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 pulpwood into paper pulp. Lignin, hemicelluloses and other substances are removed from the wood to free the cellulose fibres. The pulp industry derives a significant share its bioenergy in the form of black liquor.

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

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[1]).
Protected forests (as defined by WDPA Consortium 2004[2]) 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.

[1] *FAO 2012. FRA 2015 – Terms and definitions. Forest Resources Assessment Working Paper 180.*
[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 (m^3) of roundwood used in production. It also includes wood chips to be used for fuel that are made directly (i.e. in the forest) from roundwood. (FAOSTAT) In this project, the household and industrial uses of fuelwood are sometimes separated and referred to, respectively, as *firewood* and *roundwood for energy*.

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.

m^3 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 reprocesses into products, materials or substances whether for the original or other purposes. It includes reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels of for backfilling operations.'

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; pulpwood, round and split; other industrial roundwood, and also branches, roots, stumps and burls (where these are harvested). It is reported in cubic metres solid volume.

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 m^3 SWE, and 1 ton of pellets=2.5 m^3 SWE. In addition, fibreboard is more dense than roundwood, and followingly, 0.7 m^3 of fibreboard=1 m^3 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, ornimental plants). Forests that are used in a certain period to meet the wood demand, so–called used forests, are modelled to be managed for woody biomass production. This implies a certain rotation time, thinning events and final harvest.

Examples of used forests are:

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

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 1st and 2nd 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

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3 European Commission. EU Energy, transport and GHG emissions trends to 2050. Reference scenario 2013. (2013).

4 European Commission. Impact Assessment: Accompanying the Communication A policy framework for climate and energy in the period from 2020 up to 2030. (2014).

5 Havlík, Petr, et al. "Climate change mitigation through livestock system transitions." Proceedings of the National Academy of Sciences 111.10 (2014): 3709-3714.

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[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 taken into account the recent GECO 2015[7] analyses. Further adjustments in terms of scenarios, assumptions, and model constructions between this project and that of the 2014 IA[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[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[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[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[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.

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

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

		Main model parameters		
		Bioenergy demand in EU28	**Bioenergy demand in RoW**	**Biomass import to EU28**
Baseline	**Baseline Scenario**	As in EU Reference Scenario	As in GECO Baseline Scenario	Estimated by model
Policy scenarios	**EU Emission Reduction Scenario**	**As in GHG40/EE (increased level in 2050 compared to baseline)**	As in baseline	Estimated by model
	Constant EU Bioenergy Demand Scenario	**As in GHG40/EE until year 2020, then constant**	As in baseline	Estimated by model
	Increased RoW Bioenergy Demand Scenario	As in GHG40/EE	**As in GECO Global Mitigation Scenario (increased level compared to baseline)**	Estimated by model
	Increased EU Biomass Import Scenario	As in GHG40/EE	As in baseline	**Enhanced import (estimated by model)**

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[8]. 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**

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 **EU 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).

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 Mm3 (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 serve 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 where 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[12]; Herzogbaum GmbH, 2008[13]). Labour requirements for plantation establishment are based on Jurvelius (1997)[14], 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

12 Carpentieri, A.E., Larson, E.D., Woods, J., 1993. Future biomass-based electricity supply in Northeast Brazil. Biomass and Bioenergy 4, 149–173.

13 Herzogbaum GmbH, 2008. Forstpflanzen-Preisliste 2008. HERZOG.BAUM Samen & Pflanzen GmbH. Koaserbauerstr. 10, A _ 4810 Gmunden, Austria. Available from: /www.energiehoelzer.atS)

14 Jurve, M., 1997. Labor-intensive harvesting of tree plantations in the southern Philippines. Forest harvesting case-study 9. RAP publication: 1997/41, Food and Agriculture Organization of the United Nations

(2007)[15]. 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 Scenario[3] and GHG40/EE scenario as specified in the 2014 IA report[4] 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 report[7]. 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 report[4].

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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[15] ILO, 2007. Occupational Wages and Hours of Work and Retail Food Prices, Statistics from the ILO October Inquiry. International Labor Organisation, ISBN: 9220201747 Available from: /http://laborsta.ilo.org/S

[16] Havlík P, et al. Global land-use implications of first and second generation biofuel targets. Energy Policy (2011) 39:5690-5702.

