are large uncertainties surrounding the future sourcing of wood for the bioenergy sector in terms of how much wood can be provided from forest residues, forest-based industrial by-products, recovered wood, and the direct sourcing of roundwood from harvesting operations to energy production.

**SRC and ligno-cellulosic biomass**

The land potentially available for the biomass production from Short Rotation Coppice (e.g. willow, poplar) and ligno-cellulosic biomass (e.g. miscanthus and reed canary grass) is in GLOBIOM the same as that of the 2014 IA report. Initial land use is within the model set according to CORINE/PELCOM land cover estimates for EU and the Global Land Cover 2000 (GLC 2000). These sources of information provide an accurate baseline for the year 2000 according to which GLOBIOM can be calibrated. Note though that the use of agricultural land for the production of SRC and ligno-cellulosic biomass is highly driven by the bioenergy demand, which is set according to the PRIMES and POLES estimates.

Cost structures for SRC and ligno-cellulosic biomass in GLOBIOM are also the same as those of the 2014 IA report. Calculated plantation costs involve the establishment cost and the harvesting cost. The establishment related capital cost includes only sapling cost for manual planting (Carpentieri et al., 1993; Herzogbaum GmbH, 2008). Labour requirements for plantation establishment are based on Jurvelius (1997), and consider land preparation, saplings transport, planting and fertilization. These labour requirements are adjusted for temperate and boreal regions to take into account the different site conditions. The average wages for planting are obtained from ILO.

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For further details about cost and yield assumption for SRC, we refer to Havlík et al. (2011)16.

**Cropping residues, residues from livestock, and biogenic waste**

The Task 1 report provided information concerning the supply and demand of a number of sources of agricultural and waste related biomass feedstocks that can be used for the production of heat, electricity, and biofuels. A number of national specific sources were available that cover cropping residues, residues from the livestock sector, paper and cardboard waste, sewage sludge, textile waste, bio-waste, and food waste. The availability of these feedstocks are taken into account in the GLOBIOM modelling framework as well as the full range of technological pathways available for their conversion to heat, electricity, and biofuels. However, the PRIMES feedstock specific demand pathways will be applied for these biomass resources as that of the scenarios of the 2014 IA report. That is, the demand of these commodities for bioenergy production are strictly kept to that of the PRIMES estimates and we make no attempt to assess the competitiveness of these feedstocks against each other, nor other potential biomass sources.

### 4.3 Bioenergy demand projections

Within this project, all bioenergy demand projections for heat, electricity and transport are exogenously defined and not evaluated within the used modelling framework. The project makes no attempt to estimate future bioenergy demand levels. **For EU28**, the same bioenergy demand projects as estimated by PRIMES for the EU Reference Scenario3 and GHG40/EE scenario as specified in the 2014 IA report4 were taken as the basis for the various scenarios. An overview of the demand projections for the two EU28 bioenergy demand scenarios is provided below in Table 2. **For the Rest of the World (RoW)**, this project uses the solid and liquid bioenergy demand projections as presented in the latest 2015 GECO POLES report7. As a basis for the scenarios within this project, the baseline and Global Mitigation Scenario projections will be used for the RoW. It should be noted that these are not the same bioenergy demand projections for RoW as used for the 2014 IA report4.

For each individual EU Member State, GLOBIOM takes the demand projections of each PRIMES biomass feedstock directly as input. Furthermore, import to EU28 from RoW of biomass feedstocks directly for bioenergy production (heat, electricity and transport) is also taken as input to GLOBIOM from PRIMES. The GLOBIOM model thereafter makes sure that the trade and production of each feedstock for the bioenergy sector is equal or higher than that given by PRIMES. **The bioenergy demand is expressed within the model as a hard constraint that always has to be fulfilled.** That is, the model makes sure that the bioenergy demand is fulfilled even if it reduces the availability of biomass resources for other purposes.

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Table 2: Biomass demand for energy purposes as of the 2014 IA for EU28 (Mtoe). Note that the category “crops” in this table both covers domestic biomass used for the production of heat, electricity, and biofuels.

<table>
<thead>
<tr>
<th></th>
<th>2005</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic production biomass feedstock (Mtoe)</td>
<td>87</td>
<td>194</td>
</tr>
<tr>
<td></td>
<td>191</td>
<td></td>
</tr>
<tr>
<td>of which: forestry</td>
<td>33</td>
<td>48</td>
</tr>
<tr>
<td>of which: crops</td>
<td>4</td>
<td>65</td>
</tr>
<tr>
<td>of which: agricultural residues</td>
<td>12</td>
<td>16</td>
</tr>
<tr>
<td>of which: waste</td>
<td>28</td>
<td>47</td>
</tr>
<tr>
<td>of which: other (i.e. black liquor)</td>
<td>9</td>
<td>17</td>
</tr>
</tbody>
</table>


For the 2014 IA, the PRIMES-estimated domestic production of biomass feedstocks for bioenergy production were used as input to the GLOBIOM model. It should be noted that the split between the various feedstock categories in the 2014 IA was strictly enforced within GLOBIOM, meaning that no substitution was allowed between the use of forestry biomass, lignocellulose perennials grown on agricultural land, and biomass produced from Short Rotation Coppice (SRC). As such, the biomass demand for energy purposes for each feedstock was fixed and the shares could not change. In this project, this constraint was released, allowing for full substitution potential between forest, SRC, and industrial by-products from the forest sector. This change in assumptions from the modelling of the 2014 IA report provides information concerning feedstock competitiveness and allows full analysis of the balance between feedstock supply assumptions and demand. The constraint was however maintained in this project for cropping residues, residues from the livestock sector, paper and cardboard waste, sewage sludge, textile waste, bio-waste, and food waste as well as demand and supply of biofuels for transport applications.

For the 2014 IA, the PRIMES-estimated trade of biomass feedstocks between EU28 and the RoW for bioenergy production (heat, electricity, and transport) was also used as input to the GLOBIOM model. Trade of feedstocks was for the 2014 IA strictly enforced within GLOBIOM so that the amount of trade matched the estimates by PRIMES. For this project, the trade of feedstocks for biofuel production and trade of biofuels (conventional biodiesel and bioethanol) between EU28 and RoW was kept fixed according to the estimated by PRIMES. On the other hand, trade constraints for solid biomass for electricity and heat production were released, thereby allowing GLOBIOM to estimate the trade of each wood biomass feedstock between EU28 and RoW.

A detailed overview of how the bioenergy demands estimated in the 2014 IA report were treated within the GLOBIOM model is provided in Annex I.

4.4 Trade assumptions concerning wood biomass

As the representation of the forest materials and the forest sector has been updated for the ReceBio project, trade assumptions concerning the use of these new products have also been updated. Figure 1 shows the setup for the trade of primary woody products modelled in the GLOBIOM model framework for the ReceBio project. Here, the category “Traded product” covers only the traded primary woody products, namely chips for material use, pellets, and roundwood. Firewood trade is included only within
the EU28 to stabilize results as this biomass source is not substantially traded between regions (FAOSTAT\textsuperscript{17}). No trade of harvest residues is modelled in the project as we currently do not consider this being traded due to a lack of reliable data to harmonize the trade flows. The trade of semi-finished forest products is described later in this document.

**Figure 1.** Trade of primary woody biomass between EU28 and the RoW as considered in the model, showing the source of the traded products and the end use. Note that no trade outside of the EU is modelled for firewood. Also, the trade of chips accounts for chips used for material purposes only; the model assumes that all particles traded for energy use are traded in pelletized form.

**Key assumptions**

- SRC and eucalyptus plantations can both be used for the production of chips for material use and pellets for energy use.
- Pellets are within the model allowed to be produced from industrial by-products, SRC and eucalyptus plantations. These conversion pathways are accounted for to allow for future developments and changes in pathways. Roundwood is modelled to not be eligible as a production feedstock for pellets due to the lack of reliable data of the current use of this source of wood for production of pellets.
- Firewood is only allowed to be traded between EU 28 countries. Currently, there is some existing trade between RoW countries, but its value is very small due to the bulkiness of firewood and its low price. In the model, we include trade within the EU 28 to allow for small countries with small forest areas to continue to trade firewood for household energy needs.

\textsuperscript{17} FAOstat. http://faostat3.fao.org/download/F/FT/E
• Harvesting residues (branches, tops, etc.) are not allowed to be traded between regions within the model framework. This is both due to lack of statistics of trade and the relative small amounts that are being traded.

Overview of trade representation in GLOBIOM

International trade of the considered feedstocks, processed, and final commodities from the forest, agriculture, and livestock sectors are computed endogenously within the GLOBIOM model between geographical regions. Trade of commodities is as such modelled following the spatial equilibrium approach so that bilateral trade flows between individual regions can be traced for each commodity. This approach applies both to feedstocks commodities (crops, residues, co-products) from the forest, agricultural, and livestock sector, as well as to semi-finished and final end-use products (wood, conventional and advanced biofuels). Trade is furthermore based purely on cost competitiveness as goods are assumed to be homogenous. This implies that imported goods and domestic goods are assumed to be identical and the only differences in their prices are due to the trading costs. There are two components in international trading costs in the model: international transportation costs which are mainly computed based on distance, and tariffs (Figure 2).

Within the model, 2000 year bilateral trade flows are first taken from BACI database which is an initiative of the CEPII (Gaulier and Zignago, 2008) to provide reconciled values and quantities of COMTRADE annual trade statistics at the HS6 product level. A trade calibration method (Jansson and Heckelei, 2009) is applied to reconcile bilateral trade flows with net trade as computed as the difference between the production in a region minus all domestic uses reported by the FAO. In addition, the trade calibration approach ensures that when two regions trade together, their prices only differ by the trading costs for the base year of 2000. After 2000, the model is freely allowed to elaborate on future trade flows. For this, non-linear trade costs are assumed when trade increase with the amount of traded quantities.

Figure 2. Price determination in the context of international trade in GLOBIOM.

19 BACI provides the historically trade flows where the trade between countries is fully reconciled such that reported imports for country A from country B, fully match that of reported export from country B to country A.
4.5 Definitions

The FAO FRA definition is used when classifying land as forest, not including land that has trees on it but is predominantly under agricultural or urban land use (FAO 201221). Protected forests (as defined by WDPA Consortium 200422) are excluded from the analysis and no conversion or use of protected forest is allowed. Forest that is not protected is considered as forests available for wood supply. The model allocates harvests to this area so that the projected demand for wood for material and energy purposes will be satisfied. These forests include natural and semi-natural forests, as well as forest plantations. In this project, we classify these forests as unused and used forests, depending on whether they contribute to the wood supply or not. Unused forests do currently not contribute to wood supply, based on economic decision rules in the model. However, they may still be a source for collection and production of non-wood goods (e.g. food, wild game, ornamental plants). Forests that are used in a certain period to meet the wood demand, so-called used forests, are modelled to be managed for woody biomass production. This implies a certain rotation time, thinning events and final harvest.

Examples of used forests are:

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

The model allows for conversion from used forests to unused, and unused to used forests. Initial selection of used and unused forest areas is done in G4M according to an approach described in Kindermann et al. 200823 and based on a global map of human influence (see CIESIN (2002)24). In its core, the map of human influence is created through overlaying global data layers. Data describing human population pressure (population density/population settlements), human land use and infrastructure (built up areas, night-time lights, land use/land cover), and human access (coastlines, roads, railroads, navigable rivers) are jointly combined to create the map of human influence.

Agricultural land includes cropland, grazing land, short rotation coppice and other natural vegetation. Cropland is land used for crop production. This also includes set-aside areas declared as cropland, but not currently used for crop harvesting (e.g. fallow land). This land category also includes annual and perennial lignocellulosic plants (e.g. miscanthus and switchgrass) that may be used for bioenergy and biofuel

22 WDPA Consortium, 2004: World Database on Protected Areas. Copyright World Conservation Union (IUCN) and UNEP-World Conservation Monitoring Centre (UNEP-WCMC).
production. **Short rotation coppices** are formed by tree plantations established and managed under an intensive, short-rotation regime on agricultural land. They can be established with quickly growing species such as poplar and willow, and managed under a coppice system in a two-to-five-year rotation. **Grazing land** contains of pasture lands used for ruminant grazing. It does not include natural grasslands. **Other natural vegetation** or other natural land is a category that includes a mixture of land that cannot be properly classified such as unused cropland (if not fallow) or grassland, including natural grasslands.

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

5.1 Storyline

The reference point of the assessment is a baseline scenario that is designed to be as comparable as possible to the EU Reference Scenario used in the 2014 IA report. The baseline scenario depicts the same development as the reference scenario and is based on the same underlying assumptions concerning socio-economic growth and policy targets for EU28. The underlying goal of the baseline scenario is to provide a projection of what the world could look like in the future if our policies continue in line with historical trends. For this, the scenario is based upon the latest available statistics, policies in place today, and the latest projections of key parameters such as population growth, energy prices and macro-economic development. 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 ongoing development of international fuel prices. Moreover, it portrays a future in which consumption patterns of food, fibre, and fuels continue to evolve over time following current trends.

The baseline scenario was slightly adjusted from that of the EU Reference Scenario of the 2014 IA study to provide a scenario that is consistent with the aim of this study. The main underlying socio-economic information (GDP growth, population development, fossil fuel prices etc.), consumption patterns of commodities, land cover information, trade, and total bioenergy demand will be the same between this study and the 2014 IA report. However, differences apply due to the use of updated data as collected within Task 1 of the project (state of wood-processing industries, bioenergy production from lignocellulosic biomass, biomass feedstock availability, cost and prices of biomass resources etc.) and model developments as performed within Task 3 of the project (disaggregation of wood and agricultural commodities, separation of bioenergy demand, in depth representation of the flow of commodities between industries, etc.). These changes may impact aspects such as forest harvest projections as the demand of wood for material and energy purposes can represented with a higher detail. Also, the production and use of biomass feedstock between alternative purposes can be affected, particularly for resources that are highly market driven. Further differences between this study and that of the 2014 IA report are explained in brief below, and in more detail in the Annex II.

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 will be 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 2012 onwards, no changes in policies are assumed and no new policies are considered. This implies that only already agreed policies in the context of the 2020 package will be accounted for. Regulatory policy instruments are maintained unchanged over time and no new targets or strategies are assumed to come into play. Resulting of these policies, and as estimated for the EU Reference Scenario, the renewable energy share (RES) in the EU28 would account for...

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25 See (Commission, 2014) for a full overview of all policies as considered in the scenario.
a 24.4% share of gross final energy consumption by 2030, and 28.7% in 2050. Biomass plays an important role in this trend and demand for biomass increases significantly from 2010 until 2020, after which demand increases at a slow pace until 2050.

Furthermore, the baseline has been developed along the lines of a limited global climate action, where non-EU regions provide a restricted amount of actions for reducing greenhouse gas (GHG) emissions. All Copenhagen and Cancun pledges are assumed to be followed, but no significant additional policy actions from non-EU regions are assumed to be put forward thereafter. For EU, only GHG emission reduction targets and renewable energy targets up to 2020 are accounted for in the baseline scenario.

The analysis will account for the impact of emissions connected to land use, land use change and forestry (LULUCF), but there is no feedback loop from LULUCF emissions to policy targets in play.

5.2 Main underlying assumptions

Assumptions in line with those in the EU Reference Scenario

- Global population growth and GDP projections until 2050 are exogenously assumed to develop over time.
- GDP for EU28 is expected to rise to 1.5% pa in 2010-20, 1.6% pa in 2020-30, and 1.4% pa in 2030-50. EU population is projected to increase up until 2040 and thereafter slightly decline, mainly due to decreasing net inward migration to EU. See Commission, 2014 for a full detailed description of assumptions concerning the development of socio-economic parameters.
- Bioenergy demand (heat, electricity, and biofuels) in EU28 evolves throughout the projection period in accordance with the EU Reference Scenario. Demands for all countries, regions, and years are implemented in the model as minimum constraints, meaning that a country can produce more but not less biomass for energy use than prescribed (e.g. not price elastic). By doing this it is assured that the production of biomass in the EU is achieved, but also allowing for flexibility to produce more if demanded, e.g. through international trade. Other (non-energy) wood products are competing for the wood resource. Further details of how the bioenergy demands are taken into account within the GLOBIOM framework are specified in Annex I.
- Demand of other wood products is globally assumed to stay constant over time and does not change due to price or demand fluctuations. The category is defined in accordance with the FAOSTAT category with the same name and includes “roundwood that will be used for poles, piling, posts, fencing, pitprops, tanning, distillation and match blocks”. The 2010 regional consumption levels are taken from the FAOSTAT statistics.
- Only those sustainability criteria for biofuels, solid and gaseous biomass that were assumed in the 2014 IA report are assumed to affect the development of the bioenergy sector and demand for bioenergy. These include (i) sustainable forest management practices that enhance forest productivity; (ii) minimization of process chain emissions; and (iii) efficient use of biomass to displace greenhouse gas–
intensive fuels. See the 2014 IA report\(^4\) for further details considering the underlying assumptions.

- Land cover for EU28 is based on the CORINE/PELCOM cover maps for the base year of 2000. For the rest of the World, GLC 2000 is used.
- No technical progress or improvement in efficiency is assumed for production of harvested woody products (HWP) or harvesting of forest biomass. Investment costs for new production capacities and conversion efficiencies of wood-processing industries as well as harvesting costs therefore remain constant over time.
- Agricultural and forestry production does not expand into protected areas; however, land conversion can occur on unprotected areas.
- Demand for food and fibre is driven by human population growth and changing GDP. Demand for commodities is price elastic and therefore changes depending on consumers’ willingness to pay. Demand is modelled through the use of constant elasticity functions which are parameterized by consumption quantities from EUROSTAT and FAOSTAT data on price and quantities. Own price elasticity for woody biomass commodities are based on Buongiorno et al. (2003), and price elasticity for agricultural commodities based on Seale et al. (2003). Historical data on production and prices of commodities (agricultural and forestry) was collected from individual country submissions, FAOSTAT, and EUROSTAT. From these statistics, values for the year 2000 are taken into account in the GLOBIOM modelling framework. Estimates for the years 2020, 2030, 2040 and 2050 are results from the model projections.
- Trade of commodities\(^26\) between EU Member State and RoW is endogenously estimated by the GLOBIOM modelling framework. Current forest management and rotation periods as globally estimated by the G4M model are applied (Kindermann et al., 2008b). Rotation periods and management, however, adapt over time to demand changes to maximize forest net present value (NPV) estimates. Age class structural developments are also accounted for both in terms of NPV estimations and potential harvest rates.
- Demand for first and second generation biofuel within EU28 develop over time until 2050 following the EU Reference Scenario.
- Energy savings are projected to develop in line with the EU Reference Scenario, reaching -21% in 2030 compared to the 2007 Baseline projections.
- Although the GHG target does also imply changes for the energy and transport sectors, these sectors are not explicitly covered by the chosen modelling framework and as such does not change assumptions used within the GLOBIOM modelling framework.

**Assumptions differing from the EU Reference Scenario**

- Population growth and GDP projections for the rest of the World have been updated to develop according to the 2015 GECO POLES baseline scenario\(^7\).
- For this study, the representation of the forest-based industries and woody commodities has been further disaggregated from what was considered for the EU

\(^{26}\) This includes agricultural and forestry products both in terms of feedstocks (e.g. industrial roundwood) and wood products (e.g. sawnwood).
Reference Scenario. For the EU Reference Scenario, five primary products were considered (pulp logs, saw logs, biomass for energy, traditional fuel wood, and other industrial logs), all inherently consumed by industrial energy, cooking fuel demand, or processed and sold on the market as final products (wood pulp and sawnwood). In this study, a number of primary products (harvesting residues), industrial by-products have been disaggregated (sawdust, sawchips, black liquor), and semi-finished woody products have also been added (fibreboard, plywood, wood pellets). This allows for more detailed representation of the demand development for specific wood commodities as well as the flow of commodities between industries.

- Household fuelwood (firewood) consumption for EU28 is assumed to develop over time according to PRIMES estimates of the development of the bioenergy production through Small Scale Solid conversion units. Data from Task 1 is used for consumption levels for the year 2010, after which the use of firewood decreases if large scale conversion units are installed and district heating networks are developed. Both increasing and decreasing demand of firewood is considered in line with PRIMES estimated development of Small Scale Solid conversion units. Firewood consumption for the rest of the World follows the POLES projections.
- Trade of household fuelwood (firewood) between EU Member States has been added to the GLOBIOM model framework for this project. Currently, some trade also exist between other countries/regions but its value is relative small due to the bulkiness of firewood and its low price (FAOstat). In the GLOBIOM model framework, trade within the EU28 has been included to allow for small countries with small forest areas to continue to trade firewood for household energy needs.
- Trade of wood chips for material use and wood pellets for energy use has also been incorporated into the GLOBIOM modelling framework. It is assumed that SRC and eucalyptus plantations can both be used for the production of chips for material use and wood pellets. Trade of harvesting residues (branches, tops, etc.) is not considered within the model framework.
- Wood chips as traded are restricted to be only used for material production (fibreboard, plywood, and pulp production) in accordance with the findings of the Task 1 report of this project and the lack of accurate trade data concerning the use of wood chips. The finding of the Task 1 is that the majority of chips for the EU residential market is sourced locally, and imported chips are exclusively used in district heating or CHP plants. Chips have mainly been imported for pulp and board production. This follows the global trends, as less than 10% of the global wood chip trade is estimated to be energy-related.
- Pellets are within the model allowed to be produced from industrial by-products, SRC and eucalyptus plantations. These conversion pathways are accounted for to allow for future developments and changes in pathways. Note that wood pellets is within the model framework assumed to be only applied for large scale industrial use such as co-firing with coal and district heating.
- No trade of harvest residues is modelled in the project due to a lack of reliable data to harmonize trade flows.
- Data concerning the state of forest-based industries as collected within Task 1 of the project will also here be fully integrated within the modelling framework. This allows for more accurate representation of the current state of the industries as well as the biomass sources being used for the production of the various woody commodities.
Demand for bioenergy in the EU28 is no longer disaggregated into two sources, energy produced based on biomass from forestry and energy produced based on biomass from short rotation forestry (SRF). A single bioenergy demand is instead being considered that contains biomass from both sources. With this assumption, we allow for complete competition for land and the use of biomass sources. That is, we do not prescribe a certain development for the agricultural nor the forest sector, but instead consider the full competition between these main sources of biomass feedstock as well as between the individual feedstock for each sector (e.g. for forest: stemwood, harvesting residues, industrial residues etc.). The change in assumptions in comparison to the modelling for the 2014 IA report provides information concerning feedstock competitiveness and allow full analysis of the balance depending on feedstock supply assumptions and demand implications (see below section “Analysis of central modelling assumptions”).

Bioenergy demand (heat, electricity, and biofuels) in the rest of the World evolves throughout the projection period in accordance with the baseline scenario of the 2015 GECO POLES report. Demands for all non-EU countries, regions, and years are implemented in the model as minimum constraints, meaning that a country can produce more but not less biomass for energy use than prescribed (e.g. not price elastic).

5.3 Key outcomes of the baseline scenario.

EU land use development

Figure 3 shows the land use development for EU28. From this figure it can be seen that the largest changes in the land use happen within the intensification in forest land development and the development of SRC. The share of forest in total is projected to increase by about 14 million ha, resulting from increasing afforestation and decreasing deforestation over time. Also, there is a notable increase of the share of used forest compared to unused forest, driven by the increasing demand of wood for material and energy purposes. Still, most of this increase results from increased afforestation: the area of unused forests decreases only marginally. Some land classified as other natural vegetation is changed into cropland, and especially into SRC, which is projected to appear and increase steadily throughout the projection period, reaching an area of 3.4 million ha by 2050. The development of the SRC is to a large extent met through conversion of other natural vegetation and cropland, and a minor share of conversion of grazing land. Otherwise there are only slight changes in the land used for agricultural production; while grazing land area stays overall stable, the area of cropland increases by almost 8 million ha. This development is partly driven by the increasing use of lignocellulosic perennial crops for bioenergy purposes (e.g. switchgrass and miscanthus), whose production is projected to grow from 20 000 ha in 2010 to more than 3 million ha in 2050. Overall, the increasing share of land for SRC and perennials for bioenergy purposes is considerable, indicating a future decrease in the availability of cropland for the production of other commodities.

The results are further examined in Chapter 7, when comparing the results with other scenarios.
Figure 3. Land use development in the LULUCF sector in the EU28 in the Baseline scenario.

Use of biomass in relevant sectors and production of semi-finished forest products

In the Baseline scenario, the total wood consumption in the EU was 826 million m³ in 2010 (Table 3). About one third of this volume is energy use of wood, while two thirds is used for material production. The share of energy use is projected to increase in the near future, and already in 2030, the energy use of wood is estimated to count 41% of the total use of wood. Beyond 2030, the wood consumption is projected to increase further, while the shares of energy and material use will remain close to the level of 2030. In the projections, the increase in the energy use of wood is driven especially by increasing material production, which provides industrial residues (industry side streams) for energy use, and by a fast increase of short rotation coppices (SRC) for energy production. On the contrary, primary use of wood for energy is expected to increase until 2030, but then turn into a decline. This development causes the growth of the share of the energy use of wood to stabilize between 2030 and 2050, compared to the considerable increase between 2010 and 2030.

The baseline results for 2010 are on the same overall level as the corresponding levels reported by the EUWood study (Mantau et al. 2010) and Indufor (2011). EUWood has a higher estimate for primary energy use of wood than our baseline, and on the other hand the estimate for material use of wood is lower. The biggest individual reason for the discrepancy in the energy use of wood is the very uncertain statistics of household fuelwood available for the EU. This uncertainty is also the reason between the different estimates for energy use of wood between EUWood and the report by Indufor. Here, Indufor estimates are similar to our baseline for energy use, with roughly half of the energy use of wood resulting from industry side streams, and half from direct (primary) use of wood for energy production.

On the material production side, our baseline falls in between the EUWood and Indufor estimates. Here, the previous studies differ from each other on the pulp and paper sector. Here, a full comparison is difficult as Indufor reports “pulp and paper”, and EUWood and our baseline accounts for the wood used only for pulp production. Paper recycling is a possible cause for the large difference in the estimates: as paper can be
effectively recycled and used for production of new paper even multiple times, it is not straightforward to compile statistics for the volume of wood used in the paper industries. In fact, the same problem is present also in the virgin use of wood, as forest industries are very efficient in making use of all of the wood biomass, including production residues. That is, accounting for the use of wood in terms of input for different industries as in Table 3, inevitably includes a considerable amount of double-counting. As a result, the total consumption of wood in the wood-based industries is not the same as the volume of forest harvests needed to satisfy the raw material demand of the industries. This is clearly seen in the charts depicting the flow of wood in the industry (e.g. Figure 4).

Table 3. Comparison of the project results and reference literature on wood consumption in the EU28, divided into material and energy uses.

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Total Wood Consumption</td>
<td>825</td>
<td>942</td>
<td>841</td>
<td>1004</td>
<td>1106</td>
</tr>
<tr>
<td>Total Material Use*</td>
<td>457</td>
<td>649</td>
<td>535</td>
<td>613</td>
<td>686</td>
</tr>
<tr>
<td>Wood Products Industry**</td>
<td>314</td>
<td>308</td>
<td>367</td>
<td>436</td>
<td>498</td>
</tr>
<tr>
<td>Pulp and Paper</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulp</td>
<td>143</td>
<td>162</td>
<td>172</td>
<td>182</td>
<td></td>
</tr>
<tr>
<td>Total Energy Use, excl. SRC</td>
<td>368</td>
<td>293</td>
<td>306</td>
<td>346</td>
<td>359</td>
</tr>
<tr>
<td>Wood products industry side streams***</td>
<td>150</td>
<td>155</td>
<td>188</td>
<td>216</td>
<td></td>
</tr>
<tr>
<td>Wood used primarily for energy****</td>
<td>143</td>
<td>151</td>
<td>158</td>
<td>143</td>
<td></td>
</tr>
<tr>
<td>Energy Biomass from SRC</td>
<td></td>
<td></td>
<td>0</td>
<td>44</td>
<td>60</td>
</tr>
<tr>
<td>Energy use, %</td>
<td>45%</td>
<td>31%</td>
<td>36%</td>
<td>39%</td>
<td>38%</td>
</tr>
<tr>
<td>Material use, %</td>
<td>55%</td>
<td>69%</td>
<td>64%</td>
<td>61%</td>
<td>62%</td>
</tr>
</tbody>
</table>

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 recovered wood used for material
**In ReceBio: Sawmill and board industries
***In ReceBio: Sawdust, wood chips, bark and black liquor used for energy, and recovered wood
****In ReceBio: firewood, forest residues, industrial-quality roundwood used directly for energy, imported pellets.

Figure 4 illustrates the flow of wood biomass between the different wood using industries. The figures provide an overview of the flow of wood in the Baseline scenario for the years 2010, 2030, and 2050. Note that the figure represents the flow of wood used as input in material and energy production, not the output volume of (semi-) finished woody products.

There is a 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 into an increased production of industrial residues and by-products used for energy purposes. This applies for the use of the solid by-
products sawchips, sawdust and bark, as well as for the black liquor produced alongside the chemical pulp process.

The flow charts highlight also 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 trade of wood pellets is expected to increase from 10 Mm$^3$ 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 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, driven by an expected shift from domestic to district heating. This development is modelled in line with estimates as of PRIMES.
Figure 4. Flow of wood in the Baseline scenario, in Mm³ SWE.
Forest harvests in the EU

Figure 5 shows the forest harvests for different purposes and their development over time. In particular, the figure highlights the amount of harvested wood that will be primarily used for material and energy purposes; it should be noted that even some of the wood harvested for material production will eventually be used for energy in the form of industrial residues and by-products.

The increase in the total amount of forest harvests is clearly seen, and particularly the harvests for material production show a steadily increasing trend. Harvests for energy stay on a more stable level, and even turn into a decrease after 2030. The key reasons for this decrease are the decreasing use of firewood in combination with increasing import of wood pellets and SRC for energy purposes, which replace the energy use of harvested wood from the forests. 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.

*Figure 5. Forest harvest removal* over time within the EU28.

*The category "Harvests for direct energy use" combines harvests of forest residues, firewood, sawlogs and pulplogs that are used for energy as such, or after chipping and/or pelletization. "Harvests for material use" shows the harvested amount of sawlogs and pulplogs 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 harvests for energy and material use.

Figure 6 shows the development of harvest in terms of the two main types of industrial roundwood, wood of sawlog and pulplog quality. The development echoes the development already seen in the previous figure, with a more rapid increase seen until 2030, and a stabilizing trend thereafter. Harvest of sawlogs is projected to increase more steadily, while there is a only a minor increase in the pulplog harvests until 2030, and almost a negative trend thereafter. This stabilizing trend reflects the results seen in the previous figure: the harvest of lower-diameter wood stabilizes after 2030, these logs being less suitable for material production and hence used more for energy purposes. The relative reduction of the harvest of pulplogs and increase of sawlog harvests also reflects the larger future share of industrial by-products from domestic production that was seen in the flowcharts of Figure 4.
**Figure 6.** Harvest yield divided by sawlog and pulplog assortments in the EU28 in the Baseline Scenario. Note that sawlogs are the logs of higher quality that are acquired by sawmills, while pulplogs are generally logs of lower quality traditionally acquired by pulp mills.

Comparison with results from other studies

The increasing trend of forest biomass harvests is comparable to the harvest projections presented in the European Forest Sector Outlook Study II (EFSOS II 2011) and in EUWood (Mantau et al. 2010). In the Reference scenario of EFSOS II, stemwood removal was estimated to increase between 2010 and 2030 by 15% (from 595 Mm$^3$ to 685 Mm$^3$). This is a larger increase than in ReceBio, where the stemwood harvests (domestic harvests excluding harvest residues) increase by 10% within the same time period. In addition, EFSOS II projects an increase in harvest residue extraction from 4.5 Tg to 41.1 Tg of dry matter (8-fold increase), while Recebio follows more conservative estimates from PRIMES, resulting in 16% more forest residue extraction in 2030 than in 2010. It should be noted that the geographical scope in EFSOS II is the whole Europe including Turkey, whereas ReceBio focuses on the EU28. Nevertheless, the relative change over time between the studies can still be compared.

In opposite to EFSOS II, EUWood presents very different prospects for the development of EU harvests. In EUWood, stemwood harvests in 2010 are considered already very close to the theoretical potential (544 Mm$^3$ under bark) in the EU27. More biomass potential is assumed mainly from increased harvest residue and stump extraction. EUWood estimates the harvest residue extraction in 2010 at 103 Mm$^3$ and stump extraction at 10 Mm$^3$, and assumes a realistic potential in 2030 to lie at 152 Mm$^3$ for residues and 102 Mm$^3$ for stumps: a 50% increase in harvest residue collection over time compared to 16% in ReceBio, and ten-fold increase in stump harvests over time, compared to no increase in ReceBio.

Comparing the ReceBio results to these two studies, ReceBio estimates for forest harvest development are somewhere in between. Contrary to EUWood, ReceBio foresees potential for increasing stemwood harvests, while however with a more
modest rate than predicted in the EFSOS II. Both EFSOS II and especially EUWood stress the importance of harvest residue and stump extraction as a biomass source in 2030: in ReceBio, forest residue harvesting is much more modest. Instead, ReceBio projects a considerable development of SRC, which is outside the scope of either EFSOS II or EUWood.

**Short rotation coppices in the EU**

In Recebio baseline modelling, SRC harvests are projected to become a considerably larger source of biomass for energy, starting from a production level of 0.3 million m$^3$ in 2010 and reaching 60 million m$^3$ by 2050 (Figure 7). In the baseline projection, SRC is seen to increase especially rapidly until 2030. After 2030, the production rate continues to increase although with a slightly slower rate due to the levelling off in the bioenergy demand and increasing imports. The stepwise development seen in the graph is a result of the model being run with 10-year time steps, rather than a direct result of drivers on the policy side. As seen in the graph, the development of the production area, and the volume of SRC for energy follow the same path. This is due to the model not differentiating the production capacities of different types of soils, but instead uses an average yields of SRC based on Havlík et al. 2011\(^\text{16}\).

![Figure 7. Production of SRC in the EU28.](image)

**Price development in the EU**

The prices of both harvested wood and wood products increase over time in the Baseline scenario (Figure 8). The relative increase is much higher for the sawlog and pulplog prices than for sawnwood, panels and pulp. Especially the relatively large increase in the pulplog prices indicates that thinnings will become more profitable in the future, and overall the price development seems to profit the forest owners more than the forest industry.
Figure 8. Price development of harvested wood and semi-finished forestry products.

Trade of woody biomass and forestry products

In the following, the net trade of primary and semi-finished wood products is presented for the Baseline scenario, comparing the modelling results to the previous studies and statistics.

Figure 9 shows the total net trade of wood products between the EU and rest of the world in the baseline scenario. The EU is a net importer of roundwood, wood chips, wood pulp and wood pellets, and a net exporter of sawnwood. This situation is projected to continue and be emphasized in the future, as the EU is projected to increase its traded volumes in all of these categories. The largest increases are seen in roundwood and wood pellet imports. Also the exported volume of sawnwood is expected to clearly increase, mainly driven by the anticipated economic growth in eastern Asia (especially China), South Asia, (India), as well as in the Middle-East and Africa (Figure 10).

Wood pellet imports from Latin America, former USSR, and South-East Asia increase heavily towards 2050, adding to the already existing import flow of pellets from North America and former USSR. In total, the amount of imported pellets is projected to increase from 4 million tonnes in 2010 to more than 9 million tonnes in 2050. This development is directly driven by the EU bioenergy policies, as all of the EU pellet imports will by default be used for energy production. Roundwood, on the other hand, is imported first and foremost for material production. It forms the largest volumes in the wood trade between EU and rest of the world. According to the statistics (see Task 1 report), roundwood was in 2010 imported especially from the neighboring countries, mainly Russia, Ukraine, Norway and Switzerland. As the roundwood is a bulky material, shipping costs are relatively high and favor the transports on land and over relatively short distances. This is also seen in the Baseline scenario results, where the area of the former USSR accounts for most of the EU roundwood imports. These roundwood imports are projected to increase steadily from 2010 to 2050. It should be noted that the initial trade volumes are calibrated to the statistics from 2000. In 2009, Russia imposed a tariff for roundwood exports, causing the trade of roundwood between Russia and the EU to drop drastically (see Task 1 report). Although the trade has since recovered to some extent, this still causes an overestimate of the 2010
roundwood imports in the Baseline, as compared to the actual statistics from that year.

**Figure 9.** Net trade of wood products in traded volume and mass. Note that the negative values denote exports from the EU28 and positive values denote imports to the EU28.

**Figure 10.** Destination of EU28 sawnwood exports in 2010 and 2050.
6. Policy Scenarios

The baseline that was selected for this study forms a point of comparison in terms of the implication of various policies. Within the project, a number of policy scenarios are analysed within the context of the EU proposed climate-energy targets for 2030 (see Table 2).