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.*

	2005	2030	
		Ref	GHG40/EE
Domestic production biomass feedstock (Mtoe)	87	194	191
of which: forestry	33	48	48
of which: crops	4	65	59
of which: agricultural residues	12	16	16
of which: waste	28	47	47
of which: other (i.e. black liquor)	9	17	21

Source: European Commission. Impact Assessment: Accompanying the Communication A policy framework for climate and energy in the period from 2020 up to 2030. (2014).

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.

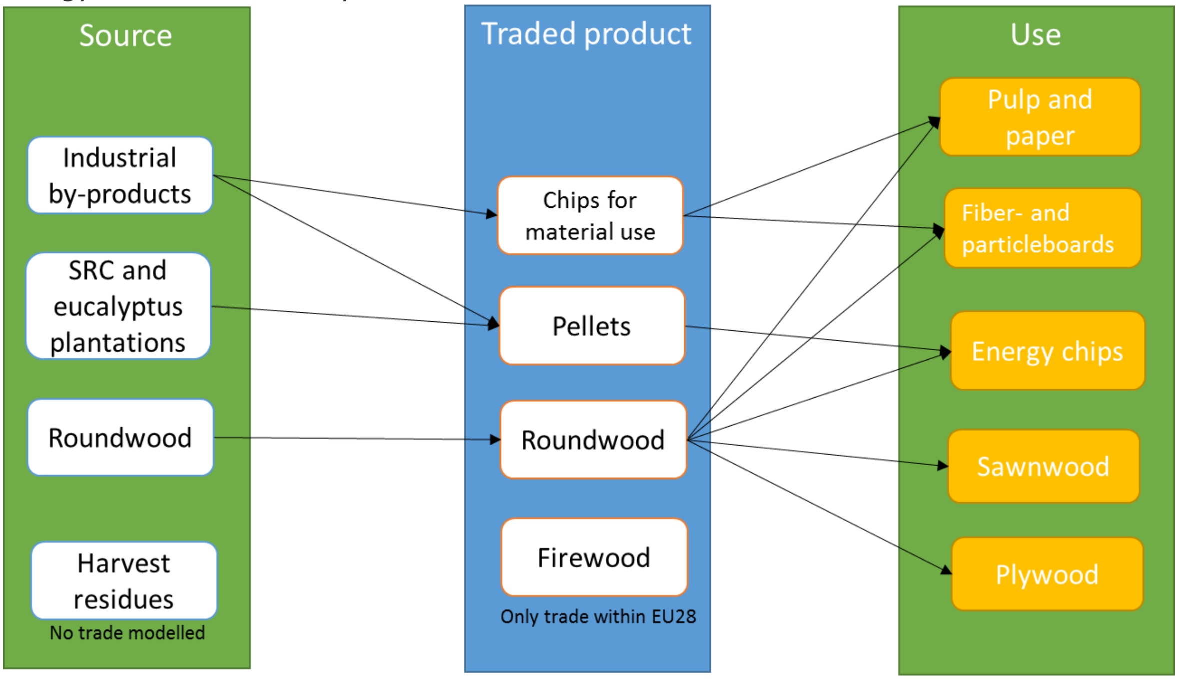
For the 2014 IA, the PRIMES-estimated trade of biomass feedstocks between EU28 and the RoW for bioenergy production (heat, electricity, and transport) was also used as input to the GLOBIOM model. Trade of feedstocks was for the 2014 IA strictly enforced within GLOBIOM so that the amount of trade matched 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[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.

[17] *FAOstat. http://faostat3.fao.org/download/F/FT/E*

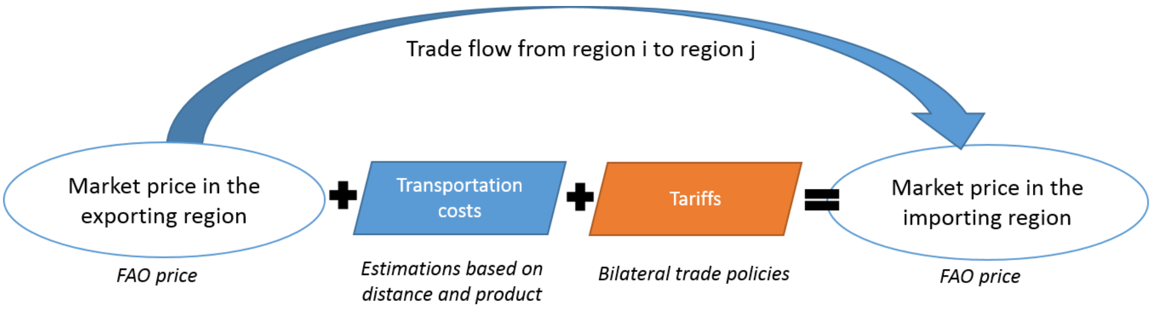
- Harvesting residues (branches, tops, etc.) are not allowed to be traded between regions within the model framework. This is both due to lack of statistics of trade and the relative small amounts that are being traded.

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[18]) to provide reconciled values and quantities of COMTRADE annual trade statistics at the HS6 product level[19]. A trade calibration method (Jansson and Heckelei, 2009[20]) 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.*



[18] *Fontagné L., Gaulier G. & Zignago S. (2008), "Specialization across Varieties and North-South Competition", Economic Policy, 2008, pp. 51-91*

[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.*

[20] *Jansson, T., Heckelei, T., 2009. A new estimator for trade costs and its small sample properties. Economic Modelling 26 (2), 489–498.*

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 2012[21]). **Protected forests** (as defined by WDPA Consortium 2004[22]) are excluded from the analysis and no conversion or use of protected forest is allowed. Forest that is not protected is considered as forests available for wood supply. The model allocates harvests to this area so that the projected demand for wood for material and energy purposes will be satisfied. These forests include natural and semi-natural forests, as well as forest plantations. In this project, we classify these forests as **unused** and **used forests**, depending on whether they contribute to the wood supply or not. **Unused forests** do currently not contribute to wood supply, based on economic decision rules in the model. However, they may still be a source for collection and production of non-wood goods (e.g. food, wild game, ornimental plants). Forests that are used in a certain period to meet the wood demand, so–called **used forests**, are modelled to be managed for woody biomass production. This implies a certain rotation time, thinning events and final harvest.

Examples of used forests are:

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

The 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. 2008[23] 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

[21] *FAO 2012. FRA 2015 – Terms and definitions. Forest Resources Assessment Working Paper 180.*

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

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

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

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[3] used in the 2014 IA report[4]. 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)[25]. 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

[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 be 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[7]. 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).

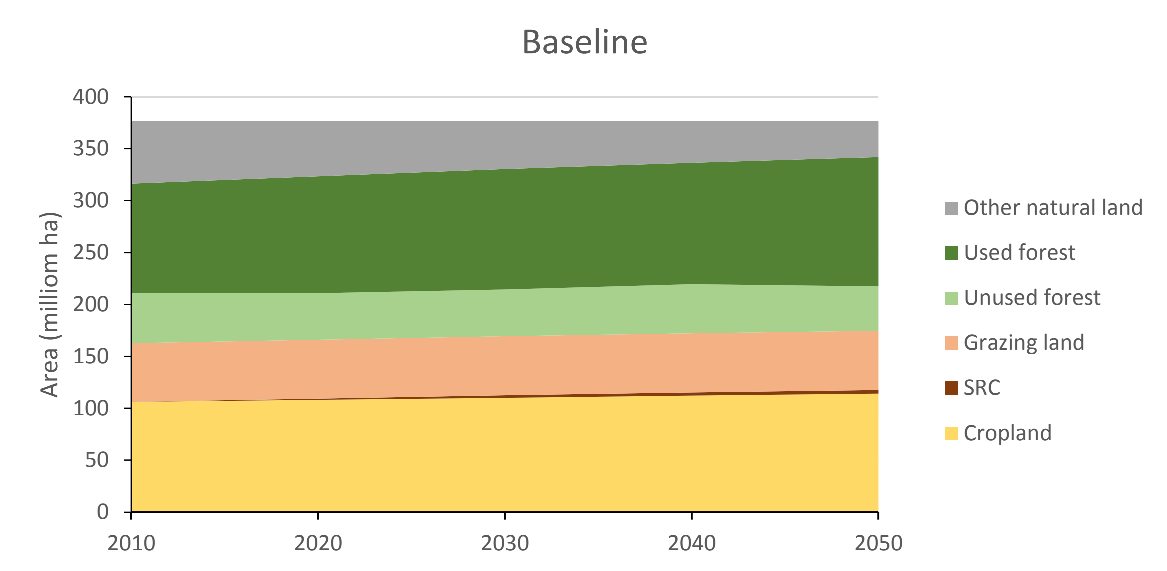
5.3 Key outcomes of the baseline scenario.