In each scenario, the level of bioenergy demand is determined when defining the scenario, in accordance with PRIMES and POLES estimates. In the modelling, change in LULUCF emissions due to increased or reduced biomass demand is not accounted for in the efforts needed for reaching an overall EU GHG emission reduction target part of each scenario. Increasing or decreasing forest carbon stocks in relation to the forest management levels are not reflected back to the bioenergy demand, due to the fact that LULUCF emissions are currently not accounted for in the political targets. These emissions are however shown as output of the model.

6.1. Storyline of the EU Emission Reduction Scenario

This scenario depicts a development where more stringent GHG emission abatement targets for EU come into play, enhancing the development of the bioenergy sector. Thus, the scenario assumes higher targets for EU in terms of GHG emission reduction in comparison to the baseline scenario. This in turn is expected to increase the demand for biomass for energy purposes, place higher pressure on biomass production, straining the amount of biomass available for material production. In short, the scenario will show implications of higher bioenergy production levels for the EU in comparison to the baseline scenario.

For EU, the scenario is based on the same overall targets and policy assumptions as for the GHG40/EE scenario in the 2014 IA report. The same differences as pointed between the EU Reference Scenario of the 2014 IA and the baseline scenario of this project (see Chapter 4.3) will also be applicable here in terms of differences between the GHG40/EE scenario and the EU Emission Reduction Scenario. Most importantly, the same bioenergy demand level as for the GHG40/EE scenario will be applied for this scenario. However, as in the baseline scenario, bioenergy demand will be considered as one category. The main points of the overall targets and policy assumptions that the scenario is based upon are described below. These are the same assumptions as those in the GHG40/EE scenario.

This scenario represents a situation where the EU would apply a GHG emission reduction target of 40% by 2030 and 80% by 2050 with respect to the 1990 emission level. The GHG emission reductions would also be in line with the milestones as set up by the Commission in the Low Carbon Economy Roadmap and the 2050 Energy Roadmap. Furthermore, the scenario would be compatible with EU’s objective to reduce GHG emissions by 80-95% as part of an effort in developed countries to reduce global warming below 2°C. Emissions from the LULUCF sector are not accounted for in these targets.

The GHG emission reduction of the scenario is assumed to be met through equalisation of marginal abatement cost of GHG emissions across the economy through the introduction of a carbon price that increases throughout the projection period. No additional energy efficiency (EE) policies are assumed on top of the baseline scenario, meaning that no set targets for energy efficiency are applied. However, economic incentives are still assumed to lead to an increase in energy savings as of 2030 in comparison to that of the EU Reference Scenario. Energy savings in 2030 in the 2014 IA (where the evaluations are made against the 2007 Baseline projections) are estimated to be -29.3% as for the GHG40/EE scenarios in
comparison to that of -21% as of the EU Reference Scenario. No pre-set renewable energy share (RES) target or additional support policies of RES in addition to the baseline scenario are assumed. Still, underlying economic conditions would promote growth of renewable energy production, enabling RES to account for a 26.5% share of gross final energy consumption in 2030, following the estimates in the 2014 IA report. Although the GHG emission target will impact a range of sectors, only sectors and impacts that are relevant for and covered by the modelling framework will be taken into account.

For the RoW, the scenario assumes the same overall targets and policy assumptions as for the baseline scenario. In other words, enhanced GHG mitigation policies in the EU are not reflected in the RoW. As such, the same bioenergy demand for RoW is assumed as for the baseline scenario.

**Main underlying assumptions**

- The same assumptions as for the baseline scenario apply for all aspects as stated earlier for the baseline scenario (GDP projections, global population growth, etc.), except for:
  - The bioenergy demand in EU28 evolves throughout the projection period in accordance with levels evaluated as for the GHG40/EE scenario. This implies that demand for biomass for energy is higher than the level assumed for the baseline scenario by 2050. 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 baseline scenario.
  - Demand for first and second generation biofuel within EU28 develop all the way until 2050 according to the levels assumed for the GHG40/EE scenario.
  - Demand for household fuelwood (firewood) within EU28 evolves throughout the projection period in accordance with Small Scale Solid production levels as evaluated by PRIMES for the GHG40/EE scenario.
  - The bioenergy demand in RoW evolves throughout the projection period in accordance with the levels assumed as for the baseline scenario.

**Key outcomes of the EU Emission Reduction Scenario**

**EU land use development**

In the EU Emission Reduction Scenario, increased demand for bioenergy accentuates the land use development seen in the Baseline scenario. The largest land use changes are seen in the development of SRC and the share of used forests (Figure 11), which both increase considerably in the scenario, especially after 2030. The total afforestation follows the trend seen in the Baseline Scenario, but more forest is taken into use in the EU Emission Reduction Scenario. The area of SRC increases heavily in this scenario. This increase is particularly noticed after 2030. By 2050, the area of SRC is projected to almost 9 million hectares, while it was 3.4 million ha in the Baseline scenario. Most of this increase in SRC area is due to other natural land being converted to SRC plantations; however, the area of grazing land and cropland is slightly smaller in 2050 compared to the baseline scenario, affecting livestock and cereal production. More detailed analysis of these results are given in Chapter 7 and the implications on land use emissions as well as food and feed production are discussed in the Task 4 report.
**Figure 11.** Land use development in the LULUCF sector in the EU28 in the EU Emission Reduction scenario.

**Forest harvests in the EU**

The forest harvests in the EU Emission Reduction Scenario are expected to increase significantly over time, emphasising the mobilisation of wood. More specifically, the use of wood for material purposes is expected to be a major driver for the increasing forest harvests in the EU until 2030 (Figure 12). This development partly reflects the high interrelationship between material and energy uses of wood, as increasing material use of wood also provides more biomass for energy through industrial by-products, and the increase in material production (together with increasing SRC and pellet imports) is enough to satisfy the bioenergy demand until 2030. However, the results also show that high bioenergy levels beyond 2030 have 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.

The higher demand for bioenergy after 2030 (compared to the baseline) is reflected clearly also in the development of the relative shares of harvest assortments (Figure 13), where the harvest of pulplogs increases strongly after 2030. Until 2030, the harvests for direct energy use decrease slightly, as seen in Figure 12, driven by the increasing use of small-scale conversion units (e.g. CHP) that substitute the use of fireswood for heating purposes. After 2030, the strong demand for bioenergy turns the harvest trend into a clear increase, affecting especially the wood for energy use and, consequently, the harvests of pulplog-quality wood.
Figure 12. Forest harvest removal* over time within the EU28 in the EU Emission Reduction Scenario.

*The category “Harvests for direct energy use” combines harvests of forest residues, firewood, sawlogs and pulplogs 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 harvests for energy and material use.

Figure 13. Development of the harvest of sawlogs and pulplogs for EU28 in the EU Emission Reduction Scenario.
Short rotation coppices in the EU
The large increase in the demand of bioenergy is projected to increase the production of SRC in this scenario, showing a strong growth in these crops until 2030 as in the baseline, but continuing to grow even faster thereafter (Figure 14). While the growth of SRC production declined in the Baseline scenario after 2030, it increases even more in the EU Emission Reduction scenario, resulting in more than twice the production volumes and area used for production compared to the Baseline scenario.

*Figure 14. Production of SRC in the EU 28 in the EU Emission Reduction scenario.*

![SRC Production, EU Emission Reduction](chart)

Use of biomass in relevant sectors and production of semi-finished forest products
In the EU Emission Reduction Scenario, the overall development of wood use within the EU28 follows the trends shown in the baseline scenario until 2030 (Figure 15). The use of woody biomass for material production follows the increasing pattern seen in the Baseline Scenario even beyond 2030, differing only in the slightly lower production of particleboard and chemical pulp in 2050 than in the baseline. On the contrary, the use of woody biomass for energy increases very heavily, both between 2010 and 2030, and especially between 2030 and 2050. Until 2030, the increase in the use of woody biomass for energy in the Emission Reduction Scenario is similar to the baseline scenario, with notable increases in the use of industrial by-products (as a direct consequence of increasing material production), as well as a clear increase in the production of SRC. By 2050, however, the industrial by-products continue the same increasing pattern, while the amount of roundwood used directly for energy and production of SRC increase much more heavily than in the baseline. The main driver for this development is the increase in the bioenergy...
demand assumed in this scenario, which draws 78 million m$^3$ of pulplog-quality roundwood into direct energy use in 2050, contrary to the Baseline scenario where no roundwood that could be used for material production were needed to satisfy the energy demand.
Figure 15. EU28 Flow of wood in the EU Emission Reduction scenario.*
6.2. Storyline of the Constant EU Bioenergy Demand Scenario

This scenario depicts a development where no further action for promoting the development of the bioenergy sector comes into play after 2020 and the focus in achieving the GHG emission reduction target is shifted from the bioenergy sector to the other renewable energy sources. This in turn is assumed to lead to a reduced pace of development in the bioenergy sector, keeping it stable at 2020 levels. This is based on the assumption that the private sector may prove unwilling to roll back the established conversion capacities, but also unwilling to invest further into the development of the sector. The scenario also assumes that no further policies, regulatory frameworks, legislations or targets are introduced related to the LULUCF sector.

For the RoW, the scenario assumes the same overall targets and policy assumptions as for the baseline scenario. The same bioenergy demand for RoW is assumed as for the baseline scenario.

These developments as assumed for the scenario are expected to reduce the pressure on biomass production compared to the Emission reduction scenario and to increase the amount of biomass available for material production. In short, the scenario shows the implication of a low bioenergy production levels for the EU in comparison to the baseline scenario.

Main underlying assumptions

The same assumptions as for the baseline scenario apply for all aspects as stated earlier for the baseline scenario (GDP projections, global population growth, etc.), except for:

- The demand for bioenergy in EU28 evolves until 2020 in accordance with assumptions for the GHG40/EE scenario in the 2014 IA report. This applies also for the energy savings, where the development follows GHG40/EE scenario until 2020, but no energy efficiency improvements are assumed thereafter.
- From 2020 onward, demand for biomass for heat and electricity remains constant in EU28 and does not change over time. Sources and types of biomass used for energy purposes are allowed to change over time in relation to changes in prices and availabilities. Demand for all other commodities evolves over time according to GDP and population growth as expressed for the baseline scenario.
- Demand for first and second generation biofuel within EU28 develop all the way until 2050 according to the levels of the GHG40/EE scenario. This is assumed to single out the effect of biomass utilization of biomass for heat and electricity.
- Demand for household fuelwood (firewood) within EU28 evolves throughout the projection period in accordance with the assumptions for the baseline scenario.
- The bioenergy demand in RoW evolves throughout the projection period in accordance with the levels assumed as for the baseline scenario.

Key outcomes of the Constant EU Bioenergy Demand Scenario

EU land use development

In the Constant EU Bioenergy Demand Scenario, the trends seen in the baseline are repeated, but not quite as strongly. Especially, the increase of the area dedicated to SRC is much smaller in this scenario (Figure 16), increasing until 2030...
but turning into a decline thereafter. Otherwise the development is quite similar to the baseline scenario, with a clear increase in afforestation over time and the area of forest taken under management towards 2050. However, the area of forest taken under management is smaller than in the baseline scenario, and a small increase is noted in the area of cropland and grazing land compared to the baseline scenario. The differences between the scenarios are further examined in Chapter 7.

**Figure 16. Land use development in the LULUCF sector in the EU28 in the Constant EU Bioenergy Demand scenario.**

![Graph showing land use development in the LULUCF sector in the EU28 in the Constant EU Bioenergy Demand scenario.]

**Forest harvests in the EU**

The forest harvest removals (Figure 17) increase in line with the former two scenarios until 2020, and grow thereafter on a slightly slower pace. The harvests for energy use turn into a slight decrease after 2020, reflecting the policy of constant bioenergy demand in the EU beyond 2020 that lowers the pressure for forest harvests for energy purposes.
**Figure 17.** Forest harvest removal* over time within the EU28 in the Constant EU Bioenergy Demand scenario.

*The category "Harvests for direct energy use" combines harvests of forest residues, firewood, sawlogs and pullogs 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 harvests for energy and material use.

**Short rotation coppices in the EU**

The most prominent difference to the Baseline (and EU Emission Reduction) scenario is the much lower production of SRC (Figure 18), that peaks in 2020 and then turns into a decline. The decrease in production after 2020 relates to the stable bioenergy demand after 2020, which to a large extent will be possible to satisfy through the use of forest biomass and particularly industrial by-products. As seen in Figure 19 below, the sourcing of industrial by-products continues to increase even after 2020, thereby reducing the pressure for the production of SRC to fulfill the total bioenergy demand.
**Figure 18.** Production of SRC in the EU28 in the Constant EU Bioenergy Demand scenario. Note that the scale of this figure is not the same to the corresponding figures for the other scenarios.

Use of biomass in relevant sectors and production of semi-finished forest products

In the Constant Bioenergy Demand scenario, the most prominent differences to the Baseline scenario and especially the EU Emission Reduction scenario, are the much lower level of SRC production and roundwood harvests for direct energy use (Figure 19). The total harvest level in 2050 is 71 Mm$^3$ lower in this scenario than in the Emission Reduction scenario. Still, it is seen that although there is less competition for pulp logs in this scenario, the material production from this feedstock (particleboard production and especially pulp production) increase only little compared to the Baseline scenario.
Figure 19. EU28 flow of wood in the Constant Bioenergy Demand scenario.
6.3. **Storyline of the Increased RoW Bioenergy Demand Scenario**

This scenario depicts a development wherein joint global efforts are taken to reduce GHG emissions beyond 2020, thereby enhancing the development of the bioenergy sector for the RoW and EU. The scenario assumes higher targets for EU and RoW in terms of GHG emission reduction in comparison to the baseline scenario. This in turn is expected to lead to globally increasing demand for biomass for energy purposes and globally increasing pressure to produce biomass resources. In its core, the scenario is selected to highlight the implication that higher bioenergy targets in the RoW may have for the EU and the RoW, in comparison to the baseline scenario.

For EU28, the scenario is based on the same overall targets and policy assumptions as the GHG40/EE scenario in the 2014 IA report (and, followingly, the EU Emission Reduction Scenario). Most importantly, the bioenergy demand level for EU28 is the same in this scenario as in the GHG40/EE scenario. RES development over time in the EU is assumed to be the same as assumed for the GHG40/EE scenario (26.5% in 2030).

For RoW, the bioenergy demand is based on the 2015 Global Mitigation scenario as jointly developed based on the POLES and GEM-E3 models. This scenario reflects that joint international actions are taken to reduce global emissions in line with ambitions to keep global warming below 2°C and where all regions put into play actions that leads to a lower GHG emission pathways. The scenario assumes a global participation in reaching the climate target and where all sectors assist in mitigation efforts. The scenario has taken into account countries individual constraints and capabilities for participating in mitigation efforts and thereby provides addition time for low income countries to enforce mitigation actions that may limit national growth potentials.

Resulting of countries mitigation contributions to mitigating emissions, the Global Mitigation scenario projects that global emission would be reduced by 60% below 2010 levels by 2050. Key developments for achieving the target are mitigation options such as increasing shares of renewables, energy savings, and reduced non-CO2 emissions from the waste sector. The renewable energy share (including biomass) is expected to globally increase from 11% share of global primary energy demand in 2010, to 20% in 2030, and 39% in 2050. Biomass is expected to play an important role in this development and the use of biomass in the energy sector is expected to increase from roughly 50 EJ per year in 2010, to 150 EJ per year in 2050. The increase in the use of biomass in the energy sector as compared to that of the POLES baseline scenario is roughly 40 EJ per year in 2050, and the increase by volume is expected to be most significant in regions such as North America, Other OECD, Latin America and India.

Bioenergy demand is increasing within EU28 (1.6 EJ per year in 2050), but the increase is much more substantial outside of the EU28. Regions such as India, North America, and Latin America are here projected to increase their bioenergy demand to a large extend in comparison to that of what is seen in the POLES baseline scenario. The Global Mitigation scenario as such projects that the use of biomass for energy purposes will increase with high amount for number regions outside the EU28.

For further details concerning the assumptions taken for the construction of the Global Mitigation scenario we refer to GECO20157.
Main underlying assumptions

The same assumptions apply for all aspects as stated earlier for the baseline scenario (GDP projections, global population growth, etc.), except for:

- The bioenergy demand in EU28 evolves throughout the projection period in accordance with levels evaluated as for the GHG40/EE scenario. This implies that demand for biomass for energy is higher than the level assumed for the baseline scenario by 2050. 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.
- Demand for first and second generation biofuel within EU28 develop all the way until 2050 according to the levels as assumption for the GHG40/EE scenario.
- Demand for household fuelwood (firewood) within EU28 evolves throughout the projection period in accordance with Small Scale Solid production levels as evaluated by PRIMES for the GHG40/EE scenario.
- Bioenergy demand in RoW evolves until 2050 in accordance to estimations by POLES as for the Global Mitigation Action Scenario. All POLES bioenergy demand variables concerning the use of woody biomass for energy production (heat and power, cooking) follow the projections as of the Global Mitigation Action Scenario. See Annex I for a detailed overview of how the POLES bioenergy demands estimated is treated within the GLOBIOM model framework.

Differences from the Global Mitigation scenario

There are some differences in the underlying assumptions between those of the Global Mitigation scenario and the Increased RoW Bioenergy Demand scenario. One of the key aspects is that the two scenarios have different underlying GDP and population growth projections.

It should also be noted that the use of a “carbon value” as of the Global Mitigation scenario is not reflected within the Increasing RoW Bioenergy Demand scenario. This implies that land use emissions within the Increasing RoW Bioenergy demand scenario are not taxed nor taken up by carbon markets associated with sectorial emissions.

Moreover, the bioenergy demand for EU28 in the Increased RoW Bioenergy Demand scenario is not the same as that of the bioenergy demand as estimated by POLES for the Global Mitigation scenario. While total bioenergy demand for EU28 is roughly the same for 2020 and 2050, some differences can be perceived for the period between 2020 and 2040. For this period, the POLES Global Mitigation scenario estimates a faster development of the bioenergy sector than that assumed in the Increased RoW Bioenergy Demand scenario. However, the difference in the demand for bioenergy as of 2050 between the two scenarios is lower than 1 EJ per year. Furthermore, both scenarios assume that the increase in bioenergy demand is to a large extent based on domestic biomass resources, and not traded biomass, hence the demand for biomass in RoW is consistent between the two scenarios.

Key outcomes of the Increased RoW Bioenergy Demand scenario

In the Increased RoW Bioenergy Demand scenario, the bioenergy demand in the EU is projected to increase in a similar way to the EU Emission Reduction scenario, but in addition to this, also rest of the world is projected to increase its use of bioenergy. This leads into a very similar pattern in the land use development as was seen in the EU Emission reduction scenario, with an even slightly stronger pressure to increase the area of SRC in the EU (Figure 20). This leads to smaller area of cropland and
grazing land in 2050 compared to the baseline scenario. As in the EU Emission Reduction scenario, afforestation of other natural land is also strong in this scenario.

**Figure 20. Land use development in the LULUCF sector in the EU28 in the Increased RoW Bioenergy Demand scenario.**

The main impact of the increasing bioenergy demand in rest of the world modelled in this scenario is the **decreased amount of EU wood pellet imports** (Figure 21 and Figure 22) compared to the EU Emission Reduction scenario. While EU could increase the pellet imports to 52 million m$^3$ Solid Wood Equivalent (SWE) by 2050 in the EU Emission Reduction scenario, the 2050 level of pellet imports is only 39 million m$^3$ SWE in the Increased RoW Bioenergy scenario. The explanation for this is that the increased demand for bioenergy in RoW requires more wood for energy production locally, decreasing the possibilities of producing pellets for trading with the EU. **The decreased amount of imported pellets in the EU is compensated with an increased production of SRC in EU,** which is projected to correspond to 172 million m$^3$ SWE in this scenario, compared to the 161 million m$^3$ SWE produced in the EU Emission Reduction scenario.
Figure 21. EU28 flow of wood in the Increased RoW Bioenergy Demand scenario.*
Figure 22. EU28 net trade of wood products in the “Increased RoW Bioenergy Demand scenario”. Positive figures denote EU net imports, negative figures EU net exports.

6.4. Storyline of the Increased EU Biomass Import Scenario

The aim of the scenario is to show the implication of increasing biomass import to the EU from the RoW in comparison to the baseline scenario. This scenario depicts a development where more stringent GHG emission abatement targets for EU come into play, but where less biomass of EU origin is used for bioenergy within EU. A number of plausible developments could potentially lead to the imposed outcome and the scenario could represent a situation where rapid infrastructural investments and developments take place, reducing international transport costs of biomass feedstocks. The development is in turn expected to lower the pressure on European forests and agricultural land to produce biomass dedicated to the bioenergy sector.

For EU28, the increase in imports does not scrutinize from which non-EU country these imports come. The trade partners outside of the EU will as such be defined by a model outcome and are of interest for the analysis. However, specific regions and zones (with high biodiversity, high ecological values, high carbon stocks e.g.) can be excluded from imports. The decrease in import price was set across the main biomass commodities being traded (roundwood, wood chips, and wood pellets). Except for its increased level of biomass import into EU28, the scenario is based on the same overall target as for the GHG40/EE scenario. The same bioenergy demand levels as for the GHG40/EE scenario will be assumed for EU28. RES development over time in the EU is assumed to be the same as assumed for the GHG40/EE scenario (26.5% in 2030).

For the RoW, the scenario assumes the same overall targets and policy assumptions as for the baseline scenario. The same bioenergy demand for RoW will be assumed as for the baseline scenario.
Main underlying assumptions
The same assumptions as for the baseline scenario apply for all aspects as stated earlier for the baseline scenario (GDP projections, global population growth, etc.), except for:

- The bioenergy demand in EU28 evolves throughout the projection period in accordance with levels evaluated as for the GHG40/EE scenario. This implies that demand for biomass for energy is higher than the level assumed for the baseline scenario by 2050. 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.
- Demand for first and second generation biofuels within EU28 develops through 2050 according to the levels as assumption for the GHG40/EE scenario.
- Increased import of biomass to the EU is represented in the model framework through a reduction of the transport costs of biomass feedstocks\(^{27}\). The cost of importing feedstocks to EU28 is decreased evenly for industrial roundwood (sawn wood and pulp wood), wood chips, and wood pellets. This implies that import of wood for energy and material purposes are equally decreased for the scenario and the use of imported feedstock is not scrutinized further. Overall, the trade cost was decreased by roughly 12% for the year 2030, and 32% for 2050. 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.
- All final trade of biomass are estimated endogenously within the GLOBIOM modelling framework. The cost of transporting wood products (e.g. sawnwood, chemical pulp, mechanical pulp, fibreboard, and plywood) within EU28 and globally is the same as for the baseline scenario.
- The bioenergy demand in RoW evolves throughout the projection period in accordance with the levels assumed as for the baseline scenario.

Key outcomes of the Increased EU Biomass Import scenario
In the Increased EU Biomass Import scenario, woody biomass trade was encouraged to emulate increased reliance on imported feedstock. This was simulated through a predefined lower cost for importing biomass feedstock to EU. The product that increased the most in terms of import is wood pellets from Latin America and industrial roundwood from the Former USSR. Increasing import of biomass feedstock reduces the pressure to use the EU forests and decreases the development of SRC (Figure 23). The decrease in development of the SRC leads to similar area of cropland and grazing land in 2050 as in the baseline scenario.

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\(^{27}\) The change in trade cost is implemented in the model through a change of two parameters in the trade cost function, the reference trade cost and the price elasticity. The reference trade cost value specifies the starting cost of trade for a specific trade quantity, while the price elasticity influences how the trade cost is impacted as the amount of trade increases or decreases. The change in the two parameters provides the overall change in the trade cost.
Figure 23. Land use development in the LULUCF sector in the EU28 in the Increased EU Biomass Import scenario.

As seen in Figure 24, the imports of both roundwood and wood pellets increase. Compared to the EU Emission Reduction scenario, the production of materials is marginally higher in this scenario, related to the increased import of roundwood of industrial quality from world regions with lower roundwood prices. Similarly to the EU Emission Reduction scenario, the increase in EU material production over time is mainly intended for the international market, as the semi-finished products are exported outside EU.

The largest differences to the EU Emission Reduction scenario are seen in the increased amount of imported wood pellets, which leads to a much lower production of SRC for bioenergy purposes than in the EU Emission Reduction scenario, and removes the need of using roundwood directly for energy. That is, the increasing import of wood pellets substitutes biomass from SRC and roundwood for energy purposes. The avoided direct use of roundwood for energy purposes is 78 Mm$^3$, and the production of SRC decreases by 92 Mm$^3$ compared to the EU Emission Reduction scenario.
Figure 24. EU28 flow of wood in the Increased EU Biomass Import scenario.

*
The clear increase in the import of roundwood and pellets to the EU is seen in Figure 25, Figure 26 and Figure 27, accentuating the development seen in the EU Emission Reduction scenario. The trade partners will also develop somewhat differently: while North America remains a major trade partner in pellet trade, USA is projected to decrease its share towards 2050. The main increase in pellet trade between 2010 and 2030 is projected to result from increased EU imports from the former Soviet Union. After 2030, pellet imports from South-East Asia and after 2040 especially from Latin America and Oceania (mainly Australia) increase heavily. This development is especially important for the future land use development in RoW, as pellet production in Latin America and South-East Asia is projected to develop mainly based on plantation wood. The effects of the additional increases in the bioenergy demand as of 2030 are clearly seen in the development of pellet imports, whose steady increase until 2030 turns into a considerable increase after 2030, especially driven by increased imports from Canada and especially as of 2040, Latin America.

Figure 25. EU28 net trade of wood products in the Increased EU Biomass Import scenario. Positive figures denote EU net imports, negative figures EU net exports.
Figure 26. Origin of EU28 pellets imports in 2010 and 2050.*

*Abbreviations: USA – United States of America, SSA – Sub-Saharan Africa, SEA – South-East Asia, REU – Other West and Central Europe, OCE – Australia, CIS – Commonwealth of Independent States (Former Soviet Union)
Figure 27. The development of EU pellet imports over time in the Increased EU Biomass Import scenario, disaggregated by country of origin.
7. Overview of the differences between the scenarios

As seen for the analyzed scenarios, the most notable shift in land use for EU is that of a shift from unused forest to used forest, and an increasing area dedicated for the production of short-rotation coppice (SRC). This development is driven by the increased bioenergy demand in the EU and rest of the world, and clearly seen in all the scenarios, and accentuated in the EU Emission Reduction scenario and Increased RoW bioenergy scenario. The changes within the forest area are elaborated in Table 4, Figure 28 and Figure 29. The share of used forest is noted to vary between the scenarios, while total forest land area only changes marginally between the scenarios, with a clear trend of net afforestation towards 2050. The most prominent difference between the scenarios is the effect of bioenergy demand beyond 2030 on the area of used forests: the high emission reduction targets in the EU Emission Reduction scenario are seen to increase the area of used forests in 2050 from 124 million ha in the Baseline scenario to 129 million ha. However, the stable bioenergy demand beyond 2020 modelled in Constant EU Bioenergy Demand scenario will cause the area of used forests to stay at 120 million hectares at 2050, well below that of the baseline. Interestingly, the same effect is seen also in the Increased EU Biomass Import scenario: there, supporting the sourcing of bioenergy feedstock from outside the EU will result in the lowest area of forest used for wood harvests in the EU (119 mill. ha) of all the scenarios simulated.

Table 4. Development of EU28 forest area in the different scenarios of this project.

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<tr>
<th>Scenario</th>
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<tr>
<td>Constant EU Bioenergy Demand</td>
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<td>Increased RoW Bioenergy Demand</td>
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A notable difference in land use between the scenarios developed within this project are seen in the areas of short rotation plantations (SRC and lignocellulosic perennials grown on cropland) (Table 5 and Figure 30). Among short rotation plantations, this study focuses on the analysis of SRC as it is considered to have similar potential end uses as wood biomass from forests. The development of the perennials is given below to enable comparison with previous studies. The area of SRC is projected to increase from almost negligible area in 2010 to 3.4 Mha by 2050 in the Baseline scenario. In the Constant EU Bioenergy Demand scenario, where no additional bioenergy policies...
are adopted after 2020, the development of SRC is much less prominent. In this scenario, the production area of SRC is 0.9 Mha by 2030, and only 0.3 Mha in 2050. In this scenario, the bioenergy demand is assumed to increase in line with the Baseline scenario until 2020, but to remain constant thereafter. At the initial very low levels of SRC, it is more profitable to increase SRC production to respond to higher bioenergy demand than expanding the already exploited forest harvests. Over time, however, additional areas for SRC will become more scarce and the bioenergy demand will be increasingly satisfied by biomass from forestry, causing the area of SRC to decline towards 2050. On the contrary, the increasing high bioenergy demand beyond 2030, as formulated in the GHG40/EE and adopted in the three other scenarios, leads to an almost three-fold increase in the area of SRC by 2050 as compared to the baseline. Encouraging the biomass trade in the Increased EU Biomass Import scenario decreases the amount of SRC needed for energy production in the EU significantly, resulting in only a slightly larger area of SRC in 2050 than in the Baseline.

Table 5. Development of the area of SRC* and perennial lignocellulosic crops** in EU28 in the different scenarios (Millions of hectares).

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<thead>
<tr>
<th>ReceBio modelling results</th>
<th>SRC*</th>
<th>Perennial lignocellulosic crops**</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline</strong></td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td><strong>2010</strong></td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>2020</td>
<td>1.1</td>
<td>2.0</td>
</tr>
<tr>
<td>2030</td>
<td>2.5</td>
<td>2.8</td>
</tr>
<tr>
<td>2050</td>
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<td>3.1</td>
</tr>
<tr>
<td><strong>EU Emission Scenario</strong></td>
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<td>0.02</td>
</tr>
<tr>
<td><strong>2010</strong></td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>2020</td>
<td>1.1</td>
<td>1.7</td>
</tr>
<tr>
<td>2030</td>
<td>2.7</td>
<td>2.3</td>
</tr>
<tr>
<td>2050</td>
<td>8.9</td>
<td>6.1</td>
</tr>
<tr>
<td><strong>Constant EU Bioenergy Demand</strong></td>
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<td>0.02</td>
</tr>
<tr>
<td><strong>2010</strong></td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>2020</td>
<td>1.1</td>
<td>2.0</td>
</tr>
<tr>
<td>2030</td>
<td>0.9</td>
<td>2.0</td>
</tr>
<tr>
<td>2050</td>
<td>0.3</td>
<td>2.0</td>
</tr>
<tr>
<td><strong>Increased RoW Bioenergy Demand</strong></td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td><strong>2010</strong></td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>2020</td>
<td>1.1</td>
<td>1.7</td>
</tr>
<tr>
<td>2030</td>
<td>2.7</td>
<td>2.3</td>
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<tr>
<td>2050</td>
<td>9.4</td>
<td>6.1</td>
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<tr>
<td><strong>Increased EU Biomass import</strong></td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td><strong>2010</strong></td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>2020</td>
<td>0.7</td>
<td>1.7</td>
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<tr>
<td>2030</td>
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</tr>
<tr>
<td>2050</td>
<td>4.0</td>
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</tr>
</tbody>
</table>

*SRC (short rotation coppice) here includes fast-growing tree species such as willow, poplar and eucalyptus that are established and managed under an intensive short rotation regime.

**Perennial lignocellulosic crops here include crops of miscanthus and switchgrass. These are grasses used for bioenergy production, which are included under cropland category in the accounting of land use and land use change.
When comparing the cropping area of SRC and perennials in 2010 shown in Table 5, some deviations can be noted between the baseline scenario and the data collected within the Task 1 of this study, which reported 0.5 million hectares of willow and poplar as of 2011. This is due to the fact that the model starts from the year 2000 and thereafter provides data for each 10 year step, while the estimates provided in Task 1 were instead based on a literature overview and data provided by AEBIOM, the European Biomass Association. While it is interesting to note that the literature review points to higher amount of areas being used for SRC in 2010 than that of the model results, implying that the model is underestimating the amount of SRC for that year, the difference can be considered as marginal as the overall levels are so low for 2010.

Nevertheless, it should be noted that there are large uncertainties surrounding the future development of the fast-growing biomass for energy. Evidence from other studies and discussions with experts suggest that the development of SRC may not follow the price signals as economic models predict. Farmer behaviour does not usually purely reflect price development. Issues such as institutional barriers, future agricultural policies, loss of flexibility in terms of crop rotation and the lack of income over the establishment period of the crop affect the farmers’ decision making behaviour as well. Furthermore, the choice of land to grow the energy crops, future yield potentials, and the value of long time selling contracts are all issues that play a role when it comes to the actual future development of these feedstocks, but may not be fully represented in any model.
When comparing the use of wood for material and energy production between the various scenarios (Figure 31 and Table 6), it is seen that the material use of wood is projected to increase in all scenarios. This increase is the most subtle in the Constant EU Bioenergy Demand scenario, while in the other policy scenarios, the increased bioenergy demand goes together with a higher level of material production. As presented in the scenario results, in 2050, the energy use of wood is the highest in the EU Emission Reduction scenario and the other two scenarios using the same projection for EU bioenergy demand (Increased RoW bioenergy demand and Increased EU Biomass Import scenarios). In 2030, the energy use of wood is somewhat smaller in these scenarios than in the Baseline, and following, also the total use of wood. This is caused by the higher energy efficiency assumed in these scenarios than in the Baseline, shown especially in a lower amount of firewood needed for energy than in the Baseline.

**Figure 31.** Total use of wood in the EU28 in the scenarios, including imported biomass feedstocks.

![Figure 31: Total use of wood in the EU28 in the scenarios, including imported biomass feedstocks.](image-url)

Note that this figure represents the total amount of woody biomass used as input for material and energy production. As in Table 3, industrial by-products are counted twice: first included in the total roundwood arriving to the forest-based industry and used in the production of materials, and second time as sawdust, shavings or bark used in the production of pulp, particleboard, or energy. This is why the total consumption is higher than the sum of harvests and imports. Please refer to the flowcharts for a detailed view of the flow of the woody biomass.
Table 6. The share of wood used for material and energy production in the different scenarios.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>2010</th>
<th>2030</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy use</td>
<td>36%</td>
<td>39%</td>
<td>38%</td>
</tr>
<tr>
<td>Material use</td>
<td>64%</td>
<td>61%</td>
<td>62%</td>
</tr>
<tr>
<td><strong>EU Emission Reduction</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy use</td>
<td>36%</td>
<td>38%</td>
<td>48%</td>
</tr>
<tr>
<td>Material use</td>
<td>64%</td>
<td>62%</td>
<td>52%</td>
</tr>
<tr>
<td><strong>Constant EU Bioenergy Demand</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy use</td>
<td>36%</td>
<td>36%</td>
<td>35%</td>
</tr>
<tr>
<td>Material use</td>
<td>64%</td>
<td>64%</td>
<td>65%</td>
</tr>
<tr>
<td><strong>Increased RoW Bioenergy Demand</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy use</td>
<td>36%</td>
<td>38%</td>
<td>48%</td>
</tr>
<tr>
<td>Material use</td>
<td>64%</td>
<td>62%</td>
<td>52%</td>
</tr>
<tr>
<td><strong>Increased EU Biomass Imports</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy use</td>
<td>36%</td>
<td>38%</td>
<td>45%</td>
</tr>
<tr>
<td>Material use</td>
<td>64%</td>
<td>62%</td>
<td>55%</td>
</tr>
</tbody>
</table>

Note that this table is constructed using the same approach as in Table 3. This implies that the shares of material and energy production are calculated as input of wood and material industries. As in Table 3 and contrary to Figure 31 above, SRC is here included as energy use of wood.

Figure 32 shows that the total forest harvests are higher in the baseline than in the policy scenarios until 2030, showing a clear increase from 2010 through 2030. After 2030, the total harvest level continues to increase in the baseline, but not as rapidly as before, caused by slightly decreasing harvests of wood for direct energy use. This development is largely driven by the decreased use of firewood. On the contrary, in the EU Emission Reduction Scenario, as well as in the Increased RoW Bioenergy Demand scenario, the harvest level increases notably after 2030. This results in a considerably higher harvest level in 2050 for these scenarios than for the baseline scenario. In the Constant EU Bioenergy Demand and especially in the Increased EU Biomass Import scenarios, the total harvests are on a clearly lower level than in the other scenarios, although increasing slightly throughout the projection period.
**Figure 32.** Total forest harvest* in solid wood equivalent, measured over bark (SWE o.b.) in the EU28 in the different scenarios.

*The category “Harvests for direct energy use” combines harvests of forest residues, firewood, sawlogs and pullogs 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 harvests for energy and material use.

Figure 33 shows the differences between the scenarios in the harvest assortments. The shares shown in the figure are direct results of the developments seen between harvests for material and energy use: material production (esp. sawmill and plywood industries) emphasizes the use of sawlogs over pullogs, and the development of sawlog harvests follows the trends seen in the harvests for material. The harvest of pullogs is seen to react on the changes of bioenergy demand over time. This is especially a results of the direct use of roundwood for energy purposes seen in the results in the future.
Figure 33. Harvest volumes of sawlogs and pulplogs in the EU28 in the different scenarios in SWE o.b.