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 Chapter7, 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 m^3 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.*

Study	**EUWood**	**Indufor**	**ReceBio Baseline**		
Reference year	2010	2011	2010	2030	2050
					Million m³
Total Wood Consumption	825	942	841	1004	1106
Total Material Use*	*457*	*649*	*535*	*613*	*686*
Wood Products Industry**	314	308	367	436	498
Pulp and Paper		341			
Pulp	143		162	172	182
Total Energy Use, excl. SRC	*368*	*293*	*306*	*346*	*359*
Wood products industry side streams***		150	155	188	216
Wood used primarily for energy****		143	151	158	143
Energy Biomass from SRC			*0*	*44*	*60*
Energy use, %	**45%**	**31%**	**36%**	**39%**	**38%**
Material use, %	**55%**	**69%**	**64%**	**61%**	**62%**

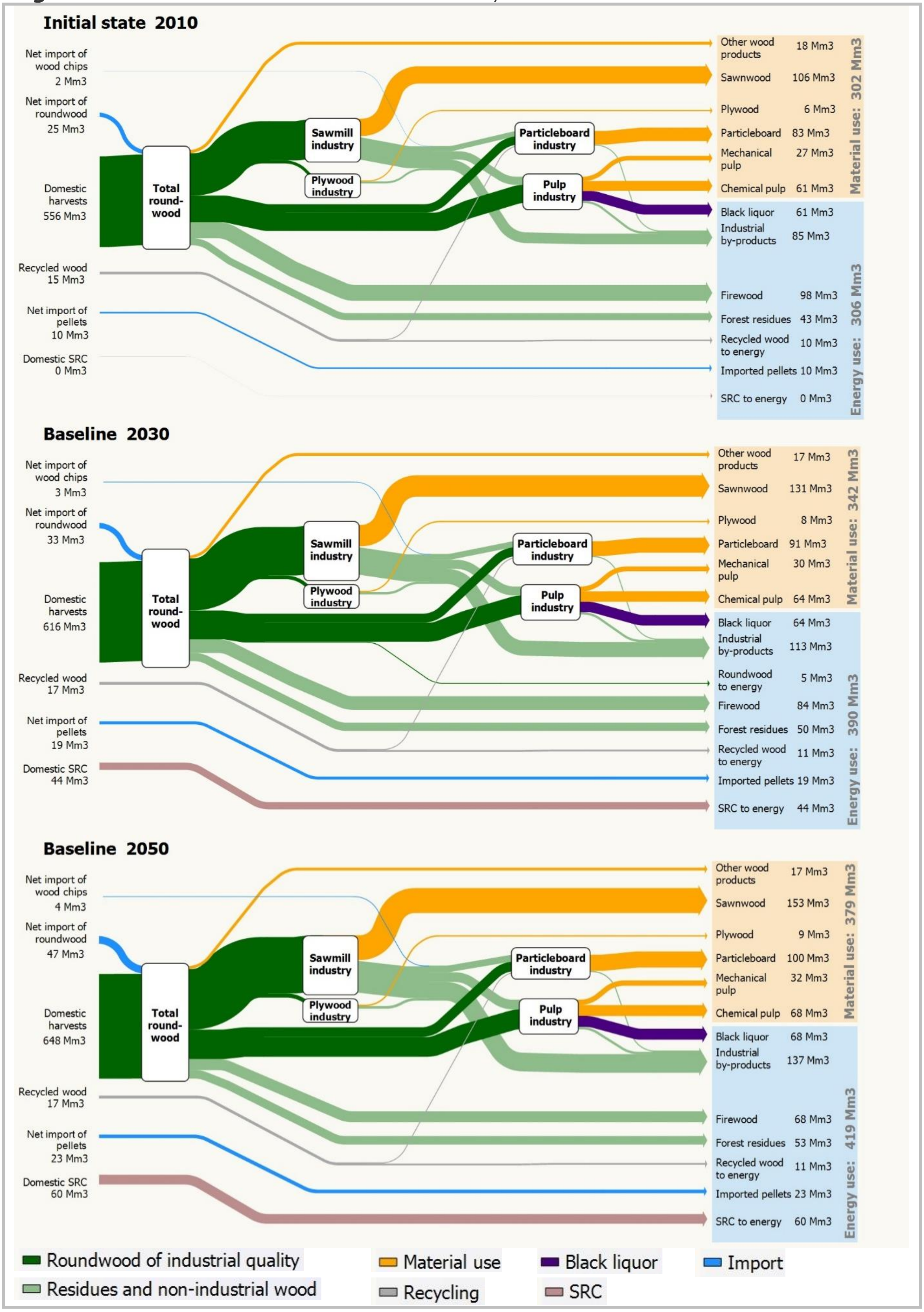
Note that this table describes the input volumes for wood-using industries. This means that some of the wood biomass is counted both within "Total Material Use" and "Total Energy Use", because by-products of the material industries can be used in the production of other materials (pulp and/or particleboards), or for energy. This is a common way of accounting for wood use found in the literature, but partial double-counting makes it impossible to compare these numbers with actual harvest volumes. The flowcharts used in this report (e.g. Figure 4) bypass this problem by showing the actual wood biomass flows through the industries.
**In ReceBio: Sawmill and board industries, pulp production, and 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 ouput 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 Mm^3 SWE.*