Price of wood and wood products in the EU

The prices of harvested wood and wood products increase in all scenarios over time (Figure 34). The price increase is generally the highest in the EU Emission Reduction and Increased RoW Bioenergy Demand scenarios, with the exception of sawnwood, which reaches highest prices in the Constant EU Bioenergy Demand scenario. For harvested wood, pulplog price is projected to increase faster than the sawlog prices, reflecting the increasing demand and competition of resources under high bioenergy demand. This development is especially prominent in the EU Emission Reduction and RoW Bioenergy Demand scenarios, where the price of pulplogs is projected to more than double by 2050, compared to the price level in 2010. In these scenarios, the use of roundwood for direct energy considerably increases the demand, and consequently the price, of pulplogs. It is notable, however, that also the price of sawlogs increases more than 60% between 2010 and 2050, indicating that forest owners will in general be able to sell wood at notably better prices.

The price development of the wood products is generally more modest than that of harvested wood, with sawnwood prices in the EU increasing by 5 to 15%, and particleboard prices increasing by 10 to 25% from 2010 to 2050. This relates partly to raw material costs being only about 50% of total cost of producing (final) wood products. Other parts of total costs (investment, labor, energy) are assumed to stay constant over time. Moreover, increased bioenergy demand increases the price of the industrial by-products (here shown for wood chips). That is, sawmill profitability will in the future be more connected to the total use of the biomass volumes, including the by-products, and not only to the volume of sawnwood produced. Wood pellet prices
show instead a more dramatic development: the pellet price in the EU is projected to increase dramatically in all scenarios, reaching levels as high as seven times the price of 2010 expected for 2050 in the Increased RoW Bioenergy Demand scenario. Here, it should be remembered that there is only little historical data for pellet trade available compared to other products, and the future projections for pellet prices are hence only indicative. Still, similar development to pellets price increase is also seen in the development of the SRC and by-products prices. That is, products that are used only for energy have higher price increase than products that are used also for material use. This reflects the higher increase of energy demand in respect to material demand.

The price development of material wood products is linked to bioenergy demand through by-products. Higher demand for bioenergy increases by-product prices, which is seen in Figure 34 in the development of wood chips price. On the one hand, this tends to increase particle board production costs and prices, because particle board production uses by-products as input. On the other hand, higher by-products prices decrease sawnwood production costs and prices, because by-products form an essential part of sawmills’ income. This development is seen most clearly in the EU Emission Reduction scenario and Increased RoW Bioenergy Demand scenario, but also to a lesser extent in the other scenarios. In the Constant EU Bioenergy Demand scenario, the particleboard price even decreases after 2040, reflecting the reduced amount of by-products demanded for bioenergy production. For sawnwood, however, the price development between the scenarios shows a very different pattern. Contrary to particleboard production which competes for the feedstock with bioenergy production, sawnwood production produces both sawnwood and bioenergy feedstock in the form of by-products (sawdust, wood chips and bark). That is, the increased demand for by-products supports the profitability of sawmills, and helps to both increase the production and keep the prices down, as is seen in the scenarios with increasing bioenergy demand. In the Constant EU Bioenergy Demand scenario, the demand for by-products is much lower, the amount of sawnwood produced much smaller (see Figure 19), and consequently, the overall profitability of sawnwood production lower. This drives the sawnwood prices upwards, resulting in clearly higher sawnwood price in the Constant EU Bioenergy Demand scenario than in the other scenarios.
Figure 34. Price development of harvested wood and wood products in the scenarios, relative to the price in 2010.
Trade of wood biomass
In all the scenarios analyzed in this project, the current overall trend in the EU trade is expected to remain as it is today: EU is a net importer of roundwood, pellets and wood pulp, and a net exporter of sawnwood and wood boards (Figure 35).

EU net imports are seen to increase considerably towards 2050 in all scenarios for pulplogs, sawlogs and wood pellets, compared to the 2010 amounts. As could be expected, the trade increase is the largest in the Increased EU Biomass Import scenario, where especially the wood pellet imports increases heavily compared to the other scenarios. However, as the trade of wood pellets is a relatively new sector, its development over time is inherently related with high uncertainties.

Of the EU net exports, sawnwood is the wood product that is projected to grow the most by 2050 in all of the scenarios. This development is the strongest in the Increased RoW Bioenergy Demand scenario, where countries outside of the EU use to a larger extent their domestic biomass sources for energy purposes, and thereby increasingly rely on EU as a source for imported sawnwood and particleboard.
Figure 35. EU28 net trade of wood biomass in the different scenarios in 2010 and 2050 (negative figures stand for EU exports, positive for EU imports).
8. Analysis of central modeling assumptions

After constructing the scenarios, some central modelling assumptions were further scrutinized to assess their effects on the modelling outcome. Here, we focus especially on changes in the EU bioenergy demand, availability of different types of biomass feedstocks, and cascading use of wood.

The results are compared to the scenario results of the EU Emission Reduction scenario, abbreviated as REDU throughout this chapter. This policy scenario depicts increased demand for bioenergy and was chosen for this analysis as it also serves as the basis for the other policy scenarios.

8.1. Changes in the EU bioenergy demand

This analysis evaluates the effects of increasing or decreasing bioenergy demand in the EU, and whether the changes of the feedstock are linear with respect to the change in the bioenergy demand. The key aspects addressed in this analysis are: i) changes in feedstocks used in the bioenergy sector as the bioenergy demand marginally increases/decreases, and ii) assessing if there are linear relationships between the change in feedstock consumption and the change in bioenergy demand.

For this, demand for biomass for heat and power was gradually decreased and increased from the level of the EU Emission Reduction scenario (REDU). The changes were done as a linear decrease or increase, starting from the demand as of 2010, and resulting in a -25% to +25% change in bioenergy demand by year 2050 as compared to the demand level of the REDU (see Figure 36). That is, the percentage changes shown in the figure represent the change as of the year 2050.

Figure 36. The projected change in the EU bioenergy demand, using EU28 bioenergy demand in 2050 in the EU Emission Reduction scenario (REDU) as a reference.

[Diagram showing projected changes in bioenergy demand from 2010 to 2050]

There is a clear difference in the impact of the changes in bioenergy demand as of 2030 and 2050, showing that some feedstocks adapt more quickly to demand changes than others (Figure 37). Furthermore, a majority of the feedstocks assessed are seen to have a linear relationship to the EU bioenergy demand. In 2030, the change in bioenergy demand has a large impact on the use of roundwood
for energy in relative terms, but in absolute terms the impact is much higher on the volume of SRC and wood pellets used for energy. The changes in the bioenergy demand affect especially the use of roundwood directly for energy production: with a 10% decrease in bioenergy demand by 2030, no roundwood would be directly used for energy (a decrease of 3 Mm$^3$). Conversely, a similar increase in the total bioenergy demand by 2030 (the trajectory leading to a 20% increase by 2050) is estimated to increase the use of roundwood for energy by roughly 150% (7.5 Mm$^3$). However, although the relative changes in roundwood use for energy are large, the absolute volumes are still very small compared to changes in demand for other feedstocks. Conversely, other feedstocks react more mildly to changes in bioenergy demand by 2030 in relative terms, but the volumes in total are in much larger scale (see Figure 38 below). For SRC, there is roughly a 2 to 1 relationship between the percentage change in the consumption of SRC and the percentage change in bioenergy demand: for example, it is seen that if the bioenergy demand is increased by 2%, then the use of SRC increases by 4%. For wood pellet import, the relationship between the changes in imported amount and bioenergy demand is about 1:1 – a 2% increase or decrease in the total bioenergy demand increases or decreases the amount of wood pellets imported similarly by 2%. Consumption of other feedstocks is not similarly impacted by the induced changes in bioenergy demand, and their consumption remains more stable.

By 2050, there is more time for the markets to adapt, leading to especially a relative increase in the use of imported wood pellets compared to 2030. This releases the pressure to use roundwood directly for energy, and although they still increase and decrease relatively more than the total bioenergy demand, this change is not as dramatic as in 2030. For SRC, a decrease in the total bioenergy demand in 2050 leads into an almost similar percentage decrease in the volume of SRC used for energy, while an increase in the total bioenergy demand is shown as a slightly smaller relative increase in the amount of SRC used for energy. This reflects the increasing scarcity of land, reducing the possibilities for new SRC plantations when the existing area is already large.
Figure 37. Linearity of the feedstock use compared to changes in the EU bioenergy demand. The dots represent the level of feedstock use with respect to the change in the total bioenergy demand (x-axis); the broken line represents a 1:1 relationship between the change in bioenergy demand and feedstock use. Please note that this figure presents only values relative to REDU: the absolute amounts of feedstock use are shown in Figure 38 below.
The total volume of each feedstock used for energy, as well as their relative shares, are shown in Figure 38. As shown in the previous figures, the amount of industrial by-products remains almost the same, independent of the level of the total bioenergy demand. However, in the reference scenario (ER) they provide more than half of the bioenergy feedstock in 2030, and about one-third in 2050. With lower levels of bioenergy demand, their role is accentuated, and with higher levels of bioenergy demand, the increased demand for bioenergy is fulfilled by an increased use of roundwood for energy and SRC in 2030, and increased use of roundwood for energy and imported pellets in 2050. Here, it is shown clearly that in 2050, the share of SRC will not increase as heavily with the increase in bioenergy demand as it did in 2030. On the other hand, roundwood share continues to increase as this feedstock is more readily available.

**Figure 38.** The total volume of the different wood biomass feedstocks used with a changing total demand for bioenergy, and the relative shares of the feedstocks. Note that the scale is different for absolute volumes of feedstock use in 2030 and 2050.
8.2. Availability of biomass feedstocks for energy

One of the major uncertainties in modelling of biomass resources is that of future feedstock availability. To better understand how the results presented within this project depend on the assumptions on the availability of lignocellulosic feedstocks for energy purposes, we evaluated the substitution effects between various feedstocks being used for bioenergy purposes within EU28. In particular, we evaluate how decreasing use of one feedstock for energy purposes increases the use of other competing feedstocks, when the bioenergy demand to be fulfilled remains unchanged.

For this analysis, the availability of SRC, roundwood for energy, imported pellets, and forest residues was decreased from the levels projected in the EU Emission Reduction scenario. The decrease was made at four levels: -5%, -10%, -20% and -40% of the availability in 2050. The decrease was modelled as a linear reduction over time; that is, the reduction in 2030 was -2.5%, -7.5%, -10% and -20%. The total bioenergy demand was kept at the level as of the EU Emission Reduction scenario.

Figure 39. The projected change in the feedstock availability, using availability in 2050 in the EU Emission Reduction scenario (REDU) as a reference.

It was seen that in the short run (between 2010 and 2030), a reduction of one of the feedstocks generally increases the uses of roundwood and SRC for energy. However, in the long run (by 2050), increasing use of industrial by-products and imported wood pellets becomes more prominent. In other words, if the use of SRC decreases, then a large share of the resulting gap of feedstock needed for energy purposes will be fulfilled by roundwood until 2030, and pellets and roundwood by 2050 (Figure 40). Vice versa, if the pellet import decreases, then a large share of this reduction will be replaced by biomass from SRC. This result is seen especially when the feedstocks are restricted more strictly (-20% or -40%). However, in 2050, when only a small reduction (-5% or -10%) in the feedstock availability was induced, the direct energy use of roundwood was seen to substitute most of the gap from a reduced amount of imported wood pellets: SRC was increased more when the imported pellets were restricted more heavily (-20% or -40%).

A reduction in the use of roundwood for energy, on the other hand, would be compensated to a high extent through an increased use of industrial by-products and
SRC for bioenergy purposes (Figure 40). When the availability of roundwood for energy was reduced, the remaining bioenergy demand was satisfied especially through an increased amount of industrial by-products used for energy, together with increased production of SRC. This increase in the use of industrial by-products for energy was also seen to affect the material side: when the energy use of the industrial by-products increased by 9 Mm$^3$, their material use decreased by about 4 Mm$^3$. The deficit in the material feedstock was compensated by an increase of 12 Mm$^3$ in the total EU harvest level. A reduction in the availability of forest residues, on the other hand, causes a similar effect to a reduction of pellet imports, with most of the biomass deficit replaced by SRC.
**Figure 40.** The effect of a reduction in one type of feedstock on the use of other wood biomass for energy in the EU Emission Reduction Scenario in 2030 and 2050, in changes in volume, and in feedstock share.
8.3. Cascading use of biomass

The analysis aims to evaluate the impact of changes in cascading use of biomass within the EU28. Cascading refers to re-using biomass: the feedstock is first used as a bio-based final product, and then at least once more for materials or energy. The incentive for cascading use is to improve resource efficiency and increase the lifetime of biomass resources. In this analysis, we are especially interested in how the cascading use of wood is developing over time and how potential policies aiming to increase the cascading use of wood may inherently impact the amount of wood raw material needed and the other related sectors. As for other analyses of the model assumptions, this section as well uses the EU Emission Reduction scenario as the comparison point for the analysis.

Cascade factor

In order to quantify the cascading use, a number of indicators or proxys has been suggested. Overall, these “cascade factors” describes the relation between the use of wood raw material (roundwood and other wood resources), and the roundwood consumption. In essence, the cascade factor expresses the extent to which woody biomass is being used multiple times throughout the various material and bioenergy value chains. Mantau (2012) has developed a detailed wood flow chart to calculate cascade factors for different cascading chains based on the input-output relation of wood for certain parts of the wood value chain. Indufor (2013) proposed a “simple” and a “total” cascade factor for the chain of woody biomass use. Carus (2014) has also proposed a “biomass utilization factor” the follows the chain utilization of biomass from harvest to subsequent use through various sectors. These cascade factors provide a useful indicator for comparisons of the extent of cascading between different value chains and also over time. It is important to keep in mind that while the cascading factor expresses the extent to which the woody biomass is used multiple times for material and bioenergy purposes, there are technical and biophysical restrictions as to the possibility of increasing cascading of wood within some forest-based industries. For example, sawmills and plywood can only use stemwood for their production, and mechanical pulp production requires a certain share of fresh fibres as input to the production.

For this project, we estimated a cascade factor and its development over time in line with the approach as suggested by Indufor (2013) for the calculation of a simple cascade factor (Table 7). The cascade factor is thus calculated as the ratio between the consumption of woody biomass for material and bioenergy use, and the consumption of roundwood. It is important to note that while the cascade factor as estimated within this project tries to emulate the approach suggested by Indufor as closely as possible, there are some differences between the two estimates. First, while Indufor’s roundwood equivalent (RWE) is in essence similar to our conversion to m$^3$ of solid wood, there may be some differences in the conversion factors used. Second,
the cascade factor as estimated within this project does not account for the use of recovered paper within the pulp & paper sector, as the coverage of the forest-based industries within this project stops at the production of mechanical and chemical pulp. In Indufor’s study, recovered paper is accounted for in the estimates of wood-based material use. These two points are the main underlying reasons for differences in the cascade factors as of 2010 between the two projects. Given these differences in how the cascade factor is calculated, the estimates provided in this project and that of the Indufor (2013) project are not directly comparable. It is as such important to focus on the direction of change over time in the two studies, rather than comparing the exact numbers.

**Table 7:** Comparison of the project results and Indufor estimates of EU28 wood related cascade factors, by end uses and development over time.

<table>
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<th>Study</th>
<th>Indufor</th>
<th>ReceBio EU Emission Reduction scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reference year</td>
<td>2011</td>
</tr>
<tr>
<td></td>
<td>RWE*</td>
<td>Million m³</td>
</tr>
<tr>
<td>Bioenergy consumption**</td>
<td>293</td>
<td>360</td>
</tr>
<tr>
<td>Material consumption</td>
<td>648</td>
<td>679</td>
</tr>
<tr>
<td>Roundwood consumption***</td>
<td>454</td>
<td>495</td>
</tr>
<tr>
<td>Cascade factor</td>
<td>2.07</td>
<td>2.10</td>
</tr>
</tbody>
</table>

* RWE refers to roundwood equivalent (over bark).
** The calculation of bioenergy consumption does not account for wood from SRC nor the use of imported pellets.
*** In ReceBio: Roundwood consumption does not here include the consumption of forest residues to allow for consistency with the estimates as of Indufor.

The cascade factor is estimated to increase from 1.53 as of 2010, to 1.58 as of 2030. This increase is in line with the Indufor study, who also projected that the cascade factor will increase until 2016. **This result indicates that the forest-based industries, and the part of the bioenergy sector covered by the cascade factor, are in the short run (between 2010 and 2030) able to intensify their use of industrial by-products for material and bioenergy purposes more than that of their increasing use of roundwood.** This development is to a large extent driven by the increasing production of wood products within the EU, which extends the cascading use of wood as the downstream by-products are being consumed for both material and energy purposes. Furthermore, the cascading use of wood is enhanced through displacement of firewood with large scale conversion units that use industrial by-products as feedstock. As the consumption of firewood is decreased and the bioenergy sector increases it consumption of downstream wood flows, the use of wood-based raw material coming directly from the forest is substituted by industrial by-products, a resource from the downstream wood flow that is derived from processed roundwood. Also, the increase in the cascade factor is to a certain extent driven by the increasing reliance of the bioenergy sector on feedstocks such as SRC and imported pellets, which are not accounted for in the estimate of the cascade factor, but that frees up resources of other lignocellulosic feedstocks to be used for material purposes.
After 2030, the cascade factor slightly decreases from 1.58 as of 2030, to 1.56 as of 2050. However, this development is derived from a higher increase in the consumption of roundwood than the increase in consumption of woody biomass for material and energy. That is, from 2030 onwards the increase in multiple use of wood through the various value chains is lower than the increase in roundwood consumption. As the bioenergy sector demand for solid lignocellulosic feedstocks increases from 2030 onwards, a large amount of roundwood is directly used by the bioenergy sector, decreasing the cascade factor (Figure 15).

In the following, we examine two separate approaches to increase cascading. First, by modelling an increase in the amount of recovered wood available and analysing the possible effects on the virgin use of wood. The second approach imposes a tax on the energy use of virgin wood, again examining the effects on the material and energy use of wood.

Increased recovery of wood for material production

In this analysis, we model the effects of increased cascading in the system through an increase in the amount of recovered wood as a feedstock for material purposes. The increase in recycling is evaluated in terms of solid wood (for example recovered sawnwood class A1 and A2) to serve as feedstock for particle board production. The amount of recovered wood was increased by 20%, 40%, 100% and 200% by year 2050, as a linear increase from the amount in 2010 (10%, 20%, 50% and 100% in 2030). The results show that recovered wood replaces first and foremost the use of industrial by-products for material production. In turn, the displaced industrial by-products are to a large extent used for energy production and decrease the use of SRC, wood pellets, and roundwood for energy purposes (Figure 41). Even a 200% increase by 2050 does not lead to notable decreases in the forest harvest level. This is a logical result, as the main material use for recovered wood is in particleboard production (here, paper production and, consequently, recovered paper are not included in the analysis). For particleboard production, a certain amount of virgin wood is required alongside the recovered wood. This explains the small increase in the material use of pulplogs when the amount of recovered wood is increased by 20% or more.

Most of the industrial residues replaced by recovered wood in material production will be instead used for energy production. This, in turn leads into a decrease in the energy use of virgin raw materials: in 2030, the main reduction is in imported wood pellets and roundwood to energy when recovered wood is increased in smaller amounts, and when the amount of recovered wood increases by 50% or 100%, further reduction is seen in SRC. On the other hand, in 2050, increased use of industrial residues leads especially to a decrease in the pellet imports, while the effects on roundwood used for energy and SRC are only minor. There is also no effect on domestic forest harvest levels.

To sum up, it is seen that increased amounts of recovered wood for material production lead to a higher availability of industrial by-products for energy production. In the short term, the small amount (5 Mm$^3$ in ER in 2030) of roundwood used for energy can indirectly be replaced by industrial by-products through increasing the availability of recovered wood for material production. In other words, increasing the amount of recovered wood available for material production is seen to lower the use of roundwood for energy purposes. In the long term (2050), an increased availability of recovered wood for material production leads to a larger decrease in the import of wood pellet than in the short term (2030). That is, increased use of recovered wood for material production not only reduces the use of roundwood for energy purposes, but also decreases the forest harvest level.
energy purposes within EU, but also reduces the net-import of wood pellets to EU from the rest of the world.

**Figure 41.** Effect of increasing the amount of recovered wood used for material production on the use of woody biomass for material and energy in 2030.
**Figure 42.** Effect of increasing the amount of recovered wood used for material production on the use of woody biomass for material and energy in 2050. Note that the scale in this figure is not the same as for year 2030 above.

**Impacts of a tax imposed on the use of virgin wood for energy**

In this analysis, we focus on policies aiming to encourage cascading use of wood through discouraging the energy use of wood biomass that could be used for material purposes. There are a number of different policy options for improving cascade use of wood. For this particular analysis, we focus on one hypothetical policy that is
compatible with the model framework applied within the project. We examine this by imposing a tax on the energy use of wood raw material for those feedstocks that could be used for material: sawlogs and pulplogs, sawdust, and wood chips. The tax is imposed in the model as a price increase of +1$, +5$, +10$, +20$, +30$, +40$ and +50$ per m$^3$ for each of these feedstocks if they are used for bioenergy purposes. These prices can be put in relation when looking at the price of industrial by-products, which range between 20 to 35 euros per m$^3$ as of 2010 (see Task 1 report). Here, the tax was imposed for each period starting from 2020 and the total bioenergy demand is always kept constant (i.e. bioenergy demand is not price sensitive). The analysis is made based on the EU Emission Reduction scenario (REDU). There is no tax on the energy use of SRC or imported pellets as these are not considered to be applicable for material production.

The results show that imposing the hypothetical tax decreases the energy use of roundwood and industrial by-products already at low levels of tax (Figure 43), thereby making more industrial by-products available for material production and slightly reducing the total harvest of stemwood. It is noted that as of 2030, no roundwood would be directly used for energy at tax levels of 5$ or higher, and the use of industrial by-products for energy decreases gradually as the tax is increased. However, it is important to note that there are trade-offs in the implementation of the hypothetical tax. For the bioenergy sector, the tax leads to a substitution of industrial by-products and roundwood by SRC and pellet imports. In other words, the decreasing use of industrial by-products and roundwood for bioenergy purposes leads to an increasing amount of land dedicated to the production of short rotation coppices within the EU28 and an increased import of pellets from RoW. In 2050, SRC is the largest feedstock for energy from wood biomass in ER, and while the tax on direct energy use increases it further, we see an even stronger increase in the volume of imported pellets at high tax levels. Also, the total demand for bioenergy is so high in 2050 that a notable amount of roundwood will still be used for direct bioenergy even for taxes as high as 50$ per m$^3$.

The increased availability of wood from roundwood and industrial by-products is partly used in the material sector, reducing the roundwood consumption for material purposes (Figure 43). Here, we see very similar development in both 2030 and 2050, reflecting the already established methods for cascading use present in the forest industry: it is relatively easy to utilize the now more competitive roundwood and industrial by-products for material production quickly after the tax imposition. All in all, however, the direct energy use tax has only a small impact on material production, affecting mainly the feedstock composition on the energy side. Moreover, at high taxation levels (in particular at +20$ per m$^3$ and above) there is some extra volume of industrial by-products that will not be used for energy on high tax levels, but will neither be used for material production. This behaviour is due to insufficient demand for sawdust and wood chips in the material sector as well as the need of fresh wood fibres for the production of some particular end use products. This also leads into a decrease in the sawnwood production (and sawnwood exports) on high tax levels (Figure 44). Because of the price elastic wood supply assumed in the model, even a high tax on the direct energy use of wood will not have a large effect on the price of wood, and thus has only a small increasing effect on the amount of wood materials produced.
Figure 43. The change in the use of wood biomass for material and energy when introducing a tax on the direct energy use of wood.
The tax aiming to encourage the cascading use of wood was also analysed in terms of its impact on the cascade factor as earlier estimated and applied to quantify the cascading use of wood. **Overall, the tax on the energy use of wood raw material is noted to only have a marginal impact on the cascade factor.** The change in the cascade factor between the years is larger than that of the change in the cascading factor imposed by the tax. As of 2030, the tax marginally increases the cascade factor until the tax reached a level of +20 $ per m$^3$. This increase in the cascade factor is related to the fact that no roundwood is being used for energy and a displacement of forest-based by-products from the bioenergy sector to the material sector, thereby slightly decreasing the roundwood consumption. However, at a tax level of +30 $ per m$^3$ and higher, it is noted that the tax decrease the cascade factor. While the tax continues to decrease the use of wood raw material within the energy sector, the increase in material consumption of wood is less than that of the decrease in the use of wood within the bioenergy sector (Figure 43). The reason for the smaller decrease in material production lies in the production processes of some forest-based industries (such as sawmills and plywood industries), who cannot replace the use of stemwood by increasing their use of by-products. Furthermore, also other wood-based industries can substitute stemwood by industrial by-products only to a certain extent.
References


Annex I – Bioenergy demand projections

The following is a description of how the exogenously defined bioenergy demand projections as of POLES and PRIMES are treated within the GLOBIOM modelling framework in this project.

Within this project, bioenergy demand projections as of PRIMES and POLES are taken as input to the GLOBIOM modelling framework. That is, bioenergy demand is exogenously defined and not evaluated within the various modelling frameworks that are being used. The approach taken for this particular study in terms of how the bioenergy demands are being treated within GLOBIOM is modified from the approach taken in the 2014 IA report for the EU. For the EU, bioenergy demand as estimated by PRIMES is being applied, for the rest of the world (RoW), demand estimated by POLES is applied. The bioenergy demand is expressed within the GLOBIOM model as a hard constraint that always has to be fulfilled. That is, bioenergy demand has to be fulfilled even if it reduced the availability of biomass resources for other purposes. Total bioenergy demand is as such not price sensitive, however, the selection of feedstocks to be used for energy production depends on the price of the various feedstocks available and technological constraints.

It is important to note that both PRIMES and POLES projections of bioenergy production only cover part of the total wood demand projection globally and in Europe. The GLOBIOM model also considers demand for the production of other wood products. The general aspects of the bioenergy demand and how these impact the demand of other sources of wood will first be described. Thereafter, the specifics of the implementation of the POLES and PRIMES bioenergy demands will be discussed.

The energy wood production in GLOBIOM is initially set to match the amounts as projected by POLES and PRIMES. This is then implemented as a minimum constraint, meaning that a country can produce more but not less wood for energy purposes than prescribed by the POLES and PRIMES biomass projections. This setup assures that the projected amount of biomass for energy is met, and also allows for flexibility to produce more and sell on the international market if profitable. Other (non-energy) wood products are left competing for the remaining wood resources. An increase in biomass demand as prescribed by POLES/PRIMES can thus be met both by increasing domestic production as well as through international trade of biomass, again allowing also for more harvests in countries with competitive production potentials. It should be noted that an increase in wood harvest for energy purposes does not necessarily lead into increased total harvests. A country might produce more wood for energy from its (limited) domestic forest resources, matching the amount prescribed by POLES/PRIMES biomass, while reducing other uses of the harvested wood. The final level of forest harvests depends on the domestic demand for wood for energy and material, as well as on wood demand in other countries and the countries’ wood price elasticity.

POLES bioenergy demand within GLOBIOM

For the rest of the world, when it comes to regional bioenergy projections from POLES, demand is provided in terms of four categories of bioenergy products:

- Regional biomass demand in heat and power (BIOINEL)
- Direct biomass use i.e. for cooking (BIOINBIOD)
- First generation liquid transport fuel use (BFP1)
- Second generation liquid transport fuel use (BFP2)
Each of these demand categories are implemented in GLOBIOM as target demands or, in other words, as minimum demand constraints. This means that a country can produce more but not less of a category of bioenergy product than prescribed by POLES. This is done to assure that the production of biomass projected by POLES is always achieved while still allowing for flexibility to produce more if demanded, e.g. through the use of by-products.

Biomass for the different types of bioenergy products can be sourced from agricultural and (existing) forestry activities but also from newly planted short rotation tree plantations (see Table 8 for an overview of the mapping). First generation biofuels include ethanol made from sugarcane, corn and wheat, and biodiesel made from rapeseed, palm oil and soybeans. Biomass for second generation biofuels is either sourced from existing forests/wood processing or from short rotation tree plantations. Havlík et al (2011) define different scenarios for the sourcing of second generation biofuels. They also conducted an analysis to establish the scale of land available for SRC. Summarised in a few words, they arrive at available area by excluding areas unsuitable for their level of aridity, temperatures, elevation and population density from total arable land area (grazing land, cropland, ‘other natural vegetation’). Biomass from existing forest activities, short rotation tree plantations, and industrial by-products (e.g. sawdust, sawchips, bark and black liquor) can also be applied as feedstock to fulfil regional biomass demand for heat and power (BIOINEL). This implies that substitution may occur between the use of wood from forest activates, plantations, and the by-products. The share between the uses of these sources of feedstock is not pre-defined and it is the GLOBIOM model that selects this use.

**Table 8: Mapping of the POLES bioenergy categories**

<table>
<thead>
<tr>
<th>GLOBIOM feedstocks</th>
<th>POLES</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Wood from forest activities (stem wood and forest</td>
<td>• BIOINEL</td>
</tr>
<tr>
<td>residues)</td>
<td></td>
</tr>
<tr>
<td>• Short rotation tree plantations</td>
<td></td>
</tr>
<tr>
<td>• Woody industrial by-products (sawdust, sawchips,</td>
<td></td>
</tr>
<tr>
<td>bark, and black liquor)</td>
<td></td>
</tr>
<tr>
<td>• Wood from forest activities (stem wood and forest</td>
<td>• BIOINBIOD</td>
</tr>
<tr>
<td>residues)</td>
<td></td>
</tr>
<tr>
<td>• Ethanol made from sugarcane, corn and wheat</td>
<td>• BFP1</td>
</tr>
<tr>
<td>• Biodiesel made from rapeseed, palm oil and soybeans</td>
<td></td>
</tr>
<tr>
<td>• Wood from forest activities (stem wood and forest</td>
<td>• BFP2</td>
</tr>
<tr>
<td>residues)</td>
<td></td>
</tr>
<tr>
<td>• Short rotation tree plantations</td>
<td></td>
</tr>
<tr>
<td>• Woody industrial by-products (sawdust, sawchips,</td>
<td></td>
</tr>
<tr>
<td>bark, and black liquor)</td>
<td></td>
</tr>
</tbody>
</table>

**PRIMES bioenergy demand within GLOBIOM**

For EU, PRIMES projection of bioenergy production is taken into account. The PRIMES projection of bioenergy production is directly specified in terms of feedstock being used for bioenergy production. In other words, the PRIMES demand projection is specified in terms of the amount of domestic biomass sources that will be directly used as feedstocks for bioenergy production. An overview of PRIMES estimated bioenergy demand as of 2005 and 2030 for the reference and GHG40/EE scenarios as of the 2014 IA is provided in Table 9.
Table 9: Biomass demand for energy purposes as of the 2014 IA

<table>
<thead>
<tr>
<th></th>
<th>2005</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic production biomass</td>
<td>87</td>
<td>194</td>
</tr>
<tr>
<td>feedstock (Mtoe)</td>
<td></td>
<td>191</td>
</tr>
<tr>
<td>of which: forestry</td>
<td>33</td>
<td>48</td>
</tr>
<tr>
<td>of which: crops</td>
<td>4</td>
<td>65</td>
</tr>
<tr>
<td>of which: agricultural residues</td>
<td>12</td>
<td>16</td>
</tr>
<tr>
<td>of which: waste</td>
<td>28</td>
<td>47</td>
</tr>
<tr>
<td>of which: other (i.e. black liquor)</td>
<td>9</td>
<td>17</td>
</tr>
</tbody>
</table>


For some of the biomass categories as specified in Table 9, the PRIMES bioenergy demand scenarios is further detailed specifically in terms of the feedstock to be used. The split for the various categories as provided by PRIMES is as follows:

- Forestry:
  - Stem wood
  - Harvesting residues

- Crops:
  - Wheat
  - Sugar Beet
  - Sunflower / rapeseed
  - Perennial lignocellulosic crops (such as miscanthus and switch grass)
  - Short rotation coppices (SRC, such as willows and poplars)

- Waste:
  - Solid
  - Gas
  - Oil fats

If the PRIMES bioenergy demand scenarios were to be directly applied within the GLOBIOM framework, a minimum demand constraint should be associated with each individual feedstock, implying that there would be no competition between the various feedstocks. This is the approach that was taken for the 2014 IA report and an overview of the mapping is provided in Table 10. An important distinguishing feature of the PRIMES bioenergy demands projections in comparison to that of the POLES bioenergy demands, is that for the PRIMES projections no competition between feedstocks is allowed for. PRIMES directly prescribe the share of biomass feedstocks to be acquired by the bioenergy sector.
Within the framework of this project, the description of the forest-based industries within the GLOBIOM model has been further extended, allowing the PRIMES categories to be expressed with further details. Furthermore, the PRIMES bioenergy demand scenarios have been modified to enable the assessment of the environmental implications of the use of feedstock for energy production. For this aim, the demand of a number of biomass feedstocks was aggregated to a single demand constraint, implying that the feedstocks are in competition to fulfil the demand and that the exact split between the sources is no longer predefined (see overview in Table 11). Perfect substitution is assumed between the various biomass feedstocks that have been aggregated, but each biomass category is associated with an individual heating value for the conversion.

The competition between feedstock for material and energy uses does not affect the total bioenergy production level as it is pre-set according to the total use of the biomass feedstocks categories. The total bioenergy production level as estimated by PRIMES is always produced.

Table 10: Mapping of the PRIMES bioenergy categories as of the 2014 IA report

<table>
<thead>
<tr>
<th>GLOBIOM feedstocks</th>
<th>PRIMES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stem wood from forest activites</td>
<td>Stem wood from forest activities</td>
</tr>
<tr>
<td>Wheat</td>
<td>Wheat</td>
</tr>
<tr>
<td>Sugar Beet</td>
<td>Sugar Beet</td>
</tr>
<tr>
<td>Sunflower</td>
<td>Sunflower / rapeseed</td>
</tr>
<tr>
<td>Rapeseed</td>
<td></td>
</tr>
<tr>
<td>Perennial lignocellulosic crops</td>
<td>Perennial lignocellulosic crops</td>
</tr>
<tr>
<td>Short rotation tree plantations</td>
<td>SRC</td>
</tr>
</tbody>
</table>

Table 11: Mapping of the PRIMES bioenergy categories applied for this study

<table>
<thead>
<tr>
<th>GLOBIOM feedstocks</th>
<th>PRIMES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood of industrial roundwood quality from forest activites</td>
<td>Stem wood from forest activities</td>
</tr>
<tr>
<td>Short rotation plantations for energy use</td>
<td>SRC</td>
</tr>
<tr>
<td>Forest-based industrial by-products (sawdust, sawchips, and bark)</td>
<td>Solid waste portion corresponding to forest-based industrial by-products</td>
</tr>
<tr>
<td>Residues from forest activities</td>
<td>Residues from forest activities</td>
</tr>
<tr>
<td>Wheat</td>
<td>Wheat</td>
</tr>
<tr>
<td>Sugar Beet</td>
<td>Sugar Beet</td>
</tr>
<tr>
<td>Sunflower</td>
<td>Sunflower / rapeseed</td>
</tr>
<tr>
<td>Rapeseed</td>
<td></td>
</tr>
<tr>
<td>Perennial lignocellulosic crops</td>
<td>Perennial lignocellulosic crops</td>
</tr>
</tbody>
</table>
Annex II – Detailed model description

GLOBIOM model description

What is GLOBIOM?

The Global Biosphere Management Model (GLOBIOM)\(^{31}\) (Havlík et al., 2014) is a global recursive dynamic partial equilibrium model of the forest and agricultural sectors, where economic optimization is based on the spatial equilibrium modelling approach (Takayama and Judge, 1971). The model is based on a bottom-up approach where the supply side of the model is built-up from the bottom (land cover, land use, management systems) to the top (production/markets) (see Figure 45 for an overview of the model framework). The agricultural and forest productivity is modeled at the level of gridcells of 5 x 5 to 30 x 30 minutes of arc\(^{32}\), using biophysical models, while the demand and international trade occur at regional level (30 to 53 regions covering the world, depending on the model version and research question). Besides primary products, the model has several final and by-products, for which the processing activities are defined.

The model computes market equilibrium for agricultural and forest products by allocating land use among production activities to maximize 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 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 is modelled following the spatial equilibrium approach, which means that the trade flows are balanced out between different specific geographical regions. Trade is furthermore based purely on cost competitiveness as goods are assumed to be homogenous. This allows tracing of bilateral trade flows between individual regions.

By including not only the bioenergy sector but also forestry, cropland and grazing land management, and livestock management, the model allows for a full account of all agriculture and forestry GHG sources. GLOBIOM accounts for ten sources of GHG emissions, including crop cultivation N2O emissions from fertilizer use, CH4 from rice cultivation, livestock CH4 emissions, CH4 and N2O emissions from manure management, N2O from manure applied on pasture, above and below ground biomass CO2 emissions from biomass removal after converting forest and natural land to cropland, CO2 emissions from soil carbon included cultivated organic soil (drained peatland, at country level). These emissions inventories are based on IPCC accounting guidelines.

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31 See also: www.iiasa.ac.at/GLOBIOM
32 The supply-side resolution is based on the concept of Simulation Units, which are aggregates of 5 to 30 arc-minute pixels belonging to the same country, altitude, slope, and soil class (Skalsky et al., 2008).
Figure 45. Illustration of the GLOBIOM model.

- **Demand**:
  - Food
  - Fibers
  - Energy
  - Industry

- **Markets**:
  - Population, GDP, consumer preferences

- **Production**:
  - EPIC Crop model
  - RUMINANT Digestibility model
  - BIOENERGY Processing
  - BIOMASS

- **Land use**:
  - Worldwide: 18 crops (FAO + SPAM)
    - Management systems: low/high input & irrigated
  - EU28: 9 additional crops, crop rotations
    - Management options: fertilizer, irrigation & tillage
  - 7 animals (FAO + Gridded livestock)
    - Cattle & Buffalo
    - Sheep & Goat
    - Pig
    - Poultry
    - 8 different systems
  - Perennial crops
  - Short rotation coppice
  - Conversion technologies
  - First generation biofuels
  - Second generation biofuels
  - Biomass power plants

- **Land cover**:
  - Cropland
  - Grassland
  - Short rotation plantations
  - Managed forest
  - Natural forest
  - Other natural land

- **Gridded representation of world land use**

- **Market & Trade**: EU + World → Prices

- **Task 3 January 2016**
Representation of land use change

The model includes six land cover types: cropland, grassland, other natural vegetation land, used forests, unused forests, and plantations. Economic activities are associated with the first four land cover types. Depending on the relative profitability of primary, by- and final products production activities, the model can switch from one land cover type to another. Land conversion over the simulation period is endogenously determined for each gridcell within the available land resources. Such conversion implies a conversion cost – increasing with the area of land converted - that is taken into account in the producer optimization behavior. Land conversion possibilities are further restricted through biophysical land suitability and production potentials, and through a matrix of potential land cover transitions (see Figure 46).

Figure 46. Land cover representation in GLOBIOM and the matrix of endogenous land cover change possibilities

Land use change emissions

Land use change emissions are computed based on the difference between initial and final land cover equilibrium carbon stock. For forest, above and below-ground living biomass carbon data are sourced from G4M which supplies geographically explicit allocation of the carbon stocks. The carbon stocks are consistent with the 2010 Forest

33 The term “used forests” refers to all forest areas where harvesting operations take place, while “unused forests” refers to undisturbed or primary forests. There are other three land cover types represented in the model to cover the total land area: other agricultural land, wetlands, and not relevant (bare areas, water bodies, snow and ice, and artificial surfaces). These three categories are currently kept constant at their initial level.
Assessment Report (FRA 2010), providing emission factors for deforestation in line with that of FAOSTAT. Carbon stock from grazing land and other natural vegetation is also taken into account using the above and below ground carbon from the biomass as of Ruesch et al. (2008). When forest or natural vegetation is converted into agricultural use, the GLOBIOM approach consider that all below and above ground biomass is released in the atmosphere.

The use of detailed and reliable statistics and maps

All processes and management options are represented at a high level of regional detail and built on trustworthy databases. GLOBIOM is based on EU data regarding area, yields, production etc. at NUTS 2 level. The market balances calculated for the 53 regions worldwide rely on EUROSTAT accounts and on FAOSTAT for outside EU. Land cover is dealt with in a geographically explicit way. The land cover description for the EU28 is based on CORINE/PELCOM cover maps, which ensure a great level of detail in land cover. The land cover for the rest of the World is based on Global Land Cover 2000 (GLC 2000).

Biomass use for large-scale energy production is usually based on the POLES or MESSAGE energy sector models (Havlík et al., 2011; Reisinger et al., 2013), but other estimates can also be utilized. For forests, mean annual increments and growing stocks for GLOBIOM are obtained from G4M. For the agricultural sector, GLOBIOM draws on results from the crop model EPIC (Environmental Policy Integrated Climate Model)\(^{34}\), which provides the detailed biophysical\(^{35}\) processes of water, carbon and nitrogen cycling, as well as erosion and impacts of management practices on these cycles. GLOBIOM therefore incorporates all inputs that affect yield heterogeneity and can also represent a different marginal yield for different crops in a same grid cell.

Categories of biomass and biomass conversion are included in GLOBIOM

GLOBIOM represents a number of conventional and advanced biofuels feedstocks:
- 27 different crops including 4 vegetable oil types\(^{36}\);  
- Co-products: 3 oilseed meal types, wheat and corn DDGS;  
- Perennials and short rotation plantations: Miscanthus, switchgrass, short rotation coppice;  
- Used forest: 4 types of stem wood, primary forestry residues from wood harvest;  
- Wood processing residues: bark, black liquor, sawdust, sawchips;  
- Recovered wood products;  
- Crop residues (e.g. straw).

Various energy conversion processes are modelled in GLOBIOM and implemented with specific technological costs, conversion efficiencies and co-products:
- Wood (forestry): sawnwood, plywood, fiberboard, pulp and paper production, combustion, fermentation, gasification;

\(^{34}\) See also: www.iiasa.ac.at/EPIC  
\(^{35}\) Biophysical means related to living (animals, plants) and non-living (light, temperature, water, soil etc.) factors in the environment which affect ecosystems  
\(^{36}\) Palm oil, rapeseed oil, soy oil and sunflower oil
Lignocellulose (energy crop plantations): combustion, fermentation, gasification;
Conventional ethanol: corn, sugar cane, sugar beet and wheat ethanol processing;
Conventional biodiesel: rapeseed oil, soybean oil, soya oil and palm oil to FAME processing;
Oilseed crushing activities: rapeseed, soybeans, and sunflower crushing activities.

This allows ethanol, methanol, biodiesel, heat, electricity and gas to be distinguished and traced according to their feedstocks. Furthermore, competition for biomass resources as considered is also taken into account between the various sectors in term of the demand for food, feed, timber, and energy.

**Agricultural production within GLOBIOM**

GLOBIOM explicitly covers production of each of the 18 world major crops representing more than 70% of the total harvested area and 85% of the vegetal calorie supply as reported by FAOSTAT. Each crop can be produced under different management systems depending on their relative profitability: subsistence, low input rainfed, high input rainfed, and high input irrigated, when water resources are available. Crop yields are generated at the grid cell level on the basis of soil, slope, altitude and climate information, using the EPIC model. Within each management system, input structure is fixed following a Leontief production function. However, crop yields can change in reaction to external socio-economic drivers through switch to another management system or reallocation of the production to a more or less productive gridcell. Besides the endogenous mechanisms, an exogenous component representing long-term technological change is also considered.

**Livestock sector within GLOBIOM**

The GLOBIOM model also incorporates a particularly detailed representation of the global livestock sector. With respect to animal species, distinction is made between dairy and other bovines, dairy and other sheep and goats, laying hens and broilers, and pigs. Livestock production activities are defined in several alternative production systems adapted from Seré and Steinfeld (1996): for ruminants, grass based (arid, humid, temperate/highlands), mixed crop-livestock (arid, humid, temperate/highlands), and other; for monogastrics, smallholders and industrial. For each species, production system, and region, a set of input-output parameters is calculated based on the approach in Herrero et al. (2008).

Feed rations in GLOBIOM are defined with a digestion model (RUMINANT, see (Havlík et al., 2014)) consisting of grass, stovers, feed crops aggregates, and other feedstuffs. Outputs include four meat types, milk, and eggs, and environmental factors (manure production, N-excretion, and GHG emissions). The initial distribution of the production systems is based on Robinson et al. (2011). Switches between production systems allow for feedstuff substitution and for intensification or extensification of livestock production. The representation of the grass feed intake is an important component of the system representation as grazing land productivity is explicitly represented in the model. Therefore, the model can represent a full interdependency between grazing land and livestock.
Available supply of wood biomass and types of wood

Total forest area in GLOBIOM is calibrated according to FAO Global Forest Resources Assessments (FRA) and divided into used and unused forest utilizing a downscaling routine based on human activity impact on the forest areas (Kindermann et al., 2008b). The available woody biomass resources are provided by G4M for each forest area unit, and are presented by mean annual increments. Mean annual increments for forests are then in GLOBIOM divided into commercial roundwood, non-commercial roundwood and harvest losses, thereby covering the main sources of woody biomass supply. The amount of harvest losses is based on G4M estimates while the share of non-commercial species is based on FRA (2010) data on commercial and non-commercial growing stocks. In addition to stemwood, available woody biomass resources also include branches and stumps; however, environmental and sustainability considerations constraint their availability and use for energy purposes.

Available woody biomass resources from plantations

Plantations are covered in GLOBIOM in the form of energy crop plantations, dedicated to produce wood for energy purposes. Plantation yields are based on NPP maps and model’s own calculations, as described in Havlík et al. (2011). Plantation area expansion depends on the land-use change constraints and economic trade-offs between alternative land-use options. Land-use change constraints define which land areas are allowed to be changed to plantations and how much of these areas can be changed within each period and region (so-called inertia conditions). Permitted land-cover types for plantations expansion include cropland, grazing land, and other natural vegetation areas, and they exclude forest areas. Within each land-cover type the plantation expansion is additionally limited by land suitability criteria based on aridity, temperature, elevation, population, and land-cover data, as described in Havlík et al. (2011).

Plantation expansion to cropland and grazing land depends on the economic trade-off between food and wood production. Hence, the competition between alternative uses of land is modeled explicitly instead of using the “food/fiber first principle,” which gives priority to food and fiber production and allows plantation to be expanded only to abandoned agricultural land and wasteland (Beringer et al., 2011; Hoogwijk et al., 2009; Smeets et al., 2007; Van Vuuren et al., 2010).

Woody biomass production costs

Woody biomass production costs in GLOBIOM cover both harvest and transportation costs. Harvest costs for forests are based on the G4M model by the use of spatially explicit constant unit costs that include planting, logging, and chipping in the case of logging residues. Harvest costs also vary depending on geographical considerations such as the region and the steepness of terrain. Transport costs are on the other hand

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37 Commercial roundwood is stemwood that is suitable for industrial roundwood (sawlogs, pulplogs and other industrial roundwood). Harvest losses and non-commercial roundwood are stemwood that is unsuitable for industrial roundwood. The difference between harvest losses and non-commercial roundwood is that the former has unwanted stemwood sizes, while the latter has unwanted wood characteristics.
not spatially explicit but are modeled by using regional level constant elasticity transport cost functions, which approximate the short run availability of woody biomass in each region. These transport costs functions are then shifted over time in response to the changes in the harvested volumes and related investments in infrastructures.

** Woody biomass demand and forest industry technologies**
The forest sector is modeled to have seven final products (chemical pulp, mechanical pulp, sawnwood, plywood, fiberboard, other industrial roundwood, and household fuelwood). Demand for the various final products is modeled using regional level constant elasticity demand functions. Forest industrial products (chemical pulp, mechanical pulp, sawnwood, plywood and fiberboard) are produced by Leontief production technologies, which input-output coefficients are based on the engineering literature (e.g. FAO 2010). By-products of these technologies (bark, black liquor, sawdust, and sawchips) can be used for energy production or as raw material for pulp and fiberboard. Production capacities for the base year 2000 of forest industry final products are based on production quantities from FAOSTAT (2012). After the base year the capacities evolve according to investment dynamics, which depend on depreciation rate and investment costs. This implies that further investments can be done to increase production capacities or allow industries to reduce their production capacities or be closed. For further details of the modelling approach of the depreciation rates, capital operating costs, and investment costs as applies, we refer to Lauri et al 2014.
G4M model description

What is G4M?
The Global Forest Model (G4M) is applied and developed by IIASA (Gusti, 2010a; Gusti, 2010b; Gusti et al., 2008; Gusti and Kindermann, 2011; Kindermann et al., 2008a; Kindermann et al., 2006) and estimates the impact of forestry activities (afforestation, deforestation and forest management) on biomass and carbon stocks. By comparing the income of used forest (difference of wood price and harvesting costs, income by storing carbon in forests) with income by alternative land use on the same place, a decision of afforestation or deforestation is made. As G4M is spatially explicit (currently on a 0.5° x 0.5° resolution), different levels of deforestation pressure at the forest frontier can also be handled. The model can use external information, such as wood prices and information concerning land use change estimates from GLOBIOM. As outputs, G4M produces estimates of forest area change, carbon sequestration and emissions in forests, impacts of carbon incentives (e.g. avoided deforestation) and supply of biomass for bioenergy and timber.

Forest management option and impacts
The available woody biomass resources is estimated by G4M for each forest area unit determined by mean annual increments, which are based on net primary productivity (NPP) maps from (Cramer et al., 1999a) and from different downscaling techniques as described in (Kindermann et al., 2008b). This information is then combined with national data sources (e.g., National Forest Inventories) to provide further and more detailed information concerning biomass stocks and forest age structure.

The main forest management options considered by G4M are variation of thinning levels and choice of rotation length. The rotation length can be individually chosen but the model can estimate optimal rotation lengths to maximize increment, stocking biomass or harvestable biomass. Increment is determined by a potential Net Primary Productivity (NPP) map (Cramer et al., 1999b) and translated into net annual increment (NAI). At present this increment map is static and does not change over time. Age structure and stocking degree are used for adjusting NAI.

The model uses external projections of wood demand per country (estimated by GLOBIOM) to calculate total harvest iteratively. In G4M, the potential harvest amount per country is estimated by choosing a set of rotation lengths that maintain current biomass stocks. If total harvests are less than the wood demand, the model changes management grid per grid (starting from the most productive forest) to a rotation length that optimizes forest increment and thus allows for more harvest. This mimics the typical observation that used forests (in many regions) are currently not managed optimally with respect to yield. The rotation length is updated for each five years’ time step. If harvest is still too small and there is unused forest available, the unused forest will be taken under management. If total harvests are greater than the demand, the

38 See also: www.iiasa.ac.at/G4M
model will change management to maximize biomass rotation length, i.e. to manage forests for carbon sequestration. If wood demand is still lower than the harvest potential, used forest can be transferred into unused forest. Thinning is applied to all used forests, and the stands are thinned to maintain a specified stocking degree. The default value is 1 where thinning mimics natural mortality along the self-thinning line. The model can also consider the use of harvest residues e.g. for bioenergy, using a cost curve algorithm.

**Carbon price and forest mitigation**

Introducing a carbon price incentive means that the forest owner is paid for the carbon stored in forest living biomass if its amount is above a baseline, or pays a tax if the amount of carbon in forest living biomass is below the baseline. The baseline is estimated assuming forest management without the carbon price incentive. The measures considered as mitigation measures in forest management in G4M are:

- Reduction of deforestation area;
- Increase of afforestation area;
- Change of rotation length of existing used forests in different locations;
- Change of the ratio of thinning versus final fellings; and
- Change of harvest intensity (amount of biomass extracted in thinning and final felling activity).

These activities are not adopted independently by the forest owner. The model manages land dynamically and one activity affects the other. The model then calculates the optimal combination of measures. The introduction of a CO₂ price gives an additional value to the forest through the carbon stored and accumulated in the forest. The increased value of forests in a regime with a CO₂ price hence changes the balance of land use change through the net present value (NPV) generated by land use activities toward forestry. In general, it is therefore assumed that an introduction of a CO₂ price leads to a decrease of deforestation and an increase of afforestation. This might not happen at the same intensity though. Moreover, less deforestation increases land scarcity and might therefore decrease afforestation relative to the baseline.

**Model applications**

Recently, the model was applied to project the future EU forest CO₂ sink as affected by recent bioenergy policies at a national level. The results were used by several EU member states to construct their individual Forest Management Reference Levels (Böttcher, et al. 2011).
References and further reading


Gusti M. An algorithm for simulation of forest management decisions in the global forest model. Artificial Intelligence (2010a) N4:45-49.


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

Task 4: Resource efficiency implications of the scenarios
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1. Introduction
The purpose of this report is to document methodology and results of Task 4 of the project "Study on Impacts on Resource Efficiency of Future EU Demand for Bioenergy". The aim of Task 4 is to use the outcomes of Task 2 and Task 3 to assess the impacts of the production of biomass for energy on natural resources and the global environment. The assessment covers direct and indirect impacts1 because the applied models (GLOBIOM and G4M) cover the entire land use sector and the whole globe. Thus, by comparing different scenarios with varying assumptions any impact on environmental indicators can be assessed. Different environmental indicators have been identified based on the findings from Task 2 and tightly linked to model output variables. In a first step the impacts on resources in the different policy scenarios are assessed against those foreseen under the baseline scenario by looking at the performance of selected indicators. In a second step constraints on specific model variables are introduced that aim to reduce impacts, shift production patterns and biomass origin. By this means we will assess not only implications of biomass use for the global environment but also implications of potential policy interventions for biomass resource efficiency in EU28.

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

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

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

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

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1 Indirect impacts or displacement effects (e.g. an indirect land use change) are occurring when increased demand for one product pushes production of the same or other products to other areas or increases demand of other products to substitute the displaced one.
The implemented constraints are grouped by topic (land use, biodiversity, GHG emissions, soil and water) to be able to present them in a more aggregated manner. Within Stage 2, we will differentiate between model runs with a combination of individual constraints for a single scenario (Dimension 1) and one model set up where all constraints combined are implemented in all prospective policy scenarios (Dimension 2, see Figure 1).

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

2.1.1. Definition of indicators

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

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

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

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

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

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

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

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

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Dataset</th>
<th>Model variables with units for interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Land use</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basic land use categories</td>
<td>Model output, projection based on GLC 2000</td>
<td>• Forest area [ha], including the categories Afforestation, Used Forest, Unused Forest • Area of Deforestation [ha] • Area of Cropland [ha], including the category Short Rotation Coppice • Area of Grazing land [ha] • Area of other natural land [ha]</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Biodiversity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unused and intact forests</td>
<td>Intact forest landscape, Greenpeace</td>
<td>• Unused forest area [ha] • Intact forest area [ha] • Unused forest converted to other land use [ha] • Intact forest converted to used forest [ha]</td>
</tr>
<tr>
<td>Land with high biodiversity value (HBV)</td>
<td>UNEP-UCMC biodiversity atlas</td>
<td>• Area of land with HBV (forests, wetland, grazing land) [ha] • Area of land with HBV (forests, wetland, grazing land) converted to other land use [ha] • Biomass extracted from land with HBV (forests, wetland, grazing land) [t]</td>
</tr>
<tr>
<td>Forest rotation period</td>
<td>Forest rotation period from national inventory</td>
<td>• Rotation period currently being applied [years]</td>
</tr>
<tr>
<td><strong>Greenhouse Gases</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emissions from agriculture and livestock</td>
<td>Model output, RUMINANT model integrated in GLOBIOM</td>
<td>• Total net emissions [t CO₂ eq.] • N₂O emissions from fertilizer application [t CO₂ eq.] • N₂O and CH₄ emissions from cropland [t CO₂ eq.] • N₂O and CH₄ emissions from livestock management [t CO₂ eq.] • Soil CO₂ emissions from cropland [t CO₂ eq.]</td>
</tr>
<tr>
<td>Emissions from forest activities and Harvested Wood Products</td>
<td>Model output based on GLC 2000, global forest carbon map</td>
<td>• CO₂ emissions from Afforestation [t CO₂ eq.] • CO₂ emissions from Deforestation [t CO₂ eq.] • CO₂ emissions from Forest management [t CO₂ eq.] • Total net forest emissions [t CO₂ eq.] • CO₂ emissions from forest biomass [t CO₂ eq.] • CO₂ emissions from forest soil [t CO₂ eq.] • CO₂ emissions from pool of Harvested Wood Products [t CO₂ eq.]</td>
</tr>
<tr>
<td>Emissions from bioenergy</td>
<td>Model output</td>
<td>• CO₂ emissions from the production and use of bioenergy [t CO₂ eq.]</td>
</tr>
<tr>
<td>Total net emissions</td>
<td>Sum</td>
<td>• Total net GHG emissions [t CO₂ eq.]</td>
</tr>
<tr>
<td><strong>Water and soil</strong></td>
<td></td>
<td></td>
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<tr>
<td>Plantation of SRC on Cropland</td>
<td>Water stress maps; maps on water scarcity/stress</td>
<td>• SRC on land with water stress [ha]</td>
</tr>
<tr>
<td>Water used for agriculture</td>
<td>Model output</td>
<td>• Irrigation area [ha] • Water used for irrigation [km³]</td>
</tr>
<tr>
<td>Steep slopes / sensitive soil classes</td>
<td>Elevation model; Harmonized World Soil Database</td>
<td>• Area of land with restrictions to avoid soil erosion [ha] • Biomass extraction from forest on steep terrain and sensitive characteristics [t]</td>
</tr>
<tr>
<td>Residue/branch extraction in forests</td>
<td>Species specific biomass expansion factor</td>
<td>• Forest area where biomass is left [ha] • Amount of dead wood left in forest [m³]</td>
</tr>
<tr>
<td>Conversion from grazing land to cropland</td>
<td>Model output based on GLC 2000</td>
<td>• Grazing land area [ha] • Grazing land area converted to Cropland [ha]</td>
</tr>
</tbody>
</table>

4 For a more detailed specification of model assumptions and data sources used within the modeling structure, we refer to the Task 3 report on detailed model assumptions.
2.1.2. Assessment of impacts
Within Stage 1 indicators will be looked at individually across all scenarios. This includes an analysis of trends of indicators in the Baseline. This analysis reveals basic drivers of indicators and their development over time; an information that is also relevant to interpret differences between scenarios. It also helps to check whether any changes regarding the choice of indicators and the interpretation of the underlying model output are necessary and how indicators compare with independent estimates from the literature.

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

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

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

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

Indicators for assessing resource efficiency of biomass use in the constrained scenarios are the following:

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

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

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

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

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

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

<table>
<thead>
<tr>
<th></th>
<th>Area of unused forest</th>
<th>Area with high biodiversity</th>
<th>Other natural land</th>
<th>...</th>
<th>All combined</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline</strong></td>
<td>Baseline Scenario</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Policy scenario</strong></td>
<td>EU Emission Reduction</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Scenario</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Constant EU Bioenergy</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Demand Scenario</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Increased RoW Bioenergy</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Demand Scenario</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Increased EU Biomass</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Import Scenario</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 1:** Overview of how the environmental constraints will be applied and their implications evaluated across the policy scenarios in two dimensions.
3. Results of Stage 1: Assessment of environmental impacts in Baseline and policy scenarios

3.1. Development of impacts observed in the Baseline scenario

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

3.1.1. Development of land use

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

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

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

Sub-Saharan Africa is characterized by a relative low amount of cropland and used forest area in 2010. Both almost double until 2050 (Figure 4). Also grazing land area, that is dominant in Sub-Saharan Africa, increases by 12% over the time period. As a result unused forest area as well as other natural land decrease by 20% and more than 30%, respectively, until 2050. The latter is likely to occur on productive areas of natural grassland.
In Latin America, used forest area covers only 5% of the land in 2010 (Figure 5). This land use category increases only slightly from 2010 to 2050. Still unused forests decrease strongly over the time period (2010: 629 Mio ha; 2050: 535 Mio ha). The main cause here is deforestation due to cropland and grazing land expansion in the first half of the simulation period. Later the expansion of cropland and grazing land occurs more into other natural land. The increase of new forest area through afforestation is also significant (55 Mio ha in 2050, not shown explicitly).
The RoW total forest area is expected to first further decrease from 3,166 Mio ha (2010) to 3,162 Mio ha (2020) but increase after that until 2050 to 3,211 Mio ha (Figure 6). Clear decreases of the total forest area from 2010 to 2050 are especially visible for Latin America and Sub-Saharan Africa. The latter shows a recovering trend after 2030. In the EU28, the forest area increases during this time period steadily by 14 Mio ha from 154 to 167 Mio ha. The total forest area includes the dynamic of used and unused forest, afforestation and deforestation. For an assessment of impacts it is important to separate these.
During the Baseline scenario the area of used forests increases in several regions of the world (Figure 7). This comes either at the expense of unused forests or conversion of non-forest land to forest. In EU28 unused forest remains fairly stable over the Baseline simulation period. However, strong declines of unused forest occur during this time period in Latin America (-94 Mio ha; -15%), Sub-Saharan Africa (-86 Mio ha; -18%), USA (-19 Mio ha; -21%), South-East Asia (-17 Mio ha; -13%), and CIS (-15 Mio ha; -2%). The reasons for the loss differ and can either be due to conversion to used forests as well as conversion to cropland or grazing land.
Table 2: Distribution of intact forest landscape in 12 regions of the world in 2000

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

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

**The area of used forests, including afforestation, increases in almost all regions of the world between 2000 and 2050** (Figure 8). For example, in EU28, area of used forest increases by 19 Mio ha from 105 Mio ha in 2010 to 124 Mio ha in 2050 as a result of expansion of forest area through afforestation and a reduction of the deforestation rate. In Eastern Asia the increase of used forests of 69 Mio ha from 2010 to 2050 (57\%) is almost equivalent with the area of new forests in 2050 (64 Mio ha), indicating that only small parts of the former unused forest area were converted to used forest. In Sub-Saharan Africa the used forest area increases by 96 Mio ha compared to a conversion of unused forests of 86 Mio ha. So here the intensification of forestry is mainly through conversion of unused forest to used forest. In other regions, however, the increase of used forest areas is much lower than the conversion of unused forests. For example, in Latin America, the used forest area increased by 29 Mio ha but unused forest area decreased by 94 Mio ha. This indicates that forest areas have been deforested, i.e. converted to other land use types, especially cropland and grazing land. The drop of the area of used forest in Sub-
Saharan Africa that can be observed in Figure 8 in 2040 is due to an increased afforestation in that region (see also Figure 11).

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

Deforestation can be more explicitly expressed as the accumulated loss of forest areas existing in 2000 (Figure 9) and as an annual deforestation rate in relation to forest area in 2000 (Figure 10). The deforestation rate represents the decline of used and unused forests already existing in 2000 without taking into account newly afforested areas. Large scale deforestation under the Baseline scenario is taking place until 2050 in Latin America (loss of 170 Mio ha) and in Sub-Saharan Africa (loss of almost 100 Mio ha). In total until 2050 360 Mio ha of forest will be lost in RoW, 4.4 Mio ha in EU28. Most deforestation rates are currently (for the period 2000-2010) below 0.5%, except for Latin America, Sub-Saharan Africa, South-East Asia and Oceania. The Baseline projects a constant decline of relative deforestation rates until 2050 with most remarkable changes for South-East Asia and Latin America (from 0.9 and 0.7 to 0.2 and 0.4, Figure 10).
Figure 9: Loss of forest area existing in 2000 (accumulated) in 12 regions of the world for the Baseline scenario.

Figure 10: Annual deforestation rate in relation to forest existing in 2000 in 12 regions of the world for the Baseline scenario.
Figure 11: Development of afforestation areas in 12 regions of the world for the Baseline scenario.

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

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

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

![Figure 12: Development of area of HBV areas converted in the Baseline scenario in 12 regions of the world.](image)

The conversion of unused forest with HBV is high in most regions (Figure 13). In regions like Latin America, South-East Asia and Sub-Saharan Africa the conversion of unused forest accounts for about half of the total conversion of HBV areas. Focusing on Latin America, most HBV areas converted belong to other natural land. Unused forest areas of HBV as well as other natural land in Latin America are mainly converted to grazing land and with a lower proportion to cropland and new forests (Figure 14).
Figure 13: Development of accumulated area of unused forest area classified as HBV converted in 12 regions of the world for the Baseline scenario.

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

Most HBV areas in Sub-Saharan Africa are on grazing land and other natural land. Other natural land with HBV is mainly converted to grazing land, and grazing land to cropland (Figure 15). The conversion of unused forest of HBV to used forest of HBV, however, also occurs.
Figure 15: Development of annual area converted of unused forest, grazing land and other natural land classified as HBV in Sub-Saharan Africa for the Baseline scenario.

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

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

RoW emissions from land use have different trends in the Baseline scenario for different categories as can be observed from Figure 17. While deforestation emissions are decreasing, other land use change emissions, including the conversion of grazing land and other natural land to cropland, and also agriculture emissions are increasing. Increasing is also the sink from afforestation. **Total LULUCF in RoW is a net sink in 2000 but projected to turn into a source of CO$_2$ as of 2010.** This is partly due to the forest management sink that is declining over the projection period, due to intensification of forest management. In addition emissions from the agriculture sector are constantly increasing. It has to be noted that uncertainties associated with these estimates are very high. Especially forest management emissions at global level need to be interpreted carefully. The underlying database (e.g. age class distributions and management information) is very scarce and at global level such estimates are difficult due to different definitions of forest, carbon densities and pools considered in existing studies. The estimates as provided here do not cover emissions from grazing land nor RoW emissions from cropland.

**Figure 17:** Development of Agriculture emissions and LULUCF emissions and removals in RoW for the Baseline scenario.
Deforestation is the main source of greenhouse gas emissions from forest activities, and GHG emissions from deforestation correspond directly to the modelled deforestation area (cf. Figure 9). Global GHG emissions from deforestation in 2010 are 6,295 Mt CO₂ and they decline to 3,053 Mt CO₂ in 2050 (Figure 18). GHG emissions from deforestation are the highest in Latin America (2010: 2,932 Mt CO₂) and in Sub-Saharan Africa (2010: 1,883 Mt CO₂) with the tendency to decline until 2050 (1,600 Mt CO₂ and 800 Mt CO₂; Figure 18).

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

Figure 20 compares regional estimates from the literature with results of this study for the period 2000-2010. It seems that emissions from deforestation are overestimated for Africa and tropical America if looking at total emissions. The range of estimates found for Africa in the literature is remarkably low and does not reflect uncertainties associated with these estimates. Emissions from deforestation in Asia are in-line with literature values. However, for this region the spread of estimates is huge, spanning almost an order of magnitude from 250 to 2200 Mt CO₂. The results of this study fall into the ranges found by other studies. There are a number of assumptions that lead to the wide spread of estimates found. Most existing studies for comparison do not provide sufficient information to reconcile estimates and factor out sources for differences. When looking only at emissions from the biomass pool, estimates of this study are much closer to literature values. For Africa differences result probably from different carbon maps. Deforestation areas are similar to other studies (not shown). Estimates for Asia of this study do not include peat emissions that form a big source in that region and have been included in some studies. Including peat leads to considerably higher total deforestation emissions.
The uncertainties found from this comparison need to be considered when comparing policy scenarios. Even if the errors are relatively large, differences between policy scenarios can still be significant because uncertainties are more or less the same for all scenarios.

Figure 19: Comparison of global deforestation estimates from the literature and this study for the biomass pool and total. Note that estimates apply different definition of forest, different carbon densities and include different pools. This is causing the relatively large spread of estimates.
Figure 20: Comparison of regional deforestation estimates from the literature and this study (tropical forests only). Note that estimates apply different definition of forest, different carbon densities and include different pools. This is causing the relatively large spread of estimates.

Figure 21: Development of Agriculture emissions and LULUCF emissions and removals (i.e. the sum of Deforestation, Afforestation, Forest management, cropland CO₂ and other land use change emissions) in EU28 for the Baseline scenario.
Figure 21 describes the development of emissions and removals of different activities in the LULUCF and agriculture sector from 2000 to 2050. **Overall net LULUCF emissions are a relatively stable net sink in the EU at around -200 Mt CO₂.**

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

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

Differences between land use change emissions (other than deforestation) and agriculture emissions that turn out to be large are due to including different pools and activities making a direct comparison at this level of aggregation difficult (see also Box 1 on comparison with EU Reference projection).
Figure 22: Comparison of EU28 emissions estimated in this study with reported (2014) emissions and removals from UNFCCC reporting (JRC AFOLU tool-historical data 2014) and projected data from the 2013 EU Reference scenario.
## Box 1: Comparison of EU28 LULUCF and Agriculture GHG projections

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

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

A comparison of the Baseline scenario projection from this study and the EU Reference projection for the years 2030 and 2050 is provided in Figure 22b. The level of net LULUCF emissions of both projections is fairly similar for both years. Both used the GLOBIOM/G4M models, however, it should be noted that a number of project specific updates of the two models has been done for this project and not the same input data is being used (for an elaboration of the scenario specifications see the Task 3 report). The EU Reference expects a sink of -214 Mt CO\(_2\) in 2030, this study estimates the sink to amount -204 Mt CO\(_2\). However, trends to 2050 are different. While the EU Reference sees a decline to -196 Mt CO\(_2\), this study projects an increase to -245 Mt CO\(_2\). The reasons are in differences between the pools and subcategories covered, differences in input data, but also in different emission and removal estimates for subcategories. For example are removals from afforestation in this study expected to be higher in 2050 (-156 Mt CO\(_2\) compared to -130 Mt CO\(_2\)) related to a higher estimate of future prices of wood commodities. In 2030 both studies still agree very reasonably (-87 and -94 Mt CO\(_2\)). Another difference is the estimate of the sink from Forest management in 2050. While also for this category in 2030 levels seem to correspond (-137 and -126 Mt CO\(_2\)) this study sees a much stronger sink in 2050 (-77 compared to -24 Mt CO\(_2\)), directly related to a lower harvest level in the Baseline scenario of this study. Other LULUCF categories are very small and therefore relative difference large. Here differences might occur due to different activities considered.

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

3.2.1. Overview of impacts

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

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

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

To enable readers to digest the data on differences of an indicator between Baseline and policy scenario and different years the results are presented in a figure including all relevant information at once. The figures include a graph a) that describes the development of the variable over time for different elements in the Baseline scenario. The trend from 2010 to 2030 and 2050 is summarized in a bar chart b). Finally differences in the policy scenarios compared to the Baseline for the years 2030 and 2050 are presented (figure c)). This presentation helps to evaluate the differences between scenarios against the background trends of the Baseline and also to point to changes in the magnitude and sign of impacts compared to the baseline over time.

The figures showing areas present the increase (positive values) and decrease (negative values) of a land use category in comparison to the baseline. The figures cover all areas and changes. This is why the sum of area increases and decreases are balancing and positive and negative bars have the same size. Figure 25 shows differences identified for land use types within the EU28. In total, in EU28 the development of the Constant EU bioenergy demand scenario and Increased EU imports scenario are contrary to the development of the other two policy scenarios. Compared to the Baseline scenario, the Constant EU bioenergy demand scenario leads to a lower amount of SRC area and higher amounts of other natural land (including abandoned cropland and grazing land) and grazing land (2030 and 2050). While the total forest area (sum of used and unused forest) does not differ between the two scenarios too much, there are comparably large shifts within the forest leaving more used forest unused.

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

It is striking that some changes in the Baseline scenario override changes across scenarios for SRC, cropland and other natural land. This does not hold for grazing lands that are hardly affected under the Baseline scenario but show up to undergo losses until 2050 in those policy scenarios that assume increased biomass demand.
From a **global perspective (RoW)**, land use patterns in the Increased RoW bioenergy demand scenario differ most from the baseline scenario, especially in the year 2050. Changes in the other three policy scenarios seem to be almost not significant in this comparison (Figure 26). The impacts are related to the conversion of more unused forest to used forest and conversion of other natural land and cropland to SRC.
3.2.3. Impacts on land with high biodiversity value

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

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

From a global perspective (RoW), the conversion of HBV land is more important because the data from UNEP-WCMC identify 20% of the global land area as highly biodiverse. Figure 28 gives the distribution of these 1,850 Mha on different land use categories in 2000. Unused forests form the largest share, followed by other natural land and grazing land.
The conversion of HBV land is not proportional to the initial distribution of HBV land in 2000 as the land use categories are affected differently by conversion under different scenarios. But it is proportional to the impacts on the overall land use pattern (see Figure 26). The land use shifts affecting HBV land differ most between the Increased RoW bioenergy demand scenario and the Baseline (Figure 29). In the other three policy scenarios other natural land with HBV is converted less intensively. Effects on forest area with HBV in the Increased RoW demand scenario show that used forest area is increased, unused forest and also afforestation area decreased compared to the Baseline. In addition cropland is increased, other natural land decreased.

Figure 28: Distribution of areas with high biodiversity on land use categories for the RoW in 1000 ha (year 2000).
Figure 29: Projected changes of HBV areas in RoW a) in the baseline, b) in the baseline between 2010 and 2030/2050 and c) in different scenarios and years compared to the baseline.
3.2.4. Impacts on GHG emissions from land use activities

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

The scenarios are also affecting non- CO₂ emissions (Figure 31). While impacts in 2030 are rather limited, stronger effects can be noted for 2050, especially for those scenarios that lead to an increased use of biomass (be it imported or domestically sourced). Only the Constant EU bioenergy scenario results in increased emissions compared to the Baseline. The change in agriculture emissions can mainly be attributed to increased livestock production related to an increase of grazing and cropping land. In all other scenarios emissions from livestock and fertilizer input are lower. The changes in livestock emissions can be attributed to reduced bovine milk and meat production in EU28, a result of decreased grazing land area. While EU28 production of these food and feed commodities decrease in these scenarios, EU28 consumption is stable but to a higher degree relying on imports. Figure 31 also shows: differences between scenarios are smaller than the changes in the Baseline scenario between 2010 and 2030/2050. Figure 32 summarizes all GHGs and presents net LULUCF and Agriculture sector emissions. It is striking that compared to the Baseline all scenarios are reducing net emissions from LULUCF (between 5 and 18 Mt CO₂eq). Agriculture emissions are higher for the Constant EU bioenergy scenario but fully compensated by LULUCF CO₂ emission reductions.

Figure 33 and Figure 34 present changes in emissions from these two sectors for the RoW. Also here impacts become stronger over time. Hardly any differences can be noted when comparing forest management emissions with the Baseline across scenarios in 2030. All scenarios show a decreased sink (positive bars) in that year. Striking is the result for the Increased RoW demand scenario. In 2050 more than 140 Mt CO₂ are emitted more from forest management in this scenario compared to the Baseline. This is contrasted by reduced emissions from deforestation of about 40 Mt CO₂.

Livestock and other non-CO₂ emissions are not reacting consistently across scenarios compared to the Baseline (Figure 34). The strong reduction of livestock related GHG in 2050 in the Increased RoW bioenergy demand scenario is reflecting the increased competition between beef and milk production and bioenergy. Also for the RoW total net LULUCF and Agriculture emissions can be compared (Figure 35).
Figure 30: Projected Changes in forestry CO$_2$ emission and removals in EU28 a) in the baseline, b) in the baseline between 2010 and 2030/2050 and c) in different scenarios and years compared to the baseline.
Figure 31: Projected changes in non-CO₂ land use emission in EU28 a) in the baseline, b) in the baseline between 2010 and 2030/2050 and c) in different scenarios and years compared to the baseline.
Figure 32: Projected changes in net LULUCF emissions and removals and Agriculture emissions in EU28 a) in the baseline, b) in the baseline between 2010 and 2030/2050 and c) in different scenarios and years compared to the baseline.
Figure 33: Projected Changes in forestry CO₂ emission and removals in RoW

a) in the baseline, b) in the baseline between 2010 and 2030/2050 and c) in different scenarios and years compared to the baseline.
Figure 34: Projected changes in non-CO2 land use emission in RoW a) in the baseline, b) in the baseline between 2010 and 2030/2050 and c) in different scenarios and years compared to the baseline.
3.2.5. Impacts on the EU Forest management sink

The policy scenarios differ from the Baseline by assuming different production and use of forest biomass. This changes also the levels of harvest in these scenarios. If the forest increment remains largely unchanged (one could assume forest fertilization, change in species etc.), increased harvest levels directly impact the carbon balance of forests. More export of carbon through harvest means that the net sink of a forest is reduced or the net source increased. Figure 36 compares harvest from forest management (excluding a small amount of wood harvested from deforestation) and forest sink development for EU28. Harvest levels increase for EU28 at a level of 470
Mm³ in 2000 (lower left side of the panel). Harvest levels in 2050 range from 519 Mm³ to 615 Mm³. What Figure 36 shows is the response of the EU forest carbon balance to changes in future harvest levels. The development of the relationship between harvested volume and carbon sink is very similar for the scenarios. In all scenarios the sink is declining, most strongly in the scenario of Increased RoW bioenergy demand, from -232 Mt CO₂ in 2010 to -109 Mt CO₂ (Constant EU bioenergy demand) and -51 Mt CO₂ (Increased RoW bioenergy demand). The response of the sink is thus quite symmetrical: the scenario with the lowest harvest level after 2020 (Baseline) results in the strongest sink. Increased EU biomass import and Constant EU bioenergy demand scenarios both cause the sink to be 10-20 Mt CO₂ smaller than in the Baseline. About 100 Mm³ more are harvested in 2050 under the EU emission reduction scenario compared to the Baseline, decreasing the sink by about 50 Mt CO₂.

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

Figure 37 puts additional harvest volume compared to the Baseline in relation to caused decline in the sink. Across the scenarios the impacts per m³ are similar, stressing again the symmetry of the sink response. The impacts are different, however, for different years. The ratio of harvest volume to sink strength in 2050 is 5-50% smaller than in 2030. This is due to the fact that the average age of EU forests is higher in 2050. Older trees take up less carbon. Leaving the trees growing in the forest (this is the alternative to harvest) therefore causes less of a sink reduction.
Figure 37: Impact of increased harvest on the EU28 forest sink relative to the baseline scenario (=1.0). The difference to the sink in the baseline scenario in Mt CO$_2$ is divided by the additionally harvested volume from forests in Mm$^3$ compared to the baseline. This results in the sink reduction per additionally harvested m$^3$.

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

The reduction of the rotation time in the other scenarios compared to the Baseline might result in higher productivity of the forest. It causes, however, also the loss of habitat for many species depending on large dimension trees, old tree age classes and dead wood. Without being able to explicitly model the loss of habitat, the average rotation time can serve as a proxy for the availability of old trees and habitat for species depending on them. Largest impacts would therefore be expected from the Increased RoW demand scenario on EU forests, causing average rotation time to drop by 4% in 2050. Similar impacts are expected for the EU emission reduction scenario.
Figure 38: Comparison of forestry rotation length in policy scenarios with Baseline.
4. Results of Stage 2: Exploring implications of environmental constraints for biomass resource efficiency

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

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

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

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

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

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

4.1.2. Area of unused forest converted to used forest

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

This indicator is a good proxy for assessing changes in the intensity of forest management due to increased biomass demand. Technically, the area of unused forest can rather easily be constrained to the same developments as in the Baseline. For the
In the Baseline scenario in EU28, about 40% of "other natural land" (25 Mha) is converted between 2010 and 2050; in the RoW, it is 500 Mha (-17%). Other natural land consists of various types of land that are not very homogenous (a mixture of land that cannot be properly classified such as unused cropland (if not fallow) or unused grassland, including natural grasslands). Across scenarios differences for EU28 are between +1.9 and -2.9 Mha compared to the baseline in 2050 (5.5% to -8.4%), for the RoW differences are up to -30 Mha (-1.2%).

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

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

**4.2.1. Implications for production of biomass in EU**

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

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

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

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

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

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

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

4.2.3. Implications for biomass use

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

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

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

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

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

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

### 4.2.4. Implications for land use in EU and the RoW

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

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

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

There is a significant conversion of unused forest to used forest (more than 5 Mha) in the RoW that is accompanied with constraining forestry intensification within EU. The area affected is of a similar size compared to the area prevented from conversion in EU (cf. Figure 42).
4.2.5. Implications for GHG emissions from the land use sector in EU and RoW

Constraints of land use changes regarding areas of High Biodiversity Value, unused forest and other natural land have implications for GHG emissions from the land use sector in EU (see Figure 44). If areas of HBV are excluded from conversion it can be observed that in EU28 forests are more intensively used and the carbon sink in those forests is reduced compared to the unconstrained EU Emission reduction scenario (shown as relatively higher emissions). Emissions from Harvested Wood Products
(HWP) are reduced, i.e. the sink is increased. Emissions from deforestation are also reduced in EU. The net sum of forestry emissions under this constraint is negative (i.e. emissions are reduced, about -5 Mt CO₂ compared to the EU Emissions reduction scenario in 2050). In 2050 all constrained scenarios yield lower net emissions from forestry in EU compared to no constraints. The effect in EU is the largest when unused forests are protected from conversion in EU28 (-24 Mt CO₂). Here the largest contribution results from an increased sink in EU forests, compensated to some degree by increased emissions/a reduced sink from HWPs. Constraining conversion of natural land in EU28 reduces emissions from deforestation in EU28. This is the result of EU28 forests becoming more valuable if other natural land is not available for wood production e.g. in SRC plantations.

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

The net balance of GHG emissions from forestry in RoW are displayed in Figure 45. In a scenario where conversion of land with high biodiversity value is constrained, emissions from deforestation will be decreased by 3 and 17 Mt CO₂ in 2030 and 2050. These emission reductions compared to the EU Emission reduction scenario are compensated by reduced removals from afforestation. Existing forest with high biodiversity value is protected from conversion but also other natural land and other non-forest land use classes with these properties are not any more available for afforestation. In total, net forestry emissions increase for RoW in 2050 if HBV areas are not converted, a clear trade-off. The effect on emissions from forest management is less consistent over time and reflects more shifts of management intensity and biomass production away from cropland towards managed forests. Increased forest management emissions of about 15 Mt CO₂ can be observed in 2050 in a scenario where unused forests in EU28 are not available for intensification. The constraint on other natural land, instead, decreases net forestry emissions in RoW slightly in 2030 and 2050. So the constraint on conversion of EU natural land reduces the net-emissions from the forest sector both in EU and RoW. In all other constrained scenarios, the forestry GHG emissions impacts go in opposite directions in EU and RoW.
Figure 45: RoW forestry emissions in the EU emission reduction scenario (a) and implications of single environmental constraints (b).

Figure 46 describes changes of net GHG emissions from the land use sector in EU28 aggregated to total LULUCF (CO$_2$) and total agriculture (non-CO$_2$) emissions compared to the EU Emission reduction scenario. Changes in net LULUCF emissions dominate changes across all scenarios and in all years. In the long-term, all constraints lead to net GHG emission reductions in EU. In 2050, net EU land use emissions would relatively be reduced by more than 5 Mt CO$_2$ with a constraint on the conversion of HBV land, by more than 25 Mt CO$_2$ with a constraint on unused European forests, and by more than 10 Mt CO$_2$ with a constraint on the conversion of other natural land. Figure 47 shows that these relative emission reductions in EU are associated with increases in emissions in RoW in 2050 in the case of a scenario where EU forest management is not intensified (unused forest constraint). Other constraints lead to net GHG emission reduction in RoW. This is especially true for constraints on HBV areas where large emission reductions compared to the reference can be observed for agricultural emissions. This is due to a reduction in global meat and milk production by 8 Mt of meat and 2 Mt of milk, (about 1-2% of total production). As the conversion of HBV areas to grazing land for cattle is limited, prices for meat and milk increase compared to the unconstrained scenario. This effect is more pronounced in the RoW than in EU28.

In the global sum of net land use emissions (EU + RoW), all scenarios with constraints result in emission reductions compared to the EU Emission reduction scenario (Figure 48). This means that there are synergies of constraints to protect biodiversity, unused forests and other natural land from conversion regarding global net GHG emissions from the land use sector. However, there are regional differences (here we show only EU28 and RoW) and the effect differs for LULUCF and agriculture emissions.
Figure 46: EU net land use emissions in the EU emission reduction scenario (a) and implications of single environmental constraints (b).

Figure 47: RoW net land use emissions in the EU emission reduction scenario (a) and implications of single environmental constraints (b).
Figure 48: Global net land use emissions in the EU emission reduction scenario (a) and implications of single environmental constraints (b).

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

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

4.3.1. Implications for production of biomass in EU

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

The impacts of the sustainability constraints are more modest in the two other policy scenarios, the Constant EU bioenergy demand and the Increased EU biomass import scenarios. In these scenarios, sustainability constraints increase EU forest harvests in 2050 by 9 Mm$^3$ in the Constant EU bioenergy demand scenario, and by 10 Mm$^3$ in the Increased EU biomass import scenario, as compared to the same scenario unconstrained. The main reason for this development is the protection of HBV areas...
outside of the EU: when no conversion is allowed for these areas, the EU imports of roundwood will decrease (see next section) and harvest pressure in the domestic forests is increased. In these two scenarios, the harvest levels in the unconstrained scenarios are below the Baseline scenario harvest level. Hence it is possible to increase the harvests to some extent, and still fulfill the constraint of keeping the conversion of unused forest at the level of the Baseline scenario. For the Increased EU biomass import scenario, this increase is not sufficient to satisfy the demand for bioenergy feedstocks within the EU: hence, also SRC production in 2050 increases by 3.5 Mm³ compared to when no sustainability constraints are implemented.

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

4.3.2. Implications for trade of biomass

As was seen already for single sustainability constraints, changes in EU biomass production observed across the constrained scenarios have implications for biomass trade between EU28 and RoW. The considerable decrease in the total EU forest harvests in the EU Emission Reduction and Increased RoW bioenergy demand scenarios as compared to their unconstrained cases leads to increased biomass EU imports, especially imports of sawlogs, pulpwood and wood pellets (Figure 50). Especially for the EU Emission Reduction scenario, the wood pellets imports in 2050 increase by almost 16 Mm³ when all sustainability constraints are applied: a 30% increase compared to the unconstrained scenario (Task 3 report).

For the Increased RoW bioenergy demand scenario, the increase in net imports of wood pellets is more modest than for the EU Emission Reduction scenario, but the EU sawlogs and pulpwood imports increase almost similarly to the EU Emission Reduction scenario: an 11 Mm³ increase compared to the unconstrained scenarios. The reason for this development is that the sustainability constraints reduce heavily the availability of industrial-quality roundwood in the EU by constraining the conversion of unused forests. However, the imported pellets are sourced from outside the EU. An increased RoW bioenergy demand, combined with decreased availability of wood because the HBV areas are not allowed to be used, results in a relatively small
increase in the EU imports of wood pellets in the Increased RoW bioenergy demand scenario compared to EU Emission Reduction scenario.

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

In the Constant EU bioenergy demand and Increased EU biomass import scenarios, the sustainability constraints slightly increase EU sawnwood exports. The increase is seen in 2030 for all scenarios, and also in 2050 - especially for the Constant EU bioenergy demand scenario, where the EU sawnwood exports are 4 Mm³ larger when the sustainability constraints are applied. This is explained by a reduced availability of sawlogs outside of the EU, as most of the protected HBV areas are located outside the EU. However, in 2050 in the EU emission reduction scenario and the Increased RoW bioenergy demand scenario, EU sawnwood exports are smaller than in the scenarios without sustainability constraints. The difference is especially large in the Increased RoW bioenergy demand scenario, where the EU sawnwood exports are almost 5 Mm³ smaller than if the combined sustainability constraints were not considered. In this scenario, the domestic harvests within the EU were much larger than in the Baseline scenario. Constraining conversion of unused forests to Baseline level leads to a large reduction in harvests, which will cause a notable decrease of the possibilities to export sawnwood from the EU.
Figure 50: Differences in net trade in constrained policy scenarios compared to unconstrained scenarios.

4.3.3. Implications for biomass use

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

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

For the other two scenarios, the Constant EU bioenergy demand and Increased EU biomass import scenarios, the effects of sustainability indicators are negligible for use of wood biomass for energy production. However, contrary to EU Emission Reduction and Increased RoW bioenergy demand scenarios, material production is seen to increase in Constant EU bioenergy and Increased EU biomass import scenarios if sustainability constraints are applied. This is driven by the increased EU exports of sawnwood, which increase the use of sawlogs for material by 6.5 Mm³ in 2050 in the Constant EU bioenergy demand scenario and by 4 Mm³ in 2050 in Increased EU biomass import scenario. The increase in sawnwood exports is possible because of the originally lower harvest level in these scenarios compared to the Baseline. In the other two scenarios the harvest level was originally much higher than in the Baseline, which is why the constraints have a much stronger effect.

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

### 4.3.4. Implications for land use in EU and the RoW

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

Overall, across all scenarios, the constraints have largest implications for the area of used and unused forests. However, these areas are affected in opposite directions. In the EU emission reduction and the Increased RoW bioenergy demand scenarios, the application of the constraints leads to an increase of unused forest in EU by 5-6 Mha. This is because less unused forest is converted to used forest, but also due to reduced deforestation (compare light and dark green bars in Figure 52).
This effect is reversed when the constraints are applied to the Constant EU bioenergy demand and the Increased EU biomass import scenarios. In both cases, the area of used forest increases. This is only to some degree due to the conversion of unused forest (which is constrained to Baseline levels) but rather due to afforestation. Indeed, when compared to the Baseline, the Constant EU bioenergy demand and Increased EU biomass import scenarios showed higher areas of unused forest in 2050, while for the other two scenarios with higher domestic biomass production, there was less unused forest (Figure 26c). Therefore, when constraints are applied, the policy scenarios resemble more the Baseline scenario, meaning that unused forest area increases in the EU emissions reduction and the Increased RoW bioenergy demand scenarios and decreases in the other two. Across all scenarios, the set of constraints applied lead to a reduction in other natural land, which is converted to forests. It is striking that, for most scenarios, the area of SRC increases until 2050 when constraints on environmental sustainability are applied. In these scenarios, other cropland is reduced in 2050 if land use is constrained. An exception is the Constant EU bioenergy demand scenario.

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

While the effect of constraints impacts land use in EU differently in different scenarios, the constraints have a very similar effect on all scenarios for the RoW, which is also consistent over time (Figure 53): Grazing land, used forest and other natural land increase, mainly because they form large shares of HBV land. Also, there are more SRC areas when the constraints are applied as compared to unconstrained scenarios. These expansions come at the expense of cropland and unused forests. It has to be noted that the figure shows the net balance of area changes. The constraints protect productive land from conversion. The land that can be converted is less fertile and therefore more grazing land has to be created on non-HBV to compensate for the loss in productivity. Therefore the net balance of land use results in more grazing land under constraints. In total, the areas affected are about...
40 Mha. Especially the constraint on the conversion of HBV areas is relatively strong as it constrains any land conversion of HBV land, leading to implications that go beyond the actual impacts observed in stage one of the analysis of most scenarios (around 10 Mha). Therefore there are rather small differences between scenarios regarding the effect of constraints.

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

The land GHG implications of applying constraints on policy scenarios are displayed in Figure 54 and Figure 55. Consistently to the land use figures, the reduction in intensity of forest management, as a result of constraints, leads to an increased sink in existing forests for the EU emission reduction and Increased RoW bioenergy demand scenario. This is contrasted by decreases of the Harvested Wood Products sink/increases of emissions. For the other scenarios, implications for forest management emissions are limited. **Net EU forestry emissions are reduced in all scenarios between 7 to almost 40 Mt CO₂ if constraints are applied.** In addition to increases in the forest sink, reduced emissions from deforestation contribute to the net emission reduction as well as removals from afforestation.

Impacts of the sustainability constraints for the RoW are dominated by reductions in GHG removals from afforestation (Figure 55). This is not obvious from the land use implications discussed above (Figure 53), where the net area of used forest is increased under constraints. This emphasizes the importance of gross area changes that are revealed when looking at changes in emissions. Constraints on land conversion shift land use across the landscape with implications for productivity. For example: even if a net area of a certain land use category is not changing the average growth rate on this area might be different.
Despite the fact that deforestation emissions are reduced under the constraints, all policy scenarios show a net increase of RoW forestry emissions in the long run (in 2050), by an amount of 20 to 60 Mt CO₂.

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

**Figure 55:** Differences in RoW forestry emissions in constrained policy scenarios compared to unconstrained scenarios.
Total net land use emissions include forestry, other land use and land use change (LULUCF) and agriculture non-CO\textsubscript{2} emissions. Figure 56 presents net land use emissions for EU28 as difference between constrained and unconstrained policy scenarios. As observed for forestry emissions in all scenarios net emissions are reduced by up to 40 Mt CO\textsubscript{2} eq. (EU emission reduction scenario) when constraints are applied. Agriculture emissions are not affected except for two scenarios. The magnitude of reduction, however, is different. Largest reductions associated with environmental constraints are achieved in the EU emissions reduction and the Increased RoW bioenergy demand scenarios.

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

In the RoW agriculture emissions are more affected by constraints than in EU (Figure 57). Figure 47b has shown that especially the constraint on HBV area conversion contributes most to this effect. **Net land use emissions in all scenarios are reduced by the sum of constraints but only due to the large reductions of agriculture emissions of more than 100 Mt CO\textsubscript{2} eq.**

The dominance of agriculture is also to be noted when looking at global (RoW + EU) net land use emissions (Figure 58) and is the strongest for the Increased RoW bioenergy demand scenario, under which more than 150 Mt CO\textsubscript{2}eq. are avoided if globally areas of HBV and EU-wide unused forests and other natural land are conserved. While the implications for agriculture GHG emissions of constraints are consistent across all scenarios, the effect for LULUCF emissions is less 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. In the global sum of net land use emissions (Figure 58), **net land use emissions in all scenarios are reduced when jointly combining the environmental constraints, due to**
large reductions of non-CO₂ emissions from the agriculture and livestock sectors. This is due to increased prices for livestock products and thus reduced demand due to elasticities. Under HBV constraints only less fertile land is available, leading to higher costs of conversion and more grazing land to be created to compensate for relative productivity losses.

**Figure 57: Differences in RoW net land use emissions in constrained policy scenarios compared to unconstrained scenarios.**
Figure 58: Differences in global net land use emissions in constrained policy scenarios compared to unconstrained scenarios.
5. Summary and Conclusions

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

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

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

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

The indicator unused forest area is a good proxy for assessing changes in the intensity of forest management due to increased biomass demand. If forests in EU are protected from further intensification (i.e. through constrained conversion of unused forest into used forest) globally an increased production of SRC can be observed (comparably less SRC is established if constraints are put on the conversion of other natural land in EU). In addition, there is a significant conversion of unused forest to used forest in the RoW that is accompanied with constraining forestry intensification within EU. This area is exceeding the area constrained in EU28, so globally slightly more forest area is converted if the constraint is applied in EU.
The impacts of sustainability constraints increase EU forest harvests in 2050. The main reason for this development is the protection of HBV areas outside of the EU: when no conversion is allowed for these areas, the EU imports of roundwood will decrease and harvest pressure in the domestic forests is increased. For all scenarios, until 2050, the area of SRC increase when combined constraints on environmental sustainability are applied. In the RoW, grazing land, used forest and other natural land increase mainly as a consequence of environmental constraints on HBV land.

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

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

Net GHG emissions from LULUCF in the Baseline scenario form an overall relatively stable net sink in the EU. The forest sink, however, is projected to decline; and more strongly in the two policy scenarios with increased domestic biomass production, which is in-line with other reports and scientific publications. Comparatively small are effects on afforestation removals between policy scenarios. The scenarios are also affecting non-CO₂ emissions. In particular, an increase in bioenergy demand is noted to lead to some agricultural emissions related to food and feed production being “exported” from EU to RoW. Looking at total net LULUCF and Agriculture sector emissions, it is striking that, compared to the Baseline; all scenarios reduce net GHG emissions from LULUCF. Agriculture emissions are higher for the Constant EU bioenergy scenario but fully compensated by LULUCF CO₂ emission reductions.

Consistently to the land use figures, the reduction in intensity of forest management, as a result of constraints, leads to an increased sink in existing forests for the EU emission reduction and Increased RoW bioenergy demand scenario. This is contrasted by decreases of the HWP sink/increases of emissions. For the other scenarios, implications for forest management GHG emissions are limited. Net EU forestry emissions are reduced in all scenarios between 7 to almost 40 Mt CO₂ if constraints are applied. Despite the fact that deforestation emissions are reduced, all policy scenarios show, under the constraints, a net increase of GHG emissions in the long run (in 2050), by an amount of 20 to 60 Mt CO₂.
In the global sum of net land use emissions, all scenarios with constraints result in less GHG emission compared to the unconstrained scenarios. It has however to be noted that this is only due to large reductions of agriculture GHG emissions, of more than 100 Mt CO$_2$eq. Global LULUCF emissions are higher with constraints for three of the four scenarios in 2050 (exception is the Increased RoW bioenergy demand scenario).

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

EU European Union
GHG Greenhouse gas
G4M Global Forest Model
GLOBIOM Global Biomass Model
HBVA High Biodiversity Value Area
HWP Harvested Wood Products
UNEP-WCMC United Nations Environment Programme - World Conservation Monitoring Centre
LULUCF Land Use, Land Use Change and Forestry
RoW Rest of the World, excluding EU
SRC Short Rotation Coppice (sub-category of cropland)
WDPA World Database on Protected Areas
Annex 1

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

Production of biomass for EU by biomass type

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

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

- **Harvest of roundwood from forest.** This is an aggregate category comprising of felled or otherwise harvested and removed wood, with or without bark. It includes sawlogs and veneer logs; pulpwod, round and split; other industrial roundwood, and also branches, roots, stumps and burls (where these are harvested). It is reported in cubic metres solid volume.

- **Forest chips.** Forest chips are fresh wood chips made directly of wood that is harvested from the forest, used for energy production, and has not had any previous use (as opposed to wood chips from industrial by-products). There are several raw material types of forest chips:
  - Tops and branches removed from trees during final felling
  - Sawlogs that are rejected being unsuitable for material purposes due to decay etc.
  - Delimbed small size stems or un-delimbed small-size trees from thinnings.
  - Pulpwood size logs allocated to energy production from thinning or final felling.
  - Tree stumps.

- **Industrial by products.** This category includes industrial chips, sawdust, shavings, trimmings and bark. They are supplied as by-products available in proportions from the processes of wood products industry, mainly sawmilling but also wood based panels and joinery production. Industrial by-products have to be clean and they are not altered by any chemical process. They are important raw materials for pulp, wood based panels (Particleboard, MDF/HDF) and wood pellet production as well as in bioenergy production as such.

- **Woody biomass from short rotation coppice.** This category covers short rotation coppices are formed by tree plantations established and managed under an intensive, short-rotation regime on agricultural land. They can be established with quickly growing species such as poplar and willow, and managed under a coppice system in a two-to-five-year rotation.

- **Woody biomass from perennials.** This category covers woody biomass from species such as miscanthus and reed canary grass that can be established and used to produce biomass for energy purposes.

- **Agricultural and livestock products** are covered such as: rice, wheat, other cereals, oilseeds, sugar crops, other crops, ruminant meat, monogastric meat and eggs, milk, and crop residues.
Land use
The main land use types are covered by the model and it endogenously calculates the change between these land use types. We indicate the amount of land use change that can be expected to occur between these various classes:
- Used and Unused Forest
- Plantations
- Cropland
- Grazing land
- Other natural land

Change in production patterns (forest intensification, change of agricultural crop)
For this indicator we evaluate and analyze the following aspects
- Forest intensification: This is expressed in terms of change in forest rotation periods and change in amount of wood from harvesting operations. Both of these two aspects are covered by the model with internal parameters.
- Agricultural intensification: This will be expressed in terms of change in crop yields and how it evolves over time for the various regions.

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

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

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

5 The term "used forests" refers to all forest areas where harvesting operations take place, while "unused forests" refers to undisturbed or primary forests. There are other three land cover types represented in the model to cover the total land area: other agricultural land, wetlands, and not relevant (bare areas, water bodies, snow and ice, and artificial surfaces). These three categories are currently kept constant at their initial level.
Study on impacts on resource efficiency of future EU demand for bioenergy
Task 5
Case studies
Executive Summary

Background

There is a wide variety in the type of forest and agricultural resources in countries across the EU, as well as in how they are managed by owners, and by their respective governments in terms of policy. The objective of this analysis is to facilitate better understanding of how the specific local circumstances in each country (from local to national level) influence, and are influenced by national and regional policies. It also aids in understanding the potential contribution of biomass utilization towards meeting renewable energy targets in contrasting policy and resource environments. We place the projections of this study in the context of the current biomass resource, consumption and policy situation within three selected case study countries.

The task will analyse information collected within the project in more detail for three selected contrasting case study countries to examine resource use, its environmental impact, and also competition for biomass and resource efficiency. Together with the Commission, the consortium has selected one country each from Northern, Central and Southern Europe: Finland, Germany and Italy.

Methodology

For the analysis of resource availability, the focus of this task is mostly on forest as a biomass resource as it covers a significant land area in Europe and is where more consistent European data is available. For more information on agricultural and other types of biomass please see Task 1 report.

For the analysis of the policy environment, the focus was a little wider. The intention was to provide a consistent record of the policies in place that will drive or impact on uptake of bioenergy specifically from solid and gaseous sources within Finland, Germany and Italy. These include highly targeted policies for bioenergy use in electricity or heating or wider policies promoting action, such as bioeconomy and biodiversity strategies. The key policy measures in place at present were identified. This analysis provides a record of the policies, legislative and fiscal actions in place in the three countries selected that are of relevance to the bioeconomy more widely. Given the future-looking purpose of this task, the analysis considers both binding measures and more strategic policy documents that might indicate future directions. For federal countries, the focus was on national action, however, when considering future direction, if any evidence emerged from key regions in terms of leadership, these were noted.

The baseline scenario, described and developed in Task 3 of the project, forms a point of comparison in terms of the implication of various policies. For the case study countries, this scenario was assessed with respect to indicators such as land use change development over time, biomass feedstock used for production of energy, materials, and other biomaterials (solid wood, energy crops, forest chips, wood chips, etc.), and the total production level of the wood processing industries showing the impact on competition of the supply of biomass resources.
Comparison of the three case study countries

Biomass availability

Germany contains the highest volume of growing stock per hectare of the three selected case study countries and Germany and Italy contain a greater diversity of tree species than Finland, due to the boreal climate of Finland. Finland's forests have a high proportion of trees in lower age classes compared to the other two countries analysed. Italy contains a high proportion of unmanaged forests. In terms of forest ownership, Germany has the greatest proportion of publically owned forest followed by Italy. Most of the forests of Finland are privately owned; with the exception of Lapland where much of the forest is in public ownership and protected. Nevertheless, Finland’s privately owned forests are usually intensively managed whereas in Italy, the privately owned forests are often unmanaged. Germany has the highest net annual increment rates of the three countries due to its temperate climate. Of the three countries, the forests of Finland are most intensively managed and harvested, however actual harvested volumes per hectare remain lower than in Germany due to the lower increment rates.

Policy highlights

The targets included in the EU Renewable Energy Directive (RED) are the main drivers for current renewable energy production in all three Member States and, beneath this, 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 in comparison, Italy’s focus is around the expansion of agro-forestry and use of 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. intensity of forestry use compared to expansion in agro-forestry area.

All three countries have their own approach to address the issue of competition for biomass. In Finland strategies are aimed at abating concerns about increased demand for biomass and its impacts on the wider availability for woody biomass for energy and material uses. In Germany there is some concern about increasing pressure on forest systems and there are some finance schemes emerging which aim to protect forest areas in line with climate mitigation and adaptation goals. In Italy, there is more focus on the expansion of energy crops, including agroforestry due to the existing resource base, however efforts are focused on marginal land and areas no longer fit for agricultural production rather than general agricultural land.

Sustainable forest management (SFM) and associated certification is supported in all three selected case study countries, however, forest management lies with the land owner, outside of protected areas. Efforts regarding higher levels of sustainability remain largely voluntary. In Germany the question of voluntary certification for energy biomass as well as wood for material use has been discussed but binding action is yet to result. Beyond this, no mandated rules were identified in the three Member States regarding wider use of solid biomass for energy or the use of biomaterials.

Key baseline modelling results

The GLOBIOM model was applied to the three countries and used to evaluate developments in land and resource use over time from the period 2010-2050 under the baseline scenario.
For Finland, the Baseline scenario estimates almost negligible change in land use over time until 2050. However, the increase in the 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 in the baseline modelling 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 within Italy – most noticeably with conversion of other natural land to forest - and also significant rises in roundwood imports and pellet imports. For Italy, the projections show changes in resource use in terms of two significant aspects i.e. within-country production and production in other countries resulting in imports.

**Results of the analysis**

The aim of this study was to examine biomass resource and consumption patterns and their associated relevant policies in the three case study countries Finland, Germany and Italy. The results of the review were then used to examine GLOBIOM outputs at the country level to look at evolution of these outputs over time to 2050 and provide a context on current practice.

From the resource side, the three countries examined here have contrasting situations. In Finland, there is an abundant forest resource which is intensively managed and harvested. There is a highly evolved and progressive timber and pulp industry and renewable energy from wood is already in common use. There is not so much scope to increase SRC outside of the extreme south of the country due to the climate. In Germany, there also a significant forest resource which is slightly less intensively managed than in Finland in general, but also supplies a very active wood industry. The agricultural land there may provide an opportunity for increased SRC plantations. In Italy, the forest area covers the same proportion of the country as for Germany; however, much of this forest is not actively managed and, as a whole, there is not as large wood industry as in the other two countries studied. Consequently, there is more policy emphasis on agroforestry and SRC. From a policy point of view, the policies and incentives available generally reflect the particular resource conditions in each of the three countries.
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Introduction and resource overview

There is much heterogeneity in the type of forest and agricultural resources in countries across the EU28 as well as how they are managed by owners, and by their respective governments. In order to facilitate better understanding of how the specific local circumstances in each country (from local to national level) influence, and are influenced by national and regional policies the specific local circumstances of three countries were examined in terms of their resources, and their policy environments. This will also aid in understanding the potential contribution of biomass utilization towards meeting renewable energy targets in contrasting policy and resource environments. The task examines information collected in detail for three selected contrasting case study countries to analyse resource use, its environmental impact, and also competition for biomass and resource efficiency. Together with the Commission, the consortium has selected one country each from Northern, Central and Southern Europe, namely Finland, Germany and Italy. These are three contrasting countries in terms of biomass resources and bioenergy consumption.

Data quality

For woody biomass there was good data available for the three countries and we used data that was collected in a consistent manner (i.e. from the same studies and sources where possible). Consistent information on agricultural biomass was less easily available but covered in depth in the Task 1 chapter.

First the resource situation is described in the three countries under a number of headings. The analysis is mostly confined to European level datasets calculated in a consistent manner, to ensure the most comparability between the three case study countries. Second, the policies affecting the use of biomass resources in the three countries are examined in detail. In the third part of this report, model results for the case study countries resulting from the GLOBIOM runs for the Baseline scenario of the project are scrutinized, based on the resource availability and policy analysis. Land definitions are consistent throughout the project and are described in detail in Task 3.

Growing stock and species

Growing stock refers to the volume of wood, standing in the living trees as measured and reported by national and/or regional forest inventory according to a specific methodology. (UNECE, 2010). This variable indicates where the greatest volume of trees is located. When evaluating the biomass resource for countries it is also important to look at the species distribution available as some species and forest types are more productive than others.

The most common tree species in Finland is Scots pine, which is the dominant species in 64% of the total forest area (Figure 5.1.1, Figure 5.1.2) and accounts for almost 50% of the growing stock. The other important species group is Norwegian spruce which is the main species in 24% of total forest area and accounts for 30% of growing stock. Birch dominated forest covers just over 9% of total area and 16.7% of growing stock. (OSF, 2013). Figure 5.1.1 shows that the growing stock volume per hectare is higher in the more productive and more temperate regions of southern Finland by comparison with northern Finland, much of which lies inside the Arctic Circle.
Figure 5.1.1: Growing stock of coniferous trees in Europe. (m³/ha)
Source: Gallaun et al. 2010

Figure 5.1.2: Growing stock of broadleaved trees in Europe. (m³/ha)
Source: Gallaun et al. 2010
In the temperate climate of Germany, the south is dominated by spruce forest whereas northern Germany has more pine dominated forests. West Germany has a higher proportion of broadleaved forests with oak and beech being commonplace. In recent decades, more importance has been attached to regeneration with site-adapted tree species. German efforts to shape the composition of forest species in a more natural way has resulted in a greater proportion of semi-natural forests (i.e. a similar species composition and structure to a natural forest in the area and a large amount of natural regeneration). Nowadays approximately 73% of German forests consist of mixed stands. Spruce accounts for the largest share among the tree species (28%), followed by pine (23%), beech trees (15%) and oak trees (10%) (Figure 5.1.3). As can be seen in Figure 5.1.1 the amount of growing stock in the forest area is much higher than in Finland. The forests of Germany are highly productive especially in the southern half of Germany where volumes of greater than 250 m\(^3\)/ha are common.

Italy has a very wide variety of tree species. The country’s forests are dominated by broadleaved species such as beech and oak (Figure 5.1.3). Poplar plantations also occur in lower lying areas of northern Italy. Most of the forest growing stock occurs in the mountainous regions of the Alps and the Apennines. The growing stock volume is in general much lower by comparison with Germany and situated in steep and often inaccessible mountainous areas. Volumes are highest in the Alpine areas of Northern Italy (>250 m\(^3\)/ha). Significant volumes also occur along the Apennines.

**Age class distribution**

A high proportion of woody biomass for energy comes from younger age classes so it is helpful to look at the age class distribution when evaluating the resource. More intensive management and harvesting of a forest reduces the average age of a forest area.

In Finland in 2010, fellings as a percentage of the net annual increment of forest available for wood supply was 65% (Forest Europe, 2011). However it is necessary to also look at the age class distribution when examining additional potential harvest. Vilen et al. (2012) gathered historical and current forest age-class distribution data from 1950 to 2010 and found that the mean age class in Finland has decreased significantly with the area weighted mean forest age reducing by 39 years over a 60 year period. This large decrease in the mean age and share of old forest can be partly explained by fellings for post war reparation and a shift in forest management from selective to clear felling. Most of Finland’s forests are in the lower age classes with few forests over 100 years of age. In the north, the age classes are more evenly distributed whereas in the south, younger age classes are more prevalent and more old forest (100 years plus) can be found there than elsewhere in Finland. In southern Finland, the spruce dominated forests are intensively managed and harvested.

For Germany, Vilen et al. (2012) found that the mean age class has decreased with the area weighted mean forest age reducing by 11 years over the 60 year period. The share of old forest has also decreased by 12% since 1950, although there are indications that this is changing (see German forest inventory 2014). Germany has a much higher proportion of older forest than Finland, with over 30% of forest in the age classes of 80 years and above.

In Italy, the islands of Sicily and Sardinia, and the North Eastern region contain more trees in older age classes (80+ years of age) than the rest of the country.
Recebio: Task 5


(Source: Brus et al., 2011)
**Forest ownership**

Forest ownership is an important indicator of forest management. In general, publicly owned forests are more intensively managed. Holding size is also an important predictor of management and harvesting levels as larger forest holdings are much more likely to be harvested than small, fragmented forest stands (Eggers et al. 2015).

Over Finland as a whole, 50% of the forest area is privately owned. 35% of forest area is owned by the state and 7.5% by companies. The proportion of privately owned forest is larger in the south of Finland with over 75% of forests in this region being privately owned. A much larger proportion of forest (over 50%) is publically owned in the northern part of Finland but much of this is protected area and outside the wood potential for industrial or energy use. By contrast, a high proportion of Germany’s forests is publically owned but there is a higher prevalence of private ownership in the north-west and south east of the country. The majority of the forest area in Italy is in private ownership; however a significant area is in public ownership, particularly in Southern Italy. A large proportion of Italian forest stands have been abandoned by their owners and are hence unmanaged. This has occurred due to the high costs of management and low profitability of harvested wood.

![Proportion of forest land in private ownership](image)

**Figure 5.1.4:** Proportion of forest land in private ownership.
Source: Pulla et al. 2013

**Net annual increment**

This refers to the average annual volume of gross increment minus natural losses on all trees over a given reference period as measured and reported by national and/or regional forest inventory according to a specific methodology. In Finland, the net annual increment (NAI) recorded varies from 7-9 m$^3$/ha in the South to under 3 m$^3$/ha in the North. This can be explained by the less temperate climate as well as less intense forest management in the northern part of Finland which has a sparse
population and lies within the Arctic Circle. In Germany, the NAI varies between 7-9 m³/ha/yr in the east to 13-15 m³/ha in the highly productive forests such as the Black Forest in the south-west.

For Italy, as can be seen in Figure 5.1.5 the NAI is low by comparison with Germany. The NAI ranged from under 3 m³/ha/yr in the South and Central Italy to 7-9 m³/ha/yr in North East Italy. This can be explained by lower water availability in southern Italy.

Figure 5.1.5: Net annual increment and fellings in the three countries for 2010. Accounting for actual removals + residues + harvest losses would result in a higher figure than fellings alone. Therefore this chart is indicative of harvest levels only. Source: Forest Europe 2011
In order to identify opportunities for mobilising unused potential it is necessary to understand forest management intensity around Europe. The forest harvesting intensity here was defined as annual fellings (removals + harvest losses) as a percentage of net annual increment. Levers et al. 2014 examined the spatial aspects of the drivers of forest harvest intensity patterns in Europe and found that spatial
patterns of forest harvesting intensity were well explained by forest resource related variables such as share of plantation species and accessibility.

Harvesting intensity was found to be especially high in southern Finland where the majority of Finland’s population lives. Harvesting decreased in intensity from south to north. Despite the high intensity of harvesting in Finland, the harvested volume per hectare is lower than in central Europe e.g. Germany and Austria, due to the boreal climate and hence lower growth and productivity levels in Finland (Levers et al., 2014) (Figure 5.1.6). Levers et al. 2014 found that Southern Germany had high levels of harvested volume. However this did not correlate with high intensity of harvesting and was accounted for by forest productivity in the area. As can be seen in Figure 5.1.6 the NAI is very high in Southern Germany.

Forest harvest intensity in Italy is much lower than in Germany or Finland (Figure 5.1.7). Unlike in Germany where the harvest intensity was relatively low but harvested volumes remained high, the harvested volumes are also relatively low in Italy. This can be explained by much of the forest area being located in the inaccessible mountainous areas of the Alps and Apennines. The red area in Italy indicates high levels of harvest intensity, corresponding to areas where poplar plantations occur. These plantations contribute to harvesting statistics but are not included in the forest inventory. The high intensity in SW France is attributable to three major storms in the period 2000-2010 which resulted in a high level of removals from the forest area due to windblow. The study utilizes for all countries national forestry reports and statistics that can be influenced by natural disturbances so this effect may be prominent in other regions also. The authors themselves states in the report that the storm Gudrun in 2005 may have influenced their assessment for Sweden.
**Figure 5.1.7:** European administrative units (NUTS 0-3) showing (a) average forest harvesting intensity (% - annual fellings (removals + harvest losses) as a percentage of net annual increment) and (b) average harvested timber volumes (m³/ha) for 2000–2010. Source: Levers et al., 2014.

**Wood flow charts**

Wood flow charts are presented here from Finland and Germany. There were no wood flow charts available from Italy.

**Figure 5.1.8.** Wood flow chart for Finland 2008
Source: EUBIONET project.

In Finland (Figure 5.1.8) wood flows are largest in the pulp industry compared with wood industry. Sawn timber also accounts for a large share of production. These have solid biofuels and black liquor as their main energy source. There is also considerable importation of round wood and chips from Russia.

For Germany (Figure 5.1.9) sawn timber makes up a large share of the wood flows. Recovered wood, particularly paper is also quite a strong feature in the German wood flows. The pulp industry and associated products such as black liquor have a much smaller role in the German wood industry.
Figure 5.1.9: Wood flows in Germany in 2008.

(Note: 2008 country flowcharts shown in this section are not to same scale.)
Source: EUBIONET project.

National level of recovered wood and share of consumption

Wood biomass is a recyclable product. The recycled amount of the overall recyclable potential depends very much on the effectiveness of the collecting system. The recovery rate for paper in the EU27 was about 74% in 2010 (Mantau et al., 2010) and has thereby reached almost its technically possible maximum. 2012 recycling rates according to Eurostat for paper and cardboard were Germany 87.6%, Italy 85.5% and Finland 99.2%). The recovery rate for post-consumer wood i.e. wood-based materials such as massive wood, plywood, particleboard, MDF etc., that leave the use process at the consumer after a shorter or longer service life - in Europe is very diverse.

As stated in Task 1, Germany, and Italy number among the biggest consumers of recycled wood in the EU. The two main importers are Italy, due to their particleboard industry and Germany with developed energy generation plants. Owing to its high bulk/value ratio, recovered wood is not transported long distances and therefore it is usually used close to the place of collection.

Germany is the biggest market of recovered wood in the EU (see Task 1). Small to very large private waste companies are responsible for collection waste and treatment of recovered wood. Leading electricity companies and energy suppliers consume recovered wood in CHP plants. Local, municipal energy suppliers and private investors operate biomass power plants also. The local particle board industry use untreated recycled wood for particle board and use treated recovered wood chips for their own power plants. Compared to supply, the demand, has been slowly increasing.
over time but there has not been shortages because of imports to domestic market. Increasing demand has caused a general price increase of recovered wood in Germany.

In Finland a significant proportion of the woody biomass is exported to other countries as products so the recycling of wood would occur in other markets. This means that the development of recycled wood is likely to be relatively small in comparison to total production of harvested wood products. The amount of wood which goes to landfill disposal is negligible (Sokka et al. 2015).

**Overview of supply and consumption patterns in the three countries**

Germany and Finland are countries with large forest areas and established forest industry. As a result established supply chains benefit the use of wood for energy. The availability of inexpensive raw material has been an essential factor contributing to the development of industrial scale wood energy utilization in countries with a traditionally strong forest industry sector. The roundwood consumption of sawmilling industries contribute to the availability of industrial by-products as well as forest chips produced from tops and branches from final fellings. This means also that the development of the wood fuel market is vulnerable to fluctuations in the sawmilling industry. Italy also has a large forest area but as a large amount of this is unmanaged, inaccessible and of low productivity there are greater challenges in bringing wood energy to market. The lack of established forest industry supply chains also represents a barrier to increased extraction of the resource particularly along the regions surrounding the forests of the Apennines.

Germany and Finland are major consumers of firewood. These countries have a strong tradition of household wood fuel consumption, especially in rural areas with abundant resources of wood not meeting quality requirements of industrial utilization and freely available for forest owners. It is difficult to acquire accurate information on this type of consumption.

Forest chips represent a significant local resource for heat and electricity production in areas with large forest resources, often located in areas with cold climate and/or high altitude and decentralized space heating infrastructure. Finland and Germany have a network of centralized heat and power production facilities to which the majority of houses are connected. Larger facilities enable the use of lower quality forest chips with variable chip size and moisture content.

In terms of international trade of biomass, forest chips have less significance due to their relatively high moisture content, low density and challenges in long term storage. Currently three of the four largest consumers of forest chips in the EU are Germany (9.0 million m³/a), Finland (7.5 million m³/a) and Italy (6.3 million m³/a). In Finland the national targets of renewable energy and related investments to district heating applications utilizing forest chips have been driving the increasing trend of forest chip consumption.

Germany is the largest supplier of industrial by-products, producing approximately 19.3 million m³/a of wood chips and sawdust. Finland is also a major supplier (9.0 million m³/a). Major suppliers of industrial by-products are also major consumers. In Finland major volumes of wood chips are used in pulp production, whereas Germany uses large shares of industrial by-products in wood-based panels manufacturing.

In Finland, despite the large forest resource, wood pellet production has not gained a strong position in domestic markets. In Finland the export oriented wood pellet sector
has lower wood paying capability in comparison to the strong pulp industry sector. The biggest wood pellet consuming countries include Germany (1.7 million tonnes), and Italy (1.4 million tonnes). In Germany the wood pellet market is dominated by consumption in the residential heating segment. Besides the consumption of domestically produced residential wood pellets, Germany imports major volumes from East-European countries. Italy is one of the biggest pellet importers within the EU internal markets importing 1.1 million tonnes in 2013.

Black liquor is the waste product formed when industrial pulpwood is digested into paper pulp. Black liquor is produced only as a result of pulp production from virgin pulpwood sources, and used as a feedstock for energy production in the pulpmills to such extent that pulpmills are usually self-sufficient in their energy consumption. The two biggest producers and consumers, Sweden and Finland, contribute almost 60% of the total black liquor consumption in the EU. This is largely due to that the share of virgin wood raw material is the highest in these countries.

Recovered wood has a very positive image and is used for energy production especially in Germany. However, lack of effective and established collection and sorting systems is preventing its more large-scale utilization. Major producers of paper and cardboard waste include Germany (8 million tonnes), and Italy (5.3 million tonnes). This amount is strongly correlated with population size. The relatively balanced import-export in Germany is largely related to national policy schemes which favour different streams of waste wood. The German renewable electricity feed-in scheme has provided strong incentives for the combustion of clean (non-treated) recovered wood. Mantau et al. 2014 analysed the resource mix in biomass power plants of greater than 1MW and found that 36.8% of the total is post-consumer wood.
Policy analysis

Policy methodology
The purpose of the case studies is to review the present situation and policy action in three Member States to understand how national action might impact or alter the outputs of the modelling analysis, for example, this might include:

- changing the distribution of biomass use across sectors of the bioeconomy;
- promoting non energy uses of biomass in the bioeconomy;
- changing planned usage of biomass in the energy sector;
- increasing competition with the energy sector by promoting for example advanced biofuels over solid biomass uses; or
- changing the availability of bioresources on the market place i.e. impacting on the availability of forest biomass, forest or agricultural residues or availability of wastes

By policy we don’t only mean legislative measures but all policy interventions and supports.

The intention was to provide a consistent record of the policies in place that will drive or impact on uptake of bioenergy specifically from solid and gaseous sources within Finland, Germany and Italy. This might be highly targeted policies for bioenergy use in electricity or heating or it may also be wider policies promoting action, such as bioeconomy strategies etc. The intention was to identify what are the key policy measures now and how might these evolve up to 2030. In so doing this should provide a record of the policies, legislative and fiscal actions etc. of relevance to the bioeconomy more widely. Given the future looking purpose it is important to highlight both measures that are currently binding and more strategic policy documents that might indicate future direction. For federal nations the focus was on national action, however, when considering future direction if any evidence emerges from key regions e.g. in terms of leadership, these were noted.

Three categories of policies that exert particular pressures on the development of the bioenergy sector were investigated:

1. Policies that will directly drive or impact on the uptake of bioenergy from solid and gaseous sources, this might be national targets, subtargets linked to renewable energy plans, incentives such as feed-in tariffs.
2. Policies that will impact on the nature or extent of the feedstock base whether this be availability from forestry systems, waste or residue production and use. This might include policies that encompass sustainability criteria to actively promote and conversely dissuade use of certain feedstocks.
3. Policies that will have a wider impact on the use of the biomass resource base including competing uses i.e. expansion in advanced biofuel production, promotion of material uses, shifts in waste policies, promotion of the wider bioeconomy and alternative uses.
Policy review - Finland

Annex I sets out in detail the full list of policies considered to impact on bioenergy within the Finnish context, their coverage and impacts. The following text represents a summary of the key measures and messages developed from the detailed listings within the Annex I tables. The full titles and references for all the national policies set out in the policy review can be found in the detailed supporting tables in Annex I.

National policy directly driving or impacting on the uptake of bioenergy

Finland has a number of national policy papers that define its strategy towards meeting its renewable energy targets. Finland’s National Climate and Energy Strategy (2013) includes approaches to delivering Finland’s targets set out at EU in relation to the reduction of emissions, promotion of renewable energy, and enhancing the efficiency of energy consumption; these have all required the enactment of a number of climate and energy policy measures. The overall headline target is to increase the use of renewable energy to 25% of final energy consumption by 2015 and 38% by 2020.

Earlier policy papers have laid out ambitions in reference to energy and climate targets, such as Government Foresight Report on Long-term Climate and Energy Policy (2009). The Energy and Climate Roadmap 2050 (2014) provides a long-term strategy paper mapping Finland’s pathway towards a practically carbon neutral society by 2050. This paper emphasises the increasing role which biomass will play in generating heat and electricity, but also the complications which Finland will face, particularly as the use of wood biomass cannot be the source of all of Finland’s renewable energy requirements.

Evidently Finland already has an established renewables (including significant hydropower) and bioenergy sector, with a clear emphasis on forestry biomass. The majority of Finland’s bioenergy – 97.5 per cent in 2012 – is produced from wood and wood-based residues such as black liquor, bark, sawdust and other industrial residues (equating to 56 TWh i.e. 97.5 per cent of biomass used for energy. Wood based energy accounted for approximately 20 per cent of energy consumption in 2012). In contrast agricultural biomass plays a relatively less prominent role, and in 2012 accounted on only for approximately 1.5 TWh or 2.5 per cent of the bioenergy use. Waste based bioenergy sources are limited but are increasing. An additional push towards wood based bioenergy has also been experienced as a consequence of increasing taxation on the use of peat as an energy source, driving a shift in use patterns.

A feed-in tariff and a number of subsidies support the uptake of renewables including biomass. Finland’s Act on Production Subsidy for Electricity from Renewable Energy Sources (2010) created Finland’s feed-in tariff for power plants powered by wind, biogas, and wood based fuels. The system guarantees a tariff for an approved power plant for a maximum of 12 years. The subsidy is based on the amount of energy produced and a price determined by the difference between the target price and the market price of the average of the previous three months. An additional feed-in tariff is paid if the heat produced by wood or biogas based plants is utilised and if the plant meets a number of additional standards.

As well as the feed-in tariff Finland offers a number of investment support programmes to expand bioenergy capacity. The schemes offered by the Ministry of Agriculture and Forestry, and Ministry of Employment and the Economy offer up to 40 per cent of investment for some renewable energy technology. A number of other
support schemes are in place for small scale projects for instance promoting biogas on farms or building renovations to improve efficiency. Most of these schemes are covered in Finland’s NREAP (2014)

**National policy impacting on the nature or extent of the feedstock base**

The Energy and Climate Roadmap 2050 estimates that Finland could more than double its use of wood chips without compromising sustainable felling rates. Finland also aims to gain 25TWh of electricity and heat from wood chips in 2020. Finland anticipates that in order to meet the EU’s 2030 energy and climate package targets non-emission trading sectors would require a considerable amount of biofuels for mobility and machinery. The Climate and Energy Roadmap 2050 suggests that this would necessitate a redirection of wood towards biofuel production, and consequently competition and even shortages of forest biomass for wider heat and power production.

For this reason the Finnish government calls for a number of alternative biomass feedstocks to be explored, such as pulpwod currently being grown for the paper industry and importing biomass from overseas. They suggest the farmers can produce energy from agricultural biomass, such as field residues and manure for their own use and resale to the grid; such uses are included in subsidies covered by the NREAP.

There are ongoing discussions regarding the climate neutrality and sustainability of using biomass for energy, particularly forest based biomass. However, the Energy and Climate Roadmap 2050 argues that as Finland has a unique situation in terms of its forest industry it must play a role in influencing any impacts such discussions may have on EU legislation, and their potential consequences for using forest biomass as a central part of renewable energy production. 17.6 million ha of forest are certified in Finland with 95% of production forest certified under the Finnish PEFC system.

Whilst Finland has a national Act on the Sustainability of Biofuels and Bioliquids (2011), the government has no specific binding sustainability scheme for solid/gaseous biomass. Although the Commission published a report on the sustainable use of solid and gaseous biomass sources in electricity, heating and cooling (COM(2010)11), these are non-binding and member states are free to put in place their own national schemes. Having said this, within its forestry legislation the Finnish Government has a number of acts in relation to bioenergy production.

The Forest Act (2014) is Finland’s main policy determining how forests can be managed. In 2014 the Finnish government made a number of amendments to its extensive forestry legislation. The new Forest Act (2014) increases the freedom which forest owners have in managing their resources, and reduces the complexity of forestry regulations. The Forest Act contains recommendations for timber and energy wood harvesting, including environmental considerations. A new Forest Damages Act (2014) which aims to improve the health of forests and prevent fungal and insect damage, reduces the time limit within which felled wood should be removed from the forest. Further policies such as the Law for Financing Sustainable Forestry and the Nature Conservation Act further develop forestry management laws in relation to bioenergy.

The Forest Act (2014) allows many different types of cuttings (a range of age and size classes), but it does not regulate the use of the extracted timber. The fellings are normally either conducted in a package deal where the industry purchases all the timber from the site and uses the less valuable assortments for energy (this is the dominant way and called “pystykauppa”, or the cutting can be done by the forest
owner and he can sell (or use himself) different sortiments to different users, e.g. to a sawmill and to a local combustion plant (=hankintakauppa).

**National policy with wider implications for the use of the biomass resource base**

The Finnish Bioeconomy Strategy (2014) highlights Finland’s commitment to an expansion of the use of biomass as an opportunity for growth, job creation and reaching its climate and energy targets. The paper aims to increase the size of the Finnish bioeconomy from EUR 60 billion to 100 billion by 2025. As well as expanding the use of Finland’s forest resources in the bioenergy sector, the strategy also highlights a number of competing uses that will become increasingly relevant in the future.

The Finnish Government runs a number of Research Programmes in order to support its bioenergy sector. For instance, one study examines the potential to replace coal with biomass in power plants (2011), another, Forest Energy 2020 (2012-2016), looks at maximising on the forestry value chain. Other research programmes exist to support bioeconomy, and low carbon energy pathways.

Research programmes are also exploring competing uses to bioenergy. For instance TEKES, The Finnish Funding Agency for Technology and Innovation, supported BioRefine (2011) exploring value added biobased products. This programme considered energy production as a last stage in cascades of potential biomass uses. Bio-fuels based on wood products, particularly oils based on pyrolysis as well as the generation of pine oil based second generation biodiesels are all covered by Finnish research programmes, which are already underway. Likewise, a number of Finnish chemical and material companies already consider bio-based raw materials as central to their resources base.

Finland has legislated to increase the role of biofuel within its transport and industrial sectors. The Act of the Promotion of the Use of Biofuels for Transport (2007) promotes the use of biofuels in the transport sector. It states the distributors of transport fuels must include biofuels within their distribution. At least 6 per cent of energy content of petrol and diesel must stem from biofuels. In 2015 this will increase to 8 per cent. A reform of the Energy Tax in 2011 created additional incentives for certain biofuel usage. Biofuels are subject to an energy tax made up of a tax on their energy content, a carbon dioxide tax, and a stockpile fee. Certain types of biofuels, particularly those produced from wastes, residues and non-food cellulose material, are exempt from the carbon dioxide element of the tax (Tulli customs, 2011).¹

**Policy review - Germany**

Annex II sets out in detail the full list of policies considered to impact on bioenergy within the German context, their coverage and impacts. The following text represents a summary of the key measures and messages developed from the detailed listings within the Annex II tables. The full titles and references for all the national policies set out in the policy review can be found in the detailed supporting tables in Annex II.

National policy directly driving or impacting on the uptake of bioenergy

Germany has a number of national level policies that promote directly or implicitly the uptake of bioenergy. The Energy Concept (BMWi 2010) has laid out measurable criteria for the country’s Energiewende. This overarching strategy paper relates directly to the European Commission’s Climate and Energy Package (COM (2008) 30); it specifies that renewables are to account for at least 18% of gross final energy consumption by 2020 and 60% by 2050 across all sectors. It generally foresees an increase in the use of biomass in Germany’s energy mix, but is also explicit regarding the limitations of biomass, particularly in relation to competition with food and issues of sustainability. The National Biomass Action Plan (2009) complements the EU Biomass Action Plan (COM(2005)628) as well as the Energy Concept, and quantified the biomass’ share in meeting renewable energy targets. Germany has the ambition to increase the bioenergy’s share of primary energy consumption to 11% by 2020.

Two Federal policies, the Renewable Energy Sources Act (EEG 2014) and the Renewable Energy Heat Act (EEWärmeG 2014) transcribe Germany’s renewable energy ambitions into national law. According to Section 1 para. 2 (EEG), renewable energy shall account for 40% to 45% of the share in the gross electricity consumption by 2025, 55% to 60% by 2035 and for 80% by 2050. Currently nearly 30% of Germany’s electricity is produced from renewable sources, making it one of Europe’s leaders in this respect.

The EEG was first established in 2000, and has had several revisions, being most recently updated in August 2014. The original EEG replaced the 1991 Stromeinspeisungsgesetz, which established Germany’s first feed-in tariff for renewable energy. Germany’s feed-in tariff infrastructure is amongst the most developed in Europe. Underpinning this system are three features, which are unique to Germany.

1 - Differentiated price guarantees
The government guarantees for 20 years payment for the energy generated from a renewable energy plant. Previously the price for this energy (ct/kWh) was defined by a fixed feed-in-tariff, today the price is determined by a market system which adjusts the price dependent on a number of variables (renewable source, capacity, payment obligations to grid operators, etc.). The EEG provides a pathway for growth for particular renewable energy sources. It is notable that Germany has reduced its emphasis on biomass in the most recent EEG, the annual growth corridor target for Biomass is 100 MW compared to 2500 MW for onshore wind and 2500 MW for solar power.

2 – Payment of a surcharge
The payment system is entirely funded by EEG-Umlage or surcharge. This surcharge is a set value added to all energy bought from the grid (ct/kWh). Through the Besondere Ausgleichsregelung (special equalisation scheme) some energy intensive industries and railways have access to reductions of the EEG-Umlage.

3 – Decreasing tariff level
Germany regularly decreases the feed-in tariff in order to exert pressure on energy generators, technology manufacturers and to promote innovation. This means that whilst remuneration remains constant for 20 years, the more recent an installation the lower the support available is to the operator.

A separate law, the Combined Heat and Power Act (KWKG 2009), places regulations on the construction and management of CHP generators. It simultaneously obliges
grid operators to provide a connection from their plant to the grid, and to accept their energy. In addition grid operators must pay those operating CHP plants an additional surcharge for the energy they generate. This surcharge is dependent on the category of CHP plant.

The second federal act, the EEWärmeG, promotes the increase of heat (as opposed to electricity) generated from renewable energy to 14% by 2020. In comparison to the EEG its targets are both more conservative and place a greater emphasis on biomass. Whilst nearly half of domestic energy use in Germany goes towards heating only 6% of this comes from renewable sources, mostly from wood.

The EEWärmeG prescribes regulations for new buildings and retrofits in terms of the percentage of heating energy that must be derived from renewable sources, including bioenergy. In parallel EEWärmeG also founded the Marktanreizprogramm (Market Incentive Program), this provides financial support for buildings that incorporate renewable energy generation. A certain biomass infrastructure is covered, including automatically fed biomass combustion, low emission wood gasification, and biogas pipelines, covering up to 30% of investment costs. Between 2009 and 2012 the Marktanreizprogramm made EUR 500 million of investment available.

**National policy impacting on the nature or extent of the feedstock base**

A number of policies impact on the availability of biomass as a feedstock. Forests make up Germany’s most significant biomass resource base. Whilst forest cover in Germany has increased over recent decades, consumption of wood has also increased. Currently 1/3 of the annual cut from German forests is consumed as energy for heat and power generation. German forestry management practices are multifunctional and are based on sustainable forest management (SFM), but in this sense are non-binding. Increasingly forest certification systems are being applied, in particular PEFC\(^2\) (around 60% of forest) and FSC\(^3\) (around 5% of forest). Federal Law including the National Forest Act (Bundeswaldgesetz) and the National Act on Nature Conservation (BNatSchG) impact on the forest biomass, particularly in areas with special status or state owned land.

The Forestry Strategy 2020 (2011) anticipates an increased competition for wood as a feedstock. It also warns of the dangers of an increasingly intensive use of forest biomass, for instance the risks of nutrient depletion following full tree harvesting (the use of timber, bark and crown).

Since 2013 the Federal ministry for agriculture and for the environment have also operated the Waldklimafonds (Forest Climate Fund), which provides measures and funding to promote the role of forests in both mitigating through sequestration, as well as adapting to climate change. The latter could further reduce the availability of wood as a feedstock.

In line with the RED, Germany implemented sustainability criteria for biofuels and bioliquids. These criteria apply for all biomass used in the transport sector and liquid biofuels used for heat and power production under the EEG.

Wider Federal level initiatives further influence the use of the biomass resource base. For example the BMELV (Federal Ministry for Food, Agriculture and Consumer

\(^2\) Programme for the Endorsement of Forest Certification

\(^3\) Forest Stewardship Council
Production) has established, INRO (Initiative Sustainable Provision of Raw Materials for the Material Use of Biomass) a voluntary scheme that applies the same ecological and social criteria to material (rather than energy) uses of biomass.

In 2014 Germany Climate Action Program requiring action from all sectors to meet goals up to 2020. This included the proposed amendment the Fertiliser Application Ordinance (Düngeverordnung) and increasing the share of organic farming. It also sets out that conserving permanent grassland and protecting moorland can also help protect the climate. Such measures may limit land use or the intensity of land use.

**National policy with wider implications for the use of the biomass resource base**

Research agendas and funding programmes could help to shape the future of Germany’s bioeconomy (including the National Strategy for the Bioeconomy (2013) and the National Research Strategy for the Bioeconomy 2030 (2010)), and hence the way in which biomass is used and made available for energy production. Many research programmes continue to promote the use of biomass for generating energy and finding innovative ways for integrating bioenergy into Germany’s energy mix.

For instance Germany has become a global leader in the field of carbon capture and storage. The CCS Act (Gesetz zur Demonstration und Anwendung von Technologien zur Abscheidung, zum Transport und zur dauerhaften Speicherung von Kohlendioxid – KSpG 2012) lays out guidelines for the sustainable use of CCS including in relation to bioenergy production. Two of the twelve EU-wide CCS demonstration projects eligible for funding are expected to be built in Germany by 2020, providing permanent CO₂ storage. A storage project for industrial biomass CO₂ emissions is also planned. The success of such demonstration projects could encourage the use of bioenergy in the future, averting concerns over climate impacts.

Biomass can be used for solid and gaseous energy solutions, and alternatively for biofuels or to deliver biomaterials and products. These alternative uses are also being promoted in Germany, alongside bioenergy. Germany has an established policy framework in place to support biofuels in the mobility sector. The aforementioned National Biomass Action Plan has the goal to increase the share of biofuels to 12 percent of overall fuel consumption by 2020. As of 1 January 2015 a carbon intensity target was intended to replace a blending target for biofuels to deliver a 6% level of emission reduction in a staggered way by 2020 (in line with the Fuel Quality Directive requirements set out in EU Directive 2009/30/EC). The Mobility and Fuels Strategy (MFS 2013) sets the agenda for an expansion in the biofuel capacity. Whilst oil based fuels will continue to dominate the market in the medium term biofuels and a need to expand alternatives are seen as a priority. Federally established research facilities like the Fraunhofer CBP are generating innovative research in the field of biofuels. Likewise federal initiatives like Aus Natur Gemacht (Made from Nature) are providing funding for research into innovative material uses for biomass.

Changing attitudes towards material uses, particularly waste management strategies will also impact upon the availability of biomass. Increasingly high rates of recycling in Germany coupled to a growing legislative framework on waste, resource efficiency and the circular economy, such as the Kreislaufwirtschaftsgesetz (2012), reflect changing agendas and attitudes towards waste. This both promotes higher levels of material recycling but also the prevention of waste generation potentially impacting on the energy resource base available or the nature of the waste available for use as energy.
Policy review - Italy

Annex III sets out in detail the full list of policies considered to impact on bioenergy within the Italian context, their coverage and impacts. The following text represents a summary of the key measures and messages developed from the detailed listings within the Annex III tables. The full titles and references for all the national policies set out in the policy review can be found in the detailed supporting tables in Annex III.

National policy directly driving or impacting on the uptake of bioenergy

Italy has a number of national policies, legislative measures and fiscal incentives in place to promote the production and use of bioenergy. The National Plan for Renewable Energy Sources (NPRES) (2010) implements the targets set out in the Renewable Energy Directive (RED 2009/28/EC) to 2020. The plan establishes a set of measures for the achievement of Italy’s 17 per cent target from renewable energy sources (RES). Besides solar energy, biomass is expected to have a key role amongst the renewables contributing 19 per cent to total RES in the electricity sector and 54 per cent in the heating and cooling sectors by 2020. The plan attributes a strategic role to agro-forestry ligno-cellulosic biomass in meeting the target for the heating and cooling sectors. According to these objectives, the total energy from biomass should increase three-fold by 2020 compared with 2010.

Figure 5.2.1: Final consumption of energy from renewable sources in Italy in 2020

The National Energy Strategy (NES) (2013) provides a long-term framework for energy policies in Italy, going beyond the objective established by the NPRES and aiming, amongst other objectives, to achieve a 20 per cent target for renewable energy sources in 2020. This is foreseen to be achieved through the replacement of the existing plants fueled by conventional fuels with new installations using RES, including bioenergy. Agro-forestry biomass is largely promoted with the aim to become the primary source of energy in the heating and cooling sectors, in line with the National Action Plan for reducing the level of emissions of Greenhouse Gases (NAP...
for GHG emission reduction) (2013). Measures assessing the potential use of marginal land for energy purposes are also envisaged.

The NAP for GHG emission reduction fits within the framework of the EU Energy Road Map to 2050 (COM(2011)885) and provides a strategic direction towards the decarbonisation of the Italian economy through a combination of policies and measures in a variety of key areas, i.e. energy, industry, transport, agriculture. In this context, a strategy for the exploitation of forests and of land devoted to agriculture is set up with the objectives to decrease CO₂ emissions and produce biomass for bioenergy and second-generation biofuels.

The Sector Plan for Bioenergy (2014) defines, within the bioenergy sector, the role of agro-forestry biomass (including waste and residues) in the production of energy and with regards to the wider objectives assigned to RES by 2020. Primary importance is given to the use of crop and livestock waste and residues, as well as processed food products. These objectives, along with those defined in NES, were already included in the Decree law (n. 28/2011) implementing Directive 29/2008/EC (RED) on the promotion of renewable energy sources.

The incentive included in the Sector Plan for Bioenergy is to promote the following:

• The use of waste and by-products;
• The production of biogas from livestock waste or by-products from agriculture, agro-food, farming and forestry activities;
• Products from non-food crops.

Investments on biomass plants, including those using biodegradable waste, are incentivized to a maximum of 80 per cent for partial refurbishing and a maximum of 90 per cent for total refurbishing.

Tax benefits for district heating from biomass sources based on a number of principles. The end users who purchase energy from biomass fueled heating networks based in certain municipalities are entitled to a tax deduction, as well as a one-off reduction on connection costs. Similarly, the Presidential Decree on bio methane of 5 December 2013 establishes a system of incentives for the production of bio methane in cogeneration plants to be used in transport or injected into the national grid. For this system to be effective, however, additional decrees will be needed and are likely to be approved in 2015.

The Finance Act (2008) promotes the production of electricity from renewable sources, including biomass, by assigning ‘green certificates’ to producers. Additionally, a feed-in tariff applies to biomass (excluding liquid biofuels) and biogas plants, not exceeding 1 MW. It also promotes more generally the production of renewable energy by agricultural enterprises. The Ministerial Decree (n. 18/2008) establishes a system of coefficients incentivizing or discouraging the use of certain raw materials. As to biomass, the system incentivizes the use of biogenic waste (coefficient 1.3), agriculture and forestry products (coefficient 1.3), and biomass produced within 70 km from the processing plant (coefficient 1.8). This measure is intended to increase the availability of those materials as a feedstock. Decree Law (n. 79/1999) introduced a system of Green Certificates, valid annually and tradable on the market, which attest the production of electricity from renewable sources, including biomass.

Finally, the Ministerial Decree of 28 December 2012 introduced incentives for the use of biomass for the production of renewable energy for heat through two systems called Thermal Account and Energy Efficiency Certificates or White Certificates. The first has the aim to encourage small-scale interventions to increase energy efficiency.
and the production of thermal energy from renewable sources, whereas the second sets national quantitative target for energy savings to be complied with by electricity and gas companies between 2013 and 2016.

The ‘Thermal account’ system may include three types of interventions all of which relate to the installation of new heating capacity and/or the replacement of existing capacity using solid agro-forestry biomass as a feedstock.

The system of White Certificates or Energy Efficiency Certificates (TEE), introduced into Italian law by the Ministerial Decrees of 20 July 2004, establishes that suppliers of electricity and natural gas annually have to reach certain primary energy savings. A certificate is equivalent to saving a ton of oil equivalent (TOE). As for the use of solid agro-forestry biomass, the White Certificate system provides standard tools to evaluation the actual energy savings.

**National policy impacting on the nature or extent of the feedstock base**

Several drivers have impacted on the feedstock base available in Italy. The Sector Plan for Bioenergy encourages efforts in the direction of expanding the plantation of herbaceous or arboreal plants with short harvest cycle, i.e. short rotation coppice, and of species that can guarantee a prolonged coverage of the ground and have long harvest cycles. The National Strategic Plan for Rural Development 2007 – 2013 goes in the same direction by promoting agricultural policies supporting dedicated energy production on marginal land, amongst others, and the collection of residues, such as straw. In addition, in order to address environmental emergencies caused by irregular waste management in two Italian regions, Campania and Puglia, mapping of no longer suitable agricultural land were undertaken with the purpose of assigning it to the production of energy crops. These measures have the effect of increasing alternative feedstock sources for biofuel production.

Decree law (n. 28/2011), implementing Directive 29/2008/EC (RED) on the promotion of renewable energy sources, introduces sustainability criteria for biomass used in the transport sector (biofuels) and for the production of electricity, heating and cooling (bioliquids). No specific binding sustainability schemes for solid and gaseous biomass have been introduced as yet.

Forest biomass is the largest source of feedstocks in Italy. The above mentioned National Strategic Plan for Rural Development 2007 – 2013 provides targeted investment support for afforestation of agricultural land and non-agricultural land, as well as conversion of land into forestry. These measures are aimed at enhancing forest management and at optimizing the sustainable extraction of forest biomass. The Framework Programme for the Forestry Sector (2008) supports sustainable management of forests and provides incentives for the use of biomass for energy production. At present PEFC certification covers 8.6% of Italy’s forest - mostly the poplar plantations of the north. At the regional level, the Programmes for Rural Development 2007–2013 include a number of measures that are directed to promote the production of energy from biomass. Two measures support investments in biomass power plants (measures 121 and 311), while others regulate the production of biomass (measures 123 and 221):

- Measure 121 allows the direct financing for the purchase and / or construction of plants for the production of electricity and heat from biomass, not exceeding 1 MW, This measure provides for funding up to 40% of overall investment;
• Measure 123 provides remuneration for the sale of biomass raw materials by companies processing and / or marketing agricultural and forestry products;
• Measure 221 finances the afforestation of agricultural land;
• Measure 311 includes different types of interventions aimed at the diversification of rural activities, including measures for the production energy from renewable sources. Such measure includes the construction of biomass plants not exceeding 1 MW, providing a maximum contribution of 200,000€.

All these measures are to contribute to increase the availability of wood and agricultural products as feedstocks.

**National policy with wider implications for the use of the biomass resource base**

A number of policies have been adopted in Italy having wider implications on the biomass resource base. At strategic level, the National Plan for Renewable Energy Sources (NPRES) foresees the possibility of prioritizing non-energy uses of biomass, although no overarching policy measures going in this direction have been adopted so far.

Within the bioenergy sector, the production of second and third generation biofuels has been incentivized by several drivers in Italy. A memorandum of understanding (2013) signed by several ministries and a leading company aims to promote important projects in the field of industrial chemistry from renewable sources, with the aim to the produce advanced (second and third generation) biofuels. In October 2014, Italy has taken the lead in Europe by introducing binding, progressive sub-targets for second generation biofuels in petrol and diesel from 2018 onwards. The quotas are set at 1.2 per cent in 2018 and 2019, at 1.6 per cent in 2020 and 2012 and at 2 per cent in 2022, and will presumably drive increasing demand of those wastes and residues, as explicitly listed by the Decree Law updating the conditions, criteria and procedures for release biofuels and second-generation biofuels (2014), that could be counted towards the targets. The first power plant (partly) fueled by waste and residues biomass, as well as dedicated energy crops, was launched in Crescentino (Province of Vercelli) in 2012. These measures are predicted to lead to a decrease of the waste biomass resource base and to competition with other non-energy sectors.

Although there is still no national policy framework for the promotion of ‘green chemistry’ and the bioeconomy in Italy, the Sector Plan for Bioenergy (2014) prioritises the creation of an inter-ministerial roundtable on ‘green chemistry’ with the purpose of defining strategies and opportunities for the development of bio-products, as promoted by the European bioeconomy strategy. No explicit priority is given to any bio-products.

**Key points emerging from policy analysis**

It is often difficult to identify specific policies and their consequences on the wider market and use of materials. This analysis is not intended to provide an ex post assessment of the consequences of national policy mixes but instead add to understanding regarding what trends might lead to shifts in the material availability and biomass use and what trends might influence future demand for biomass. Key policy messages, synthesising points from all three Member States analysed, are summarised in the following sections.
**Policies driving uptake of bioenergy**

As might be anticipated in all three Member States the policies in place to promote renewable energy expansion are implementing the EU level targets under the Renewable Energy Directive (RED). This does not mean to say policies did not predate the RED or that countries would have not pursued renewable energy in the absence of the RED, but at present targets are determined by those set in the EU measure. In all three countries there are specified proportions of relevant targets to be delivered by bioenergy, with an important contribution to renewable heat provision in particular. Finland also has a longer term Roadmap to 2050 that emphasises the role of biomass in generating heat and electricity.

As outlined in the country resource analysis, Finland and Germany have established large-scale, historic industry built on solid biomass: in Finland the pulp and paper industry; and in Germany sawnwood. This has provided an established industry base upon which to build, where by forestry products and woody biomass were already managed and processed on an industrial scale and forests already utilised and managed to provide biomass for existing industry. Moreover, cultural acceptance of wood based heating is high given traditional ties to forestry, the use of district heating plant and disaggregated heating systems in both Member States. This, alongside direct incentives in the form of feed-in tariffs in both Member States, has promoted the expansion of bioenergy for electricity and heating to meet national renewable energy targets and bioenergy ambition within this. In addition, separate investment support is also available for example in Germany for buildings that incorporate certain biomass infrastructure.

In Italy, management of forestry is less normalised, with high levels of unmanaged woodland on abandoned agricultural land and inaccessible stands. In the Italian ‘Sector Plan for Bioenergy’ emphasis is placed on the role of agro-forestry, alongside the use of crop and livestock waste and residues. The sector plan focuses on use of wastes, biogas production and use of non-food crops. A number of incentives exist for biomass production including a feed-in tariff for small scale generation and a system of specific incentives for use of certain raw materials including waste and biomass produced local to a processing plant.

In all three Member States there is evidence to suggest that policies to promote bioenergy are having an impact in the form of shifting use profiles and consumption patterns for wood biomass. In Finland renewable energy policy has been driving investment in district heating using forest/wood chips, leading to a noted increase in forest chip demand. In Germany and Italy, expansion in the use and importation (in Italy’s case from the Balkans and US) of wood pellets has been noted.

The resource overview within this report notes an increase in demand in all countries either resulting in a drive to import (Italy), shift consumption patterns of forest chips (Finland) or pressure to expand production of wood chips to roundwood (Germany). All of these impacts could be driven by the increased demand and consequent price of the certain categories of biomass as energy use expands. In turn this pressure could impact on decisions around the management of growing stock and in turn the species and age class distribution.

**Policies impacting on the nature of the feedstock base**

In Finland the primary feedstock base is forest biomass and at present this is primarily residues and wastes from the wider material based industry or less valuable classes of a given forestry stand. The nature of the feedstock base is therefore determined by the coverage and limitations placed in forestry policies – although there are increasing efforts to expand alternative bioenergy production on agricultural holdings.
Forests also make up Germany’s most significant biomass resource base. Whilst forest cover in Germany has increased over recent decades, consumption of wood has also increased. The Forestry Strategy 2020 (2011) anticipates increased competition for wood as a feedstock. Concerns as to the impact of expanded use and impacts both for material and energy uses are beginning to be expressed within financial support schemes and voluntary schemes for biomass use.

In Italy there is a greater emphasis on imported wood pellets, but also on agricultural materials, wastes and residues. There have been active efforts under the auspices of the Sector Plan for Bioenergy and National Strategic Plan for Rural Development 2007-2013 to expand the plantation of herbaceous and arboREAL plants with short harvest cycles i.e. short rotation coppice and specifically dedicated energy crops of marginal land and land no longer suitable for agricultural production. In contrast to Finland, therefore, Italian policies are actively promoting expansion of energy crops specifically; although it should be noted that this also supports the active investment in advanced biofuels taking place in Italy, not exclusively electricity production and heat. The National Strategic Plan also provides targeted investment for afforestation of agricultural and non-agricultural land. The emphasis is on increasing the availability of wood and agricultural products as feedstocks.

All three countries have systems in place for ‘sustainable forest management’ (SFM) although it is beyond the scope of this analysis to compare these in detail. However, neither Finland nor Italy have detailed guidance on the sustainable use of solid biomass for bioenergy. In Germany forestry management is multifunctional and based on SFM, with increasing uptake of forest certification systems. Their Forestry Strategy 2020 (2011) anticipates increased competition for wood as a feedstock and highlights potential dangers of increased ‘efficiency’ of extraction of forest biomass. There is rising concern over these impacts with the Federal Ministry, from 2013, operating a Forest Climate Fund, which provides support to promote the role of forests in climate mitigation and adaptation. The Federal government has also put in place a voluntary scheme that applies environmental and social criteria to material well as energy uses of biomass. However, schemes and sustainable management approaches remain voluntary.
Model results for the case study countries

The results and analysis presented here are those emerging from the baseline scenario model runs. For further details of the parameters applied see work under task 3.

Initial state

Feedstocks

The GLOBIOM model framework is initialized at year 2000, and as a result, already the initial year of this project, 2010, is a model result. In other words, the model is initialized and calibrated to statistic for the year 2000, after which the model projects the development between 2000 and 2010. However, to improve on the representation of specific feedstocks where historical data is not available, or where key-changes in trends have occurred, the model was complemented with data and analysis derived from Task 1 for year 2010. In particular, production of industrial by-products, trade of wood pellets, collection of fuelwood, and collection of recovered wood and waste, was complemented with information from Task 1.

In should though be kept in mind that, the 2010 model outputs should not be directly compared with the statistics for the year 2010 alone as the GLOBIOM outputs are representative of the development over an average of 2015-2015.

To analyse the initial state of the model, we here compare the model numbers for 2010 with reported statistics in FAOstat, Forest Europe (2011, 2015) and the Joint Wood Energy Enquiry (2011). Tables 5.3.1 and 5.3.2 show key production and trade figures for the three countries. It is noteworthy that the different statistical databases are not unanimous and that there are high uncertainties concerning collection of specific feedstocks: the reporting practices vary between different EU Member States, and especially for non-traded feedstocks, such as firewood and industrial by-products, the data is based on approximations and experts evaluation. For further information concerning feedstock availability and use, we refer to the Task 1 report. To explore the initial state in the model in more detail, historical data from FAOstat is compared to the model initial state in figures 5.3.1 to 5.3.3 for those feedstocks where long-term historical data is available.

As can be seen from Figure 5.3.1, GLOBIOM follow the same historical trend as FAOSTAT for all the three countries. However, estimates for industrial roundwood production in 2010 are somewhat higher than those reported by FAOstat for Germany and Finland. For these two countries, GLOBIOM projects higher domestic production of industrial roundwood than reported in the statistics. The reason for this is the global recession of 2009/2010, which abruptly decreased demand for industrial roundwood and is clearly visible in the statistics. However, the effect of the economic recession is not captured in the model as the year impact of the recession and rebound effects have to be jointly represented within the model framework. The case of Finland highlights this, where the recession is seen to have a clear impact on the production valued for 2008 and 2009, but where already in 2014 the actual roundwood production is in line with the trend projection by GLOBIOM. The GLOBIOM projection of domestic roundwood production for Germany is also higher than statistics due to the impacts of the global recession. For Germany, there was a clear peak in the reported industrial roundwood production for 2000 according to which the GLOBIOM numbers are initialized. While the overall trend in the statistics would propose a lower production in the long term, it has been noted that statistics for industrial roundwood
production in Germany are likely to be an underestimated (cf. Mantau et al. 2010a, who approximate a 20% underestimate in the statistics). Initializing the model production figures for Germany using the relatively high value of 2000 is supported by industrial material balance numbers, which suggest a higher domestic production of industrial roundwood in Germany than given in the FAOstat. That the production levels of industrial roundwood has been initialized to a higher level than FAOSTAT may slightly underestimate the future production potential of wood products in Germany as a higher level of wood is already being harvested for the domestic forest resources. Also, it may lead to a slightly lower dependence for Germany on imported sources of biomass.

The estimates for recycled wood in 2010 is commonly acknowledged to be highly uncertain and differs highly between sources (here, only recovered wood for energy and wood based panels are considered). The uncertainty surrounding availability of recovered wood both relates to how different sources of data have been collected and conversion factors being applied. As an example, in the Joint Wood Energy Enquiry (2011), statistics for recycled wood are reported in tonnes and converted into cubic metres using the conversion factor of 1.67 m$^3$/tonne. Forestry Statistics 2009 (Forestry Commission, 2009) instead uses a conversion factor of 1 tonne being equivalent to 2.5m$^3$ of recycled wood. In Task 3, the uncertainty of the statistics and future development of recovered wood was analysed further on the level of EU28, by simulating different levels of recovered wood availability. In other words, the impact of an increasing or decreasing future level of recovered wood was assessed. It was found that changes in the amount of wood recovery mostly affected pellet imports and SRC production: that is, the domestic production level of semi-finished woody material was found to be robust to changes in recovered wood availability. Hence, while the differences in the statistics for this feedstock are acknowledged, the impact of the uncertain statistics is likely to be minor for the estimates of future production of woody products.

The figures for imports of roundwood, pellets and wood chips in Table 5.3.1 were extracted from the Joint Wood Energy Enquiry (2011), to compare with the GLOBIOM numbers for 2010. Germany was a net importer of roundwood in 2010 (FAOstat), while the GLOBIOM numbers assume it a net exporter. As shown in Figure 5.3.2, the trend of roundwood trade in Germany has changed very recently, and GLOBIOM instead assumes a continuation of the historical trend. While the difference between the model results and statistics is notable when looking at trade statistics, the total German roundwood trade is still only a fraction of the total domestic roundwood harvests, and is not likely to have a large impact on the projected future development in Germany. For Italy, the model predicts stable roundwood imports after 2000, while the statistics show that the imports have turned into a slight decline. This development reflects the economic recession not represented by the model, while the model is more representative when looking at long term development of Italian roundwood imports. For Finland, the net import of roundwood in 2010 is higher in GLOBIOM than the statistics. The trade of roundwood to Finland shows large yearly fluctuations. A strong increase in trade can be seen after 2000, followed by an abrupt drop in 2008 due to roundwood export tariffs introduced in Russia.
### Table 5.3.1: GLOBIOM modelled vs reported amounts of industrial roundwood production, recycled wood, and pellets, roundwood and wood chips net imports for Finland, Germany and Italy. (Million m$^3$) in 2010.

<table>
<thead>
<tr>
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<th>Germany</th>
<th>Finland</th>
<th>Italy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Model</td>
<td>Statistics</td>
<td>Model</td>
</tr>
<tr>
<td><strong>Industrial Roundwood</strong></td>
<td>55</td>
<td>45</td>
<td>53</td>
</tr>
<tr>
<td><strong>Pellet imports</strong></td>
<td>4.2</td>
<td>0.25</td>
<td>0</td>
</tr>
<tr>
<td><strong>Roundwood net imports (FAOstat)</strong></td>
<td>-2.0</td>
<td>3.9</td>
<td>9.3</td>
</tr>
<tr>
<td><strong>Wood chip net imports (FAOstat)</strong></td>
<td>-2.4</td>
<td>-1.3</td>
<td>2.2</td>
</tr>
</tbody>
</table>

### Table 5.3.2: GLOBIOM recycled wood vs reported recycled wood in 2010.

<table>
<thead>
<tr>
<th></th>
<th>Germany</th>
<th>Finland</th>
<th>Italy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Model, 1000 m$^3$</td>
<td>EUWood, 1000 m$^3$</td>
<td>JWEE (1000 m$^3$)</td>
</tr>
<tr>
<td></td>
<td>12.5</td>
<td>10.3</td>
<td>No value</td>
</tr>
<tr>
<td></td>
<td>0.4</td>
<td>1.3</td>
<td>(2.7 tonnes)</td>
</tr>
<tr>
<td></td>
<td>3.5</td>
<td>6.5</td>
<td>1.8 (1.1 tonnes)</td>
</tr>
</tbody>
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*EUWood reports “total post-consumer wood”, which includes both recovered wood used for energy and material, as well as recovered wood that goes to landfill. In GLOBIOM, only recovered wood used for material or energy is accounted for.

** reported in JWEE as tonnes and converted to m$^3$ using a conversion factor of 1.67 m$^3$/tonne as in JWEE.
**Figure 5.3.1**: Industrial roundwood production from 1980-2014 on continuous line (FAOSTAT) and GLOBIOM industrial roundwood production from 2000 onwards (hatched line).

**Figure 5.3.2**: Net imports of industrial roundwood from 1980-2014 on continuous line (FAOSTAT) and GLOBIOM net industrial roundwood imports from 2000 onwards (hatched line).
Figure 5.3.3: Net imports of wood chips from 1980-2014 on continuous line (FAOSTAT) and GLOBIOM net wood chips imports from 2000 onwards (hatched line).

**Semi-finished forest products**

In figures 5.3.4 to 5.3.6, the initial production values of semi-finished woody products from the model are compared to historical development according to FAOSTAT. The figures show the production values for sawnwood, wood-based panel and pulp production in the case studies as these are the semi-finished wood products for which long-term statistics are available in FAOSTAT. For all of these product classes, GLOBIOM was initiated to match the reported production values of FAOSTAT for the year 2000. As seen in the figures below, the production levels for all product categories and case study countries estimated by GLOBIOM are in line with historical development of these products. However, there are some fluctuations in the actual production numbers reported by FAOSTAT between 2000 and 2014 that are not captured by the model.

For Italy, sawnwood production (Figure 5.3.4) in the GLOBIOM results for 2000-2014 are well in line with the observed production. However, sawnwood production industry is relatively small in Italy. For Finland and Germany however, there are large fluctuations in the reported statistics, leading to some discrepancies between the model estimates and the statistics. In Germany, sawnwood production increased rapidly between 2004 and 2007, to fall back over the course of one year in 2008. The production recovered somewhat thereafter, increasing again with a higher rate than observed before 2004. In GLOBIOM, this fluctuation is not reflected, but the sawnwood production is modelled to continue along the trend seen before 2004, leading to an underestimate of the production levels in 2010. In Finland, sawnwood production decreased in 2008 as well, and further in 2009. While there is some recovery of the production detected in the statistics thereafter, the GLOBIOM results expecting a small but steady growth after 2000 are still an overestimate of the actual levels.
Figure 5.3.4: Production of sawnwood in the case study countries from 1980-2014 on continuous line (FAOSTAT) and GLOBIOM net wood chips imports from 2000 onwards (hatched line).

Wood-based panel production (Figure 5.3.5) is partly connected to sawnwood production, as particle- and fibreboard industries use the by-products of sawmills, wood chips and sawdust, as feedstock. Hence, the rapidly decreased production levels following the global economic recession in 2008 are clearly shown also in the production statistics for wood-based panels. Here, we consider plywood, particleboard and fibreboard within the same group to accommodate with FAOSTAT classification – in GLOBIOM. Plywood is reported separately from other panels. Historically, panel production has been very stable in Italy and Finland. In 2008, the production level in these countries decreased: in Finland only slightly, while in Italy somewhat more prominently. In the GLOBIOM estimates for 2010, the effect of the global economic recession for wood-based panel production is not fully captured for these countries, leading to a slight overestimation in the production levels. For Germany, the development of panel industries has historically been very positive. However, the 2008 recession decreased the production levels considerably and the statistics show that the production levels are not yet fully recovered.
Figure 5.3.5: Production of wood-based panels (plywood, fibreboard and particleboard) in the case study countries from 1980-2014 on continuous line (FAOSTAT) and GLOBIOM net wood chips imports from 2000 onwards (hatched line).

For wood pulp production (mechanical and chemical pulp combined) (Figure 5.3.6), the model represents actual development very well. For Germany, some small fluctuation in the production levels between 2000 and 2014 can be seen in the statistics. However, the levels oscillate closely to the level predicted by GLOBIOM for those years. For Italy as well, the GLOBIOM estimates for wood pulp production are well in line with the reported historical data. Finland is one of the largest wood pulp producers in the EU. The impact of the 2008 economic recession is seen clearly in the statistics, which show a large drop in the pulp production from 2008 to 2009, caused by shutdowns of several of the pulpmills in the country. Pulp production has not yet fully recovered to the levels reported in the beginning of the 21st century, leading also to a discrepancy between the GLOBIOM data for 2010 and the reported statistics. However, there are several large-scale pulpmills being built in Finland, e.g. the Äänekoski biorefinery (with pulp production capacity of 1.3 Mton) estimated to be finished in 2017. With these ongoing investments, it is likely that the GLOBIOM estimates for wood pulp production is well in line with the actual production for the period 2010-2020.
Figure 5.3.6: Production of wood pulp (mechanical and chemical pulp) in the case study countries from 1980-2014 on continuous line (FAOSTAT) and GLOBIOM net wood chips imports from 2000 onwards (hatched line).

**Land use development in Finland**

For Finland, the Baseline scenario estimates almost negligible changes in land use to 2050 (Figure 5.3.7). There is some unused forest taken into use, and the overall land use structure of the country remains dominated by forests used for wood harvests.

Figure 5.3.7. Land use development in Finland in the Baseline scenario.
Sectoral development in Finland

Figure 5.3.8 shows that harvested volumes in Finland remain relatively static (74 Mm$^3$ in 2010, compared to 76 Mm$^3$ in 2050). However, a greater proportion of this volume comes from forest residues in 2050 (11.3 Mm$^3$) compared with 2010 (6.9 Mm$^3$). This is a realistic increase given the current emphasis on increasing use of forest residues for bioenergy. Over the same time period, the use of firewood decreases by 2.3 Mm$^3$, driven by the increasing use of district heating, centralized large scale conversion units, and wood pellets (see the Task 3 report for further descriptions of how demand of firewood is being modelled). Between 2010 and 2030, the total use of wood for energy is reduced somewhat due to improved energy efficiency, but increased demand for bioenergy turns the trend into an increase between 2030 and 2050. Overall, GLOBIOM estimates an overall increase of wood for energy from 42 Mm$^3$ in 2010 to 48 Mm$^3$ in 2050, which can be done in conjunction with an increase in use of wood for material use.

The timelined wood flows in Figure 5.3.8 show some changes in imports of roundwood. There are also increases in sawnwood outputs and the use of industrial by-products for energy. However, the most noticeable trend is the doubling of imported wood chip from 2.2 to 4.6 Mm$^3$ between 2010 and 2050. Chips are used for pulp production, but also for heating: a large part of Finland’s biomass for energy comes from wood chips. A majority of this import is expected outside of EU28, mainly from the former USSR, but also closer at hand from within EU28 such as Latvia. Together with the estimated roundwood imports increase from 10 to 15 Mm$^3$ by 2050, the GLOBIOM projections imply an increasing reliance on imported feedstocks to fulfill the increasing use of wood for energy. The analysis therefore suggests that the increased demand for wood could partially be fulfilled by domestic harvests, but also requires increases in the volumes of imported feedstocks.

In the Baseline scenario, the use of wood for material production in Finland stays relatively constant from 2010 onwards or increases only marginally, with the exception of increasing sawnwood production from almost 14 Mm$^3$ in 2010 to almost 16 Mm$^3$ in 2050. This reflects the higher demand for sawmill by-products driven by increased bioenergy demand, indicating that bioenergy demand supports the profitability of sawmills. The large-scale biorefineries being built in Finland are not shown in the development of pulp industry and, consequently, nor is black liquor for bioenergy. If successful, these investments may increase the production of pulp to higher levels than estimated for 2030 and 2050, and more importantly, prove more effective in utilizing the by-products of pulp production in energy production than the current technologies.
Figure 5.3.8. Wood flows in Finland.
Land use development in Germany

For Germany, the most notable trend is the evolution of short rotation coppice (SRC)\(^4\) over the 2010 to 2030 time horizon (Figure 5.3.9). Also cropland area increases from 2010 to 2050, while forest area and other land use classes remain approximately the same throughout the projection period.

![Figure 5.3.9: Land use development in Germany for the Baseline scenario.](image)

Sectoral development in Germany

In Germany, domestic harvests increase from 75 Mm\(^3\) to 80 Mm\(^3\) by 2030, and thereafter stagnate until 2050 (Figure 5.3.10). There is also an increase in importation of wood pellets from 4.2 Mm\(^3\) to 6.6 Mm\(^3\) between 2010 and 2050.

As was seen for Finland, the increase in the bioenergy demand leads to a higher demand for industrial by-products, driving an increase in the production of sawnwood. The results show a moderate increase in sawnwood production from 17.4 Mm\(^3\) in 2010 to 21.7 Mm\(^3\) in 2050. Particleboard production is an important sector of material production in Germany, competing of the same feedstock with bioenergy production (wood chips and sawdust). In the model, we see that the increased by-products are directed to bioenergy production, while the particleboard production level is projected to stay constant from 2010 through 2050.

Due to unreliable data on the historical development and current levels of recycled wood use, this feedstock was held constant within the model at 2000 levels. To investigate the impacts of this assumption, different levels of recycled wood were simulated and analysed on the EU level as part of Task 3. The wood flow analysis for

\(^4\) SRC is defined as poplar and willow in the model. Grasses, such as miscanthus and other energy perennials are under cropland.
Germany shows a consistently small amount of recycled wood being driven through the material route, with the majority going to the energy route. This is not fully in line with the wider resource efficient drive to promote collection and reuse, where Germany has been in the forefront of promoting new policies. This may be due to the assumption of constant recycled wood.
Figure 5.3.10: Wood flows in Germany.

Land use development in Italy

In Italy, the most noticeable trend is the decline in the share of ‘other natural land’ and the increase in share of both used and unused forest and the emergence of SRC. The other natural land refers here to a mix of land (excluding that protected for nature conservation) that cannot be classified to any of the other classes (abandoned cropland, unused grassland, etc.). In Italy, the change detected in this land class is attributed largely to abandoned agricultural land which changes to scrubland and eventually unmanaged forest since the area of land in agricultural use in Italy has been declining over the past decade. The results for Italy show the land uses of cropland, SRC, grassland and forestry all expanding to 2030 and other natural land contracting by over 3,500 ha. A prominent trend in Figure 5.3.11 below is also the expansion of forestry in Italy, which is further explored in Figure 5.3.12. In Figure 5.3.12 it is seen that majority of the increase in forest land in Italy results from afforestation (reported as a cumulative afforestation since the year 2000). As seen in Figure 5.3.11, most of this new forest area falls under the unused forest category, indicating that most of this land use change is a result of natural afforestation rather than active efforts to increase the areas managed for timber production. An example of such natural afforestation is abandoned agricultural land converted naturally over time to the ‘unused forest’ category. The model predicts linear afforestation levels, reflecting the relatively linear historical trends noted for Italy in FAOSTAT. However, it is possible that over time the levels of afforestation would level off, in particular if this development was the result of conversion of abandoned agricultural land.

For Italy, as for Germany, there is significant expansion in SRC use for energy (shifting from 0 ha in 2020 to 186 thousand ha in 2050 (Figure 5.3.11 and Figure 5.3.13). However, cropland expansion in Italy is less prominent than in Germany.

Figure 5.3.11: Land use development in Italy in the Baseline scenario.
Figure 5.3.12: Total forest area and the cumulative afforested area since 2000 in Italy.

**Sectoral development in Italy**

The model outputs show significant domestic impacts in terms of land use change in Italy. However, the forest harvest level is not projected to increase notably: between 2030 and 2050 it will even turn into a decline (Figure 5.3.13). Instead, there are noticeable rises in roundwood imports (6.6 Mm$^3$ in 2010 to 11.5 Mm$^3$ in 2050) and pellet imports (3.3 Mm$^3$ in 2010 to 4.2 Mm$^3$ in 2050). This implies a further reliance of the Italian biomass use and land use system on SRC and biomass imports, instead of forest harvests.

In Italy, the total amount of wood used for bioenergy production shows the same pattern as seen for Finland, with energy efficiency improvement decreasing the use of firewood between 2010 and 2030, and pulling down the total amount of wood used for energy. However, there is a clear increase of wood biomass used for energy after that: the total energy use of wood increases from 19 Mm$^3$ in 2030 to 24 Mm$^3$ in 2050. Most of this increase results from the development of SRC, which is shown to develop in Italy only after 2030.

On the material side, wood used in the production of semi-finished woody products is projected to increase from a total of 13 Mm$^3$ in 2010 to almost 18 Mm$^3$ in 2050. As the domestic harvests decrease slightly over this time period, the increase is sourced almost fully by increased roundwood imports. In Italy, sawnwood industry is projected to increase in line with what was seen in other case study countries as well. However, also particleboard production increases, and the energy use of industrial by-products is relatively smaller in Italy than in Finland or Germany.

As for Germany, the level of recycled wood remains low within the analysis. As discussed earlier, this may be an underestimate in the long run, given other policy processes and emphasis on the wider bioeconomy and circular economy.
Table 5.3.13: Wood flows in Italy.
Future trends and policies – key points identified in the modelling analysis.

Land use and land management developments
The shifts in land use identified in the analysis are most notable in Italy with significant decline in the natural land category, expansion in unused forest and expansion in SRC areas. The latter reflects current policies encouraging SRC in Italy and there are precedents for poplar expansion in northern Italy that might be built upon. The model predicts significant additional expansion in SRC land and there remains a question over the likelihood of this transition. There are known to be potentially significant barriers to SRC expansion including farmer attitude to uptake. Also, the question of water availability was not addressed in this study, but should not be neglected in the case of Italy were local water availability may constraint the development of SRC due to its inherent high water demand. Given that there already is locally low water availability in southern parts of Italy, the question remains if there are sufficient water levels for fulfilling future demand. There is, therefore, a question as to whether the significant increase in SRC predicted might actually occur. Moreover, the land use changes envisaged in natural land and unused forests, due to natural afforestation and other abandonment processes, may also be subject to change were policies put in place to promote additional production or to cause market pressures to shift. Changes in production would potentially lead to abandoned land coming back into production. Such pressures might include the increasing interest in advanced biofuel production in Italy, as associated policy support. While much of the emphasis is on waste and residue based fuels, these will commonly require additional energy crop based feedstocks to supplement and or balance supply.

For Germany, the same queries could be raised regarding the SRC expansion as for Italy i.e. whether the price and policy stimulus are strong enough to overcome the known barriers to SRC uptake. This would impact on the resource base in Germany and Italy and may lead to different patterns of feedstock use and land use change – as investigated in the sensitivity analysis under Task 3.

For Finland, land use is anticipated to remain largely static under the model outcomes and the policy assessment, but there may well be potential changes in management practices as a consequence of a move towards an expanded bioeconomy, however, the balance of land uses is anticipated to remain stable. There is also a potential for geopolitical issues to impact on levels of harvest and most likely land management decisions: In the dispute between Russia and Europe, Russia has flagged possible sanctions in the timber trade. This would potentially impact significantly on elements of the Finnish woody biomass chain, specifically birch pulpwood and wood chips imported from Russia. This increases uncertainty and, if action were taken, would change potential patterns of demand and hence forest management decisions.

Sectoral developments
In all there three countries there is an increasing recognition of the potential future demand for new products and material/energy flows as part of a wider bioeconomy. In Germany, this has translated into efforts focused on: securing the sustainability of the wider material use as well as energy use, including consideration of more resource
efficient use of biomass; a bioeconomy strategy and research strategy and significant investment in novel biomaterials. In Finland, alongside interest in the wider economic potential of a bioeconomy (although arguably this is in many ways effectively in place already), concern over the impact of a potential expansion of lignocellulosic biofuel production on the wider bioenergy sector for heat and power has been raised, with strategies put in place to consider needs and conflicts. In Italy, biomass production is being pushed to expand energy use, however, solid bioenergy is not the only driver with a stated desire to expand an emerging advanced biofuel industry. There is also a rising interest in the bioeconomy and bio-products.

These policies and trends towards action on the wider bioeconomy may change the balance of inputs and feedstocks used into the future for material and energy uses. In particular there is an emphasis on increasing the use of recycled wood, but also increased focus on the maximising the efficient use of uncontaminated industrial by-products emerging from the material use of lignocellulosic material.

**Conclusions**

The purpose of this task was to assess the current situation with respect to resource availability, use, and the associated policies in three contrasting case study countries. The country-level projections by GLOBIOM have been reviewed in the context of current practices and national policies.

From a resource perspective, the three countries examined here have contrasting situations. In Finland, there is an abundant forest resource which is intensively managed and harvested. There is a highly evolved and progressive timber and pulp industry and renewable energy from wood is already in common use. There is not so much scope to increase SRC outside of the extreme south of the country due to the climate. The resource situation was not predicted to change drastically over the course of the modelled period to 2050. In Germany, significant forest resources are available, but slightly less intensively managed than in Finland. However, the domestic forest biomass resources are still sufficient to supply a very active wood industry. To meet future increases in bioenergy demand, GLOBIOM found that the agricultural land in Germany may provide an opportunity for increased SRC production. In Italy, the forest area covers the same proportion of the country as for Germany. However, much of this forest is not actively managed and the scale of the wood industry is smaller than in the other two case study countries. Model outputs showed a decrease in other natural land and an increase in the forested area over the time period of the project. From a policy point of view, the policies and incentives available in each country generally reflect the particular resource availability. The emergence of an emphasis on the bioeconomy is evident in all three countries and there is an increasing recognition of the increasing demand for new products and material/energy flows as part of this wider bioeconomy. For all three case study countries, the projected biomass use over time to 2050 was found to be in line with the current resources and policies in place.
References


## Annex 1 Table of Key Policies: FINLAND

<table>
<thead>
<tr>
<th>Policy title</th>
<th>Nature of measure</th>
<th>Summary of the measure, its goals and coverage</th>
<th>Relevance to biomass use</th>
<th>Potential consequences for biomass resource use</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Category 1 - directly drive or impact on the uptake of bioenergy from solid and gaseous sources</strong></td>
<td></td>
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<tr>
<td>National Climate and Energy Strategy (2013)</td>
<td>Binding targets</td>
<td>The strategy provides the objectives proposed by the European Commission for Finland regarding the reduction of emissions, promotion of renewable energy, and enhancing the efficiency of energy consumption, require new, prominent climate and energy policy measures. Increasing the use of renewable energy by at least 25% by 2015 and 40% by 2025. 2020 - 20% biofuel blending obligation on liquid fuel suppliers Replace 10% of natural biomass based solutions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Government Foresight Report on Long-term Climate and Energy Policy</td>
<td>Binding targets</td>
<td>In the emissions trading sector, cutting emissions on the EU level by 34 per</td>
<td></td>
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</table>

http://www.tem.fi/files/36292/Energia_ ja_ilmastostrategia_nettijulkaisu_ENGLANNINKIELINEN.pdf
<table>
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<tr>
<th>(2009)</th>
<th>Energy and Climate Roadmap 2050 (October 2014)</th>
</tr>
</thead>
<tbody>
<tr>
<td>cent from 2005 levels, by 2020. Reducing emissions by 16 per cent in sectors not covered by the Emissions Trading System (ETS) (such as construction, the heating of buildings, housing, agriculture, transport and waste management, and fluorinated greenhouse gases from industrial sources). Increasing the use of renewable energy to 38 per cent of final energy consumption.</td>
<td></td>
</tr>
<tr>
<td>Roadmap and targets The roadmap to 2050 serves as a strategic-level guide on the way toward a carbon neutral society. The roadmap contains an analysis of the means for the construction of a low-carbon society and an 80–95% reduction in greenhouse gas emissions in Finland from the level of 1990 by 2050. The building of a carbon-neutral society requires activity on all levels.</td>
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See pages 31-34 for
<table>
<thead>
<tr>
<th>Event</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finnish Energy Tax Reform (1st January 2011)</td>
<td>Tax</td>
<td>The Finnish energy tax reform changed the basis of the fuel excise tax: Fossil fuels and biofuels are subject to an energy content tax proportionate to their energy content, and to a carbon dioxide tax based on fuel's carbon dioxide emissions. This gave a tax incentive to bio components meeting the sustainability criteria.</td>
</tr>
<tr>
<td>The act on sustainability of biofuels and bioliquids (393/2013)</td>
<td>Incentives: Double Credit Biofuels</td>
<td>Double credit biofuels will be those manufactured of waste and residue materials, as well as non-food cellulose materials and lignocellulose materials. Bioethanol produced in Finland of waste and residue materials as well as biodiesel produced of logging waste meet the criteria for double credit biofuels. Their raw material may be waste,</td>
</tr>
</tbody>
</table>
Residue or other non-food cellulose and lignocellulose materials.

The life cycle emissions of this type of biofuels are as much as 80-90 per cent lower than those of fossil fuels. Increase of domestic biofuel production will improve Finland’s energy self-sufficiency and security of supply and decreases the country’s dependence on fossil fuels.


**Act on Production Subsidy for Electricity Produced from Renewable Energy Sources (1396/2010)**

**Feed in tariff**

Provisions for a feed-in tariff system for which power plants fuelled with wind, biogas, forest chips and wood-based fuels meeting the prescribed preconditions could be approved.

In the feed-in tariff system, an electricity producer whose power plant is approved in the system will receive a subsidy (feed-in tariff) for a maximum of twelve years. The subsidy varies on the basis of a three-
<table>
<thead>
<tr>
<th>Category 2 - Impact on the nature or extent of the feedstock base</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>The act on sustainability of biofuels and bioliquids (393/2013)</strong></td>
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### Category 3 - Wider impact on the use of the biomass resource base

<table>
<thead>
<tr>
<th>Act on the promotion of the use of biofuels for transport (446/2007)</th>
<th>Transport</th>
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<tbody>
<tr>
<td>Under the Act on the promotion of the use of biofuels for transport (446/2007), a distributor of transport fuels liable to pay tax must distribute biofuels for consumption. The energy content of biofuels must account for at least 6.0 per cent of the total energy content of the petrol, diesel oil and biofuels delivered by the distributor for consumption in 2011—2014 (distribution obligation). After that, the distribution obligation rises steadily up to 20.0 per cent in 2020. The energy contents of biofuel will be calculated to satisfy the delivery obligation twofold if the biofuel is made from waste or remains or inedible cellulose or lignocellulose (double calculation).</td>
<td></td>
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<table>
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<tr>
<th>Research Programme: Replacing coal with</th>
<th>Research</th>
</tr>
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<tbody>
<tr>
<td>The study estimates that by 2015, about 6 TWh of</td>
<td></td>
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<tr>
<td><strong>biomass in pulverised coal-fired combined heat and power plants</strong></td>
<td>coal could be replaced with biomass fuels. The use of coal will decrease once the planned waste incineration plants and multi fuel power plants have been completed. The annual consumption of coal totalled approximately 14 TWh at the power plants studied.</td>
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</table>
| **Research Programme: Forest Energy 2020** | The five year (2012-2016) joint research and innovation programme at METLA (Finnish Forest Research Institute) and VTT (VTT Technical Research Centre of Finland). It covers the whole span of forest energy value chain from biomass production, supply chain to conversion plant and end use.  
Main aims  
• creating new technology and business opportunities for rapidly growing forest energy markets.  
• producing profound knowledge for biobased sustainable development. |
- developing innovative concepts and products combining energy and material use of woody biomass.

Covers whole span of forest energy value chain from biomass production, supply chain to conversion plant and end use
Study of impacts of forest biomass production
Covers issues such as CHPC and biofuels for transport, bioenergy, and biorefineries


| Research Programme: FIBIC Bioeconomy Cluster | Research | Finnish Bioeconomy Cluster FIBIC is one of six Strategic Centers for science, technology and innovation in Finland (SHOK). The aim of FIBIC is to turn science and technology into sustainable bio-based solutions
Ongoing BEST – Sustainable Bioenergy Solutions for Tomorrow
FuBio JR2 – FuBio Joint Research 2
FuBio – Products from |
| Research Programme: Low Carbon Finland 2050 | VTT’s strategic project “Low Carbon Finland 2050” gathered VTT’s technology experts in clean energy production, smart energy infrastructures, transport, buildings, and industrial systems as well as experts in energy system modelling and foresight. The projects synthesis report Low Carbon Finland 2050 – VTT clean energy technology strategies for society, published in November 12th, 2012 in VTT Visions publication series, is a summary of VTT’s findings on the role of new technologies in moving Finland sustainably towards a low carbon economy.

The analysis has been |
contributed by creating three different low carbon storylines, “Tonni” and “Inno” and “Onni” for Finland, which are compared to the business-as-usual scenario. The analysis includes systematic modelling and assessments of the whole energy chain, including fuel and energy production, energy infrastructures and end use in buildings, transportation, and industries.


Finnish National Public Procurement Policy for Wood-Based Products (2010)

GPP

Impacts on the types of wood/biomass products bought by public services.


Finnish National Food Strategy 2010

Food waste

Reducing food waste and investing in biotechnology

## Annex 2  Table of Key Policies: GERMANY

<table>
<thead>
<tr>
<th>Policy title</th>
<th>Nature of the measure</th>
<th>Summary of the measure, its goals and coverage</th>
<th>Relevance to biomass use</th>
<th>Potential consequences for biomass resource use</th>
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<tbody>
<tr>
<td><strong>Category 1 - directly drive or impact on the uptake of bioenergy from solid and gaseous sources</strong></td>
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<tr>
<td>National Biomass Action Plan for Germany 2009</td>
<td>Strategy paper with number of binding targets</td>
<td>Compliments the EU Biomass Action Plan, and Climate and Energy Package targets to increase share of renewable energy in primary use. Sets out the potential for the use of biomass in Germany, quantifies the biomass share in meeting current demand and identifies available reserves. It also describes the German government’s strategies towards promoting bioenergy use in the heating, electricity and fuel sectors, and the measures it intends to take in implementing them.</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>double the share of</td>
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</table>
Bioenergy in Germany’s energy supply by 2020. Increasing the share of renewable energy in electricity production to at least 30 percent by 2020.

Increasing the share of renewables-generated heat from the current 6.6 percent to 14 percent by 2020.


<table>
<thead>
<tr>
<th>Renewable Energy Sources</th>
<th>Binding Act</th>
<th>It lays out legislation for renewable energy, including the German equivalent of a feed-in-trial.</th>
<th>The EEG 2014 aims to constantly and cost-effectively increase the share of renewable energy sources in the German electricity supply. According to Section 1 para. 2 EEG 2014, renewable energy shall account for 40% to 45% of the share in the gross electricity consumption by 2025, 55% to 60% by 2035, and for 80% by 2050.</th>
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<tbody>
<tr>
<td>EEG 2000</td>
<td></td>
<td></td>
<td>According to Section 3 EEG 2014 the individual expansion corridor targets are as follows:</td>
</tr>
<tr>
<td>EEG 2014 (1st August 2014)</td>
<td></td>
<td></td>
<td>Onshore wind power: net annual growth corridor target of 2500 MW</td>
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<tr>
<td>number of updates until August</td>
<td></td>
<td></td>
<td>Offshore wind power: reduction of the national targets for offshore wind power from 10 GW to 6.5 GW by 2020 and from 25 GW to 15 GW by 2030</td>
</tr>
<tr>
<td>EEG Energie and Umweltact 2013</td>
<td></td>
<td></td>
<td>Solar power: gross annual growth corridor target of 2500 MW</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Biomass: gross annual growth corridor target of 100 MW</td>
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Notable reduction of...
requirements for biomass and these must be further defined in a separate sustainability ordinance. The German government’s draft sustainability standards for biofuels, which will finalise these requirements and govern monitoring activities, are now being reviewed in line with the EU Sustainability Directive.

Costs of the EEG system are distributed to electricity consumers via the so-called EEG Surcharge (EEG-Umlage). Details of this reallocation can be found in the 2010 Equalisation Scheme Ordinance (Verordnung zur Weiterentwicklung des bundesweiten Ausgleichsmechanismus - AusglMechV) and the Equalisation Scheme Execution Ordinance (Verordnung zur Ausführung der Verordnung zur Weiterentwicklung des bundesweiten Ausgleichsmechanismus (Ausgleichsmechanismus-

Comparable to the EEG but with focus on energy used for heating.

The Renewable Energies Heat Act (Gesetz zur Förderung Erneuerbarer Energien im Wärmebereich – EEWärmeG) promotes the increase of heat generated from renewable energy to 14% by 2020. Whilst nearly half energy use in Germany goes towards heating only 6% of this is renewable, and mostly comes from wood. For new buildings it provides a prescribed percentage of renewable energy, and for old buildings there are requirements for retrofits.

Requirements depend on the type of renewable energy, for new builds: Thermal solar: 15% Geothermal and biomass, bioenergy: 50%

The Renewable Energy Heat Act sets out largely increase use of biomass for heating, but placed some sustainability criteria.
sustainability requirements for the type of biomass used. For example, palm and soya oil produced under nonsustainable conditions may not be used to comply with the Act’s obligations to use renewable energy.

Also creation of Market Incentive Program to provide incentives for renewable heating and cooling systems


**Combined Heat and Power Act**

Binding act affecting grid operators

The law on the maintenance, modernisation and expansion of combined heat and power (CHP) generating systems obliges the grid operators to provide a connection to their grid for the CHP plants and units listed in the law and to accept the CHP electricity generated by these CHP plants and units in their grid.

The price which the operator of the CHP plant or unit and the grid operator agree for this provides incentives for creating CHP systems
Electricity has to be paid in addition to a surcharge stipulated in the law and dependent on the type of CHP plant or unit.

<table>
<thead>
<tr>
<th>Energy Concept (2010) and 2011 Energy Package</th>
<th>BMWi 2010 Energy Concept</th>
<th>Important measurable criteria of the Energy Concept:</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>The reduction of greenhouse-gas emissions,</td>
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<td></td>
<td>• Renewable energies' share in gross final energy consumption,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• The proportion of electricity generation from renewable energies in gross electricity consumption and</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Primary energy consumption</td>
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<td></td>
<td>The German government's 2010 Energy Concept specifies that renewable energies are to account for 18 percent of gross final energy consumption by 2020 and 60 percent by 2050 across all sector</td>
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<td></td>
<td>But also reduces a number of bonuses in relation to biomass which were linked to earlier versions of the EEG.</td>
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<td></td>
<td>Describes conditions for sustainable biomass. Calls for need to minimise uses which compete with food.</td>
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<tr>
<td></td>
<td>Nevertheless biomass and biogas assumed to have a more prominent role in both heating and electricity production.</td>
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</table>

### Market Incentive Programme (MAP)

Part of the EEWärmeG provides financial incentives for new builds and retrofits incorporating renewables. Promote renewables-generated heat €500 million for the period 2009 to 2012.

Provide financial support for the following:
- Solar panels,
- Automatically fed combustion systems for biomass, low emission wood gasification,
- Efficient heat pumps,
- Geothermal systems,
- District heating networks powered on renewables,
- Biogas pipelines.

For biogas plants up to a capacity of 350 Nm³/h of upgraded biogas are entitled to a grant of up to 30 percent of the investment costs.

Increase uptake of renewable energies, including biomass.


### Category 2 - Impact on the nature or extent of the feedstock base

**Biomass-electricity-sustainability ordinance (BioSt-NachV)**

<table>
<thead>
<tr>
<th>Sustainability criteria for bioenergy</th>
<th>Germany has been among the top runners in trying to implement sustainability criteria for biofuels</th>
</tr>
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</table>


The BioSt-NachV shall ensure that liquid biomass used for electricity production and paid for under the EEG regime will comply with binding ecological and social sustainability standards. It establishes a biomass certification scheme.

The ordinance will enter into force on 24 August 2009, except for provisions regarding certification (§§ 24 and 34 BioSt-NachV) which will enter into force on 1 January 2010.


| Initiative for the Sustainable Supply of Raw Materials for the Industrial Use of Biomass (INRO) |
| Voluntary Industrial Certification Scheme for Renewable Raw Materials |
| Initiative on Sustainable Provision of Raw Materials for the Material Use of Biomass” (INRO) is to reach an agreement with the industry on voluntary certification of renewable resources before primary processing |

http://www.inro-biomasse.de/en.htm

<table>
<thead>
<tr>
<th>Category 3 - Wider impact on the use of the biomass resource base</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>National Strategy for the Bioeconomy (2013)</strong></td>
</tr>
<tr>
<td>Nationale Politikstrategie Bioökonomie (2013)</td>
</tr>
<tr>
<td>Strategic policy document</td>
</tr>
<tr>
<td>It sets out the strategy of the German government on how to develop a bioeconomy</td>
</tr>
<tr>
<td><strong>National Research Strategy for the Bioeconomy 2030 (2010)</strong></td>
</tr>
<tr>
<td>Nationale Forschungsstrategie BioÖkonomie (2010)</td>
</tr>
<tr>
<td>Strategic research document</td>
</tr>
<tr>
<td>It sets out the strategy of the German government on how to development research and development projects to allow the bioeconomy to develop</td>
</tr>
<tr>
<td><strong>Biomass-electricity-sustainability ordinance (BioSt-NachV)</strong></td>
</tr>
<tr>
<td>Sustainability criteria for bioenergy</td>
</tr>
<tr>
<td>Germany has been among the top runners in trying to implement sustainability criteria for biofuels</td>
</tr>
<tr>
<td>The BioSt-NachV shall ensure that liquid biomass used for electricity production and paid for under the EEG regime will comply with binding ecological and social sustainability standards. It establishes a biomass certification scheme.</td>
</tr>
</tbody>
</table>
The ordinance will enter into force on 24 August 2009, except for provisions regarding certification (§§ 24 and 34 BioSt-NachV) which will enter into force on 1 January 2010.

<table>
<thead>
<tr>
<th>Initiative</th>
<th>Description</th>
<th>Website/Link</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initiative for the Sustainable Supply of Raw Materials for the Industrial Use of Biomass (INRO)</td>
<td>Voluntary Industrial Certification Scheme for Renewable Raw Materials</td>
<td>Initiative on Sustainable Provision of Raw Materials for the Material Use of Biomass” (INRO) is to reach an agreement with the industry on voluntary certification of renewable resources before primary processing</td>
</tr>
<tr>
<td></td>
<td></td>
<td><a href="http://www.inro-biomasse.de/en.htm">http://www.inro-biomasse.de/en.htm</a></td>
</tr>
<tr>
<td>Fraunhofer Center for Chemical and Biotechnological Processes (CBP)</td>
<td>Research institute/Programme</td>
<td>Currently under construction at the chemical site in Leuna (Saxony-Anhalt). After completion in 2012, this will function as a ‘biorefinery development centre’ aimed at pro-</td>
</tr>
</tbody>
</table>
Providing the appropriate framework for connections between research and industry in the context of ambitious projects. The CBP Leuna will be financed by the German federal government (BMBF, BMELV, BMU), the state of Saxony-Anhalt, and the Fraunhofer Society.

| Plant Biotechnology of the Future (2011) | Research programme | The "Plant Biotechnology of the Future" research initiative was launched in 2011 as the successor to the national research program GABI (Genome Analysis in the Biological System of the Plant) and involves public institutions and private enterprises (public-private partnership). Its focal areas of research are:

1. Increasing yields and yield stability in crops
2. Creating and selecting quality traits
The Federal Government has provided the financial basis for the establishment of a forest climate fund in the draft Federal Budget for 2012. Resources are to be allocated amounting to Euro 35 million per year for the fund, which is to be set up by 1 January 2013 under the joint patronage of the Federal Ministries of Agriculture and of the Environment.

The funds are to be used especially to plan for schemes to restore balanced landscape water resources, to better adjust to climate change, to maintain and secure forest mires, to establish new carbon-rich riparian and moist forests, as well as to set up reference areas, but also to expand the CO2 reduction potential of wood. There are also plans to prevent and cope with the occurrence of large-scale damage such as storms.
or forest fires. Additionally, research, monitoring, communication and knowledge transfer are to be supported.


http://www.waldklimafonds.de/

**New Products Made from Nature**

Federal Initiative Promotes multiple/innovative uses for biomass

http://www.bmel.de/SharedDocs/Downloads/Broschueren/NeueProdukteNaWaRoImAlltag.pdf?__blob=publicationFile

**Too good for the bin**

Federal Initiative Discourage food waste

https://www.zugutfuerdietonne.de/

**CCS Act (2012)**

Gesetz zur Demonstration und Anwendung von Technologien zur Abscheidung, zum Transport und zur dauerhaften Speicherung von Kohlendioxid – KSpG

National implementation of EU CCS Directive 2009/31/EC

Lays out guidelines for the sustainable use of CCS. Based on this CCS Act, two of the twelve EU-wide CCS demonstration projects eligible for funding are expected to be built in Germany by 2020, providing permanent CO2 storage. A storage project for industrial CO2 emissions (e.g. a joint project for CO2 from industrial biomass) is also planned. The CCS plants can often be powered by biomass.
A demonstration stage will be evaluated to aid decisions about the potential commercial use of CCS technology.


<table>
<thead>
<tr>
<th>National Climate Initiative</th>
<th>Funding instrument. Mostly infrastructure projects both in Germany and in developing countries</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Since early 2008, funds accrued from the sale of emissions trading certificates have been used to finance a climate change mitigation initiative. Some €400 million was available in 2008. The initiative comprises a national section and an international section. The aim is to exploit existing potential for emission reductions with cost-effective measures and in broader scope, and to promote model projects. Promotion focuses on climate change activities which serve to increase energy efficiency, foster use of renewable energy and optimise biomass use in energy, heat and fuel production.</td>
</tr>
<tr>
<td></td>
<td><a href="http://www.klimaschutz.de/">http://www.klimaschutz.de/</a></td>
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<tr>
<td>Forest Strategy 2020 (2011)</td>
<td>Discusses competition for wood as a feedstock. Calls for an increase in the use of “full tree harvesting” (timber, bark and crown) particularly for use in bioenergy. But also discusses issues with increase nutrient depletion and soil erosion. Need for cohesion with Biomass action plan.</td>
</tr>
<tr>
<td>Federal Emission Control Act BImSchV/BImSchG (Bundes-Immissionsschutzgesetz)</td>
<td>Binding Multiple legislation in relation to air pollution, noise, vibrations. Multiple legislation covering issues, small boilers, large power plants, biofuels, etc etc 1-39. Relates to competing feedstocks, some issues relating to biomass.</td>
</tr>
<tr>
<td>Mobility and Fuels Strategy (2011)</td>
<td>Strategy Paper Focus on mobility issues. Highlights potential for biofuels in the mobility sector, but also many of its limitations.</td>
</tr>
<tr>
<td><strong>Sustainable-biofuels ordinance (Biokraft-NachV)</strong></td>
<td>The Sustainable biofuels ordinance relates to biofuels/liquids formed in or outside the EU. Determines if they can be included as part of the EEG. Provides a number of criteria for qualification: only raw materials from sustainable cultivation can be included, raw materials from primary forests are excluded. Has been in force since January 2011, since then all biofuels must meet the criteria.</td>
</tr>
</tbody>
</table>
# Annex 3  Table of Key Policies: ITALY

<table>
<thead>
<tr>
<th>Policy title</th>
<th>Nature of measure</th>
<th>Summary of the measure, its goals and coverage</th>
<th>Relevance to biomass use</th>
<th>Potential consequences for biomass resource use</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Category 1 - directly drive or impact on the uptake of bioenergy from solid and gaseous sources</strong></td>
<td></td>
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<tr>
<td><strong>Sector Plan for Bioenergy (2014)</strong> [Piano di Settore per le Bioenergie (2014)]</td>
<td>The Sector Plan sets out <strong>strategic direction</strong> in the field of bioenergy. It is a strategic tool to engage and guide government and farmers towards the development of sustainable bioenergy. This is done through: 1) Dissemination of good practices; 2) Adjustment, harmonisation and simplification of national and regional legislation; 3) Enhancement and expansion of research.</td>
<td>The plan in question is intended to: summarize the strengths and weaknesses of bioenergy, strategies, goals for the future, threats, opportunities and economic implications; define shared strategies and identify possible specific interventions with effective and appropriate legislative policies, economic and trade in the medium and long term; propose appropriate support measures to enhance sustainable bioenergy in the medium and long term, in the more general framework of</td>
<td>The Sector Plan foresees a major role of the agriculture and forestry sectors in the production of energy. In particular, it is emphasised that biomass has to be produced or made available by the recovery of agro-forestry and agro-industrial residues. Biomass production should aim to avoid the generation of conflicts or competition with food and feed production. In addition, the forest sector is recognised as an important source of biomass. (p. 17) Residual biomass is also recognised as an important resource for bioenergy production.</td>
<td><strong>Walter Righini, president of Italian renewable energy producers association FIPER commented: 'We hope [the report] is the first step towards... the increased use of large forests for energy and wood production'. Further information can be gathered at the following link (in English): <a href="http://www.endswasteandbioenergy.com/article/1307079/call-action-bioenergy-italy">http://www.endswasteandbioenergy.com/article/1307079/call-action-bioenergy-italy</a></strong></td>
</tr>
</tbody>
</table>
The main priority of the Sector Plan is to set out the necessary conditions to allow the bioenergy sector to help achieving the objective set out in the National Plan for Renewable Energy Sources.

This document is likely to serve as a platform to launch a participatory process to review sectorial legislation and create an all-encompassing national framework on bioenergy.

It is stated that the production of biomass for energy must rely primarily on crop and livestock waste and residues, and on processing of food products. Secondly, dedicated energy crops can be used. (p. 17)

The development of biogas production is encouraged through the use of residual biomass and/or dedicated crops. (p. 29)

Environmentally sustainable productions are also encouraged through incentives to new technologies such as the production of bioethanol from ligno-cellulosic biomass and bio-methane. (p. 30)

<table>
<thead>
<tr>
<th><strong>National Energy Strategy (2013)</strong></th>
<th>The National Energy Strategy is a strategic reference for national energy policies in the medium-long term, aiming to define the multi-functionality of agriculture; prepare a plan for communication and training to be carried out in collaboration with the regions to make the policy of social sustainability of bioenergy feasible.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>[Strategia Energetica Nazionale (SEN) (2013)]</strong></td>
<td>The Energy Strategy identifies four main objectives and seven priorities characterizing the Italian energy sector going forward.</td>
</tr>
<tr>
<td></td>
<td>Given the 20% target for renewable energy by 2020, it is recognised that the achievement of this goal is related to the replacement of part of the existing plants fuelled by</td>
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</table>
The Energy Strategy establishes a target of 20% by 2020 for renewable energy; thus, going beyond what established by the National Plan for Renewable Energy Sources (17%).

The key objectives include:

1) Reducing the gap of cost for energy for consumers and enterprises, aligning it to the European average;
2) Meeting and exceeding the objectives set in the 2020 Climate package;
3) Securing energy supply and reducing energy dependency;
4) Favouring sustainable economic growth through the energy sector.

The seven priorities by 2020 include:
- Energy efficiency;
- Competitive gas market and south European hub;
- Sustainable development of renewable energy;
- Development of infrastructure and electricity market;
- Restructuring of conventional fuels with new installations and to the evolution of the obligation of integration of renewables in the construction sector. It is predicted that in the coming years the share of technologies, such as biomass boilers, will increase. (p. 72) For this reason, it is acknowledged that particular attention needs to be dedicated to the promotion of investments in the national forest sector, in order to face the increasing demand of biomass for energy production (and of second generation biofuels from biomass).

Measures assessing the potential use of marginal land for energy purposes are also envisaged, given that marginal land is not suitable for food production or breeding and competition would be avoided. (p. 82)
- the refining and fuel distribution network;
- Sustainable production of national hydrocarbons;
- Modernization of the system of governance.

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<tr>
<td>The Decree Law on Incentives for biomethane injected into the natural gas grid (2013) [Decreto legislativo sulle Modalità di incentivazione del biometano immesso nella rete del gas naturale (2013)]</td>
<td>The Decree establishes incentives for biomethane production, according to the guidelines contained in Decree Law n. 28 of 3 March 2011</td>
</tr>
<tr>
<td>The Decree Law provides for the possibility to incentivise the production of biomethane in cogeneration plants, to be used in transport or to be injected into the national gas grid. In the first two cases, incentives are already in place, whereas in the third, a new incentive will be introduced.</td>
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</table>
### Decree Law on Incentives for the production of electricity from plants fuelled by renewable energy sources other than photovoltaic (2012)

| The Decree establishes **new incentives** for the production of electricity from renewable sources later than 31 December 2012. | The Decree establishes two different incentive mechanisms. An all-encompassing tariff for power plants up to 1 MW and an incentive for power plants beyond 1 MW, which do not opt for the all-encompassing rate. |


| The Decree Law defines the tools, mechanisms, and incentives, as well as the institutional, financial and legal framework, necessary to achieve the objectives for 2020 with regard to the overall share of energy from renewable sources (out of gross final energy) |


Ministerial Decree of 6 July 2012 on the Implementation of Article 24 of the legislative decree of 3 March 2011, n. 28 containing incentives for the production of electricity from plants fuelled by renewable energy sources other than photovoltaic. [Decreto Ministeriale del 6 Luglio 2012 sull’Attuazione dell’art. 24 del decreto legislativo 3 marzo 2011, n. 28, recante incentivazione della produzione di energia elettrica da impianti a fonti rinnovabili diversi dai fotovoltaici](http://www.gazzettaufficiale.it/eli/id/2012/07/10/12A07628/sg)
Italy’s target for renewable energy generation is 17% by 2020.

The Decree establishes a new incentive system, beginning 1 January 2013, based on a set of general criteria and to be implemented by ministerial decrees. The new incentives will aim to ensure a return on investment and operation costs. Specific criteria are indicated for biogas, biomass and sustainable bioliquids.

For power plants not exceeding 5 MW, the incentive is going to be diversified according to the energy source and to power.

As to biomass plants, including those using biodegradable waste, the maximum incentive cannot exceed, for partial refurbishing, 80% and, for total refurbishing, 90% of the incentive given to new plants.

The National Plan for Renewable Energy Sources (2010) provides strategic direction on the measures to put in place, in the context of transport, electricity, heating and cooling sectors, in order to achieve the 17% renewable energy target established by the Directive 2009/28/EC for Italy.

In addition, the Plan analyses the main actions and tools for the development of renewable energy sources. In particular, current and future incentives are analysed.

The Decree of 15 March 2012 defines regional objectives as to renewable energy sources, according to the objectives set out in the National Plan for Renewable Energy Sources.

The Plan contains several novelties in relation to the development of the electricity sector, the upgrading of the heating and cooling sectors, and special emphasis on the use of biomass. Besides solar energy, it is expected to provide the biggest share amongst the renewables by 2020. It is stressed that the energy produced by Italy from renewable sources by 2020 (+15 Mtoe) will derive for half from biomass (+7.6 Mtoe), the use of which will have to increase by more than three times. (See Tables 1 and 2 in Annex 1)

Chapter 4.6 is dedicated to measures aiming to promote the use of energy from biomass. These include:
- Measures to encourage the use of unused land, degraded land and other land (See National Strategic Plan for Rural Development 2007 – 2013, and regional Programmes for...
Rural Development);%5B5%5D
- Use of primary materials already available for energy production, such as waste and residues, as dictated by the Waste Framework Directive 2009/98/EC. Electricity production from the biodegradable fraction of waste may benefit of the incentives for the production of electricity from renewable sources;
- Incentives for the production and use of biogas (Green Certificates and all-inclusive tariff);
- Measures to enhance forest management and to optimise the sustainable extraction of forest biomass (See National Strategic Plan for Rural Development 2007 – 2013 and regional Programmes for Rural Development).

<table>
<thead>
<tr>
<th><strong>Law 2/2009 on incentives for energy efficiency and installations in buildings (2009)</strong></th>
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<tr>
<td><strong>[Legge 2/2009 sugli incentivi per l’efficienza energetica e di apparecchiature in edifici (2009)]</strong></td>
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<tr>
<td>The law provides incentives aimed at reducing energy requirements, improving thermal insulation of buildings, the installation of solar panels and the replacement of winter heating systems.</td>
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<tr>
<td>Replacing existing boilers with a biomass boiler can benefit from a deduction of 55% (maximum 30,000€), provided compliance with certain requirements.</td>
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<table>
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<tr>
<th><strong>Conversion into law, with amendments, of Decree-Law of 29 December 2008, n. 185, containing urgent measures to support families, work, occupations and businesses and revisit as an anti-crisis the national strategic framework [Conversione in legge, con modificazioni, del decreto-legge 29 Novembre 2008, n. 185, recante misure urgenti per il sostegno a famiglie, lavoro, occupazioni e impresa e per ridisegnare in funzione anti-crisi il quadro strategico nazionale]</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><a href="http://www.parlamento.it/parlam/leggi/09002l.htm">http://www.parlamento.it/parlam/leggi/09002l.htm</a></td>
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<tr>
<th><strong>Tax benefits for district heating (Several norms, amongst which Finance Act (2009))</strong></th>
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<tr>
<td><strong>[Benefici fiscali per il teleriscaldamento (Numerose norme, tra cui Legge Finanziaria (2009))]</strong></td>
</tr>
<tr>
<td>Several norms have defined the tax benefits in favour of biomass district heating, amongst which Financial Act (2009).</td>
</tr>
<tr>
<td>The end user who purchases energy from biomass-fuelled heating networks in certain municipalities is entitled to a tax deduction of 0,02582 €/kWh. The user is also entitled to a one-off reduction of 20,6583€/kWh of power installed on the connection costs.</td>
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<tbody>
<tr>
<td><a href="http://www.camera.it/parlam/leggi/08203l.htm">http://www.camera.it/parlam/leggi/08203l.htm</a></td>
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</tbody>
</table>

The Financial Act provides the legislative framework for the year 2008 on:
- Financial provisions;
- Provisions on revenues;
- Provisions on internal matters.

According to Decree Law 79/1999 and as modified by the Finance Law 2008, each producer of electricity from renewable sources is assigned a number of Green Certificates related to the amount of energy produced, including biomass. Such producers resell the Certificates to producers of energy from non-renewable sources for which there is an obligation to buy or auto-generate a percentage of energy from renewable sources.

Alternatively, as to power plants fuelled by renewable energy sources and not

The Finance Act introduces several coefficients of differentiation in order to privilege some sources and reduces incentives to others.

The Ministerial Decree 18/2008 establishes that the production of electricity from plants fuelled by renewable sources is entitled to Green Certificates according to a system of coefficients, called K, superior or inferior to 1. Biogenic waste is assigned a coefficient of 1,10. (p. 212)

Biomass and biogas produced from agricultural activities, livestock and the forestry sector in high efficiency cogeneration plants with re-use of thermal energy in agriculture are assigned a coefficient of 1.3. (p. 212)

Biomass produced in the context of industry agreement (as defined by Decree Law 102/2005) or within 70 km from the processing plant is assigned a coefficient of 1,8.
<table>
<thead>
<tr>
<th>Provisions for the formulation of annual and multi-annual budget (Finance Act 2008). [Disposizioni per la formazioni del bilancio annual e pluriennale dello Stato (Legge Finanziaria (2008))] [<a href="http://www.parlamento.it/parlam/leggi/07244l.pdf">http://www.parlamento.it/parlam/leggi/07244l.pdf</a>]</th>
<th>The inclusive tariff for biogas and biomass (either local or imported) power plants (excluding liquid biofuels with the exception of vegetable oil) is equivalent to 0.28€ / kWh. All these provisions remained valid until 31 December 2012.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decree Law on Incentives for the production of biogas (2007) [Decreto Legge sugli Incitivi alla produzione di biogas (2007)]</td>
<td>The Decree Law established incentives for the production of biogas and energy produced from biomass. The Decree Law encourages the production of electricity from plants fuelled by biomass and biogas produced from agricultural, livestock and forestry products, including by-products, through the provision of Green Certificates.</td>
</tr>
<tr>
<td>Convention into law, as amended, of Decree Law of 1 October 2007, n. 159, on urgent action in economic and financial matters, for development and social fairness. [Conversione in legge, con modificazioni, del decreto-legge 1 Ottobre 2007, n. 169, recante interventi urgenti in materia economico-finanziaria, per lo sviluppo e l’equità sociale] [<a href="http://www.camera.it/parlam/leggi/07222l.htm">http://www.camera.it/parlam/leggi/07222l.htm</a>]</td>
<td>In order to encourage the production of renewable energy by agricultural enterprises, the Finance Law sets out that the production</td>
</tr>
<tr>
<td><strong>Finance Act (2007))</strong></td>
<td>budget for year 2007. and sale of electricity and heat from renewable agro-forestry (and photovoltaic) plants carried out by farmers, as well as biofuels and chemical products (bioplastics) constitute activities producing agricultural income, provided that the raw materials used come from the property.</td>
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<tr>
<td><strong>Consolidated Law on Excise Duty (1995), as modified by Decree Law n. 26/2007</strong></td>
<td>Provisions for the formulation of annual and multi-annual budget (Finance Act 2007). [Disposizioni per la formazioni del bilancio annual e pluriennale dello Stato (Legge Finanziaria) <a href="http://www.altalex.com/?idnot=34980">http://www.altalex.com/?idnot=34980</a>]</td>
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<tr>
<td>[Testo Unico Ambientale. Decreto legislativo sulle Norme di natura ambientale (2006)]</td>
<td></td>
</tr>
<tr>
<td>Value Added Tax (VAT) – Several Laws</td>
<td>Indirect taxes on energy consumption and energy products</td>
</tr>
<tr>
<td>[Imposte indirette sul valore aggiunto (IVA) – Varie norme]</td>
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companies and for sale to wholesale customers;
- 21% rate on Green Certificates;
- Reduced 10% rate on forest biomass;
- Reduce 10% rate for the purchase of services and supplies of equipment and materials related to the supply of thermal energy for domestic use through district heating networks.

Presidential Decree of 16 October 2017, no. 633 on Introduction and implementation of value added tax.


Category 2 - Impact on the nature or extent of the feedstock base

**Sector Plan for Bioenergy (2014)**

[See above Category 1]  [See above – Category 1]

It is suggested that an effort must be made in the direction of introducing short rotation crops (herbaceous or arbooreal plants with a short harvest cycle).

It is suggested that the search for new genetic materials should be directed to favour those characterised by high growth autonomy or event those with high ability to

This implies, in the short term, the introduction of allochthonous material and, in the medium term, a commitment to the improvement of it. (p. 22)
colonize, reducing the demand for additional nutritional input.

Species that can guarantee a prolonged coverage of the ground should also be prioritised, as they have long harvest cycles and are able to become interlayers in the annual cycle of conventional crops. (p. 22)

<table>
<thead>
<tr>
<th>Decree Law on Urgent measures to tackle environmental and industrial emergencies (2013)</th>
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<tr>
<td>The Decree Law establishes provisions to address environmental emergencies (related to waste management) in two Italian regions, i.e. Campania and Puglia. Article 1 establishes the conduct of technical investigations for the mapping of land used for agriculture in Campania. It is expected the indication of land that cannot be allocated to food production, as well as that destined to certain agri-food productions. Such lands are expected to be used for the production of energy crops.</td>
</tr>
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<table>
<thead>
<tr>
<th>National Strategic Plan for Rural Development 2007 – 2013 (2010) [Piano Strategico Nazionale per lo Sviluppo Rurale 2007 – 2013 (2010)]</th>
<th>Programme designed in the framework of the Common Agricultural Policy (CAP)</th>
<th>The Plan, aiming at assessing the state of health of the PAC, was renovated with new strategic objectives and resources to be allocated to sectors such as ‘climate change’, ‘renewable energy’ and ‘biodiversity’. The Plan is divided into four axes:  • Improving the competitiveness of the agricultural and forestry sector;  • Improving the environment and the countryside;  • Quality of life in rural areas and diversification of the rural economy;  • Leader. The Plan provides targeted investment support for afforestation of agricultural land and non-agricultural land, as well as conversation of land for forestry and agro-forestry systems. The Plan also promotes agricultural policies to support dedicated production (e.g. short rotation coppice), also through the use of marginal land, and the collection of residues, i.e. straw. Finally, policies to support the sustainable use of forest are promoted.</th>
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</table>
Proposals for regional Rural Development Programmes for the period 2014 – 2020 are being examined by the European Commission.

• Measures 123 and 221 regulate the biomass production phase.

Measure 121 allows the direct financing for the purchase and / or construction of plants not exceeding 1 MW for the production of electricity and heat from biomass, provided that the energy produced is mainly within the company. This provides funding equal to 40% of overall investment.

Measure 123 targets the company operating within the supply chain which process and / or market agricultural and forestry products, by providing remuneration for the sale of biomass raw material.

Measure 221 finances the afforestation of agricultural land.

Measure 311 includes different types of interventions aimed at the diversification of rural
activities, including measures for the production energy from renewable sources. Such measure relates to the construction of biomass plants not exceeding 1 MW. The maximum contribution amounts to 200,000€.

Each region designed a specific Programme for Rural Development.

<table>
<thead>
<tr>
<th>Framework Programme for the Forestry Sector (2008) [Programma Quadro per il Settore Forestale (2008)]</th>
<th>The Framework Programme for the Forestry Sector is a <em>strategic document</em> setting out the main priority in the forestry sector. The Framework Programme encourages sustainable forest management in order to protect the territory, mitigating climate change, activating and strengthening the forest industry and ensuring the long-term, multi-functionality and diversity of forest resources. It promotes sustainable forest management and incentivises the use of biomass for energy production.</th>
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<tr>
<th>Category 3 - Wider impact on the use of the biomass resource base</th>
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<tr>
<td><strong>Decree Law on Updating the conditions, criteria</strong></td>
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</table>
and procedures for implementing the obligation to release biofuels for consumption, including advanced biofuels (2014)


1 Advanced biofuels are defined in the Decree Law as follows: ‘Biofuels and other fuels produced exclusively from the raw materials listed in Annex 3, Part A. These materials include: algae, the biomass fraction of municipal waste, organic waste, the fraction of biomass corresponding to industrial waste, straw, animal manure and sewage sludge, tall oil, crude glycerine, bagasse, marc and wine lees, shells, hucks, corncob, the fraction of biomass waste and residues from forest industry (bark, branches, products of pre-commercial thinning, leaves, needles, crowns, sawdust, chips, black liquor, brown slurry, sludge fibres, lignin, tall), other cellulosic, non-food materials, including residues of food crops and annual feed (straw, shells, leaves, stems, stalks and corncobs), dedicated crops (Panicum Virgatum, Miscanthus, Arundo Donax), waste materials coming from industrial processes (residues of food crops or animal feed), and organic waste; Other lingo-cellulosic materials made of lignin, cellulose and hemicellulose, such as residual wood biomass, dedicated energy crops, residues and wastes from wine production, except sawn logs, Renewable liquid and gaseous fuels from non-biological origin.
| **Sector Plan for Bioenergy (2014)** | [See above – Category 1] | [See above – Category 1] | One of the key horizontal priorities of the Plan is the creation of an inter-ministerial round table on Green Chemistry defining strategies and opportunities for the development of bio-products, in the context of the European bio-economy strategy. No prioritisation is given to any specific bio-products. (p. 20) |


**Memorandum of understanding for the creation of a project on ‘Sustainable chemistry’ (2013)** | Memorandum of understanding | The initiative aims to promote important projects in the field of industrial chemistry from renewable sources, which will allow producing second and third generation biofuels. |
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<td>[Piano di Azione Nationale per le fonti rinnovabili di energia (PAN)]</td>
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It is foreseen the possibility for biomass and bioliquids the introduction of priority for purposes other than energy and, if destined for energy, discrimination between those destined to the production of heat or the use in transport and those destined for electrical purposes. As to the latter, it is suggested to favour, in particular, the use of waste biomass in co-generation plants. (p. 8)

In addition, as to biomass, particular attention will be devoted to the dynamics of the cost of raw material and operating costs, pursuing a convergence of the intensity of support with European trends. (p. 9)
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