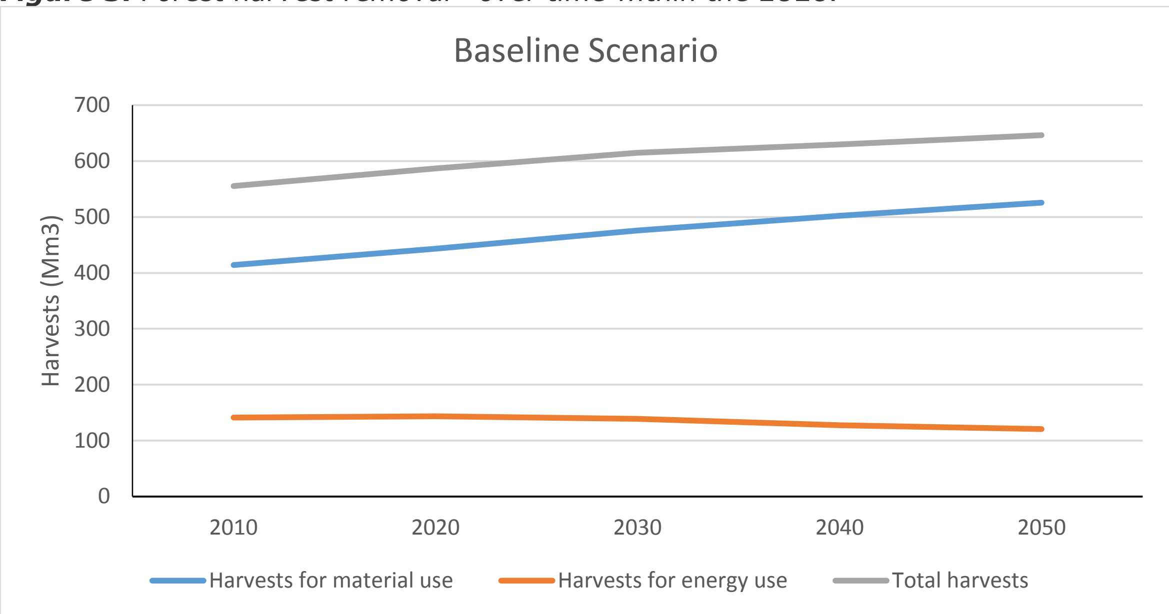


Forest harvests in the EU

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.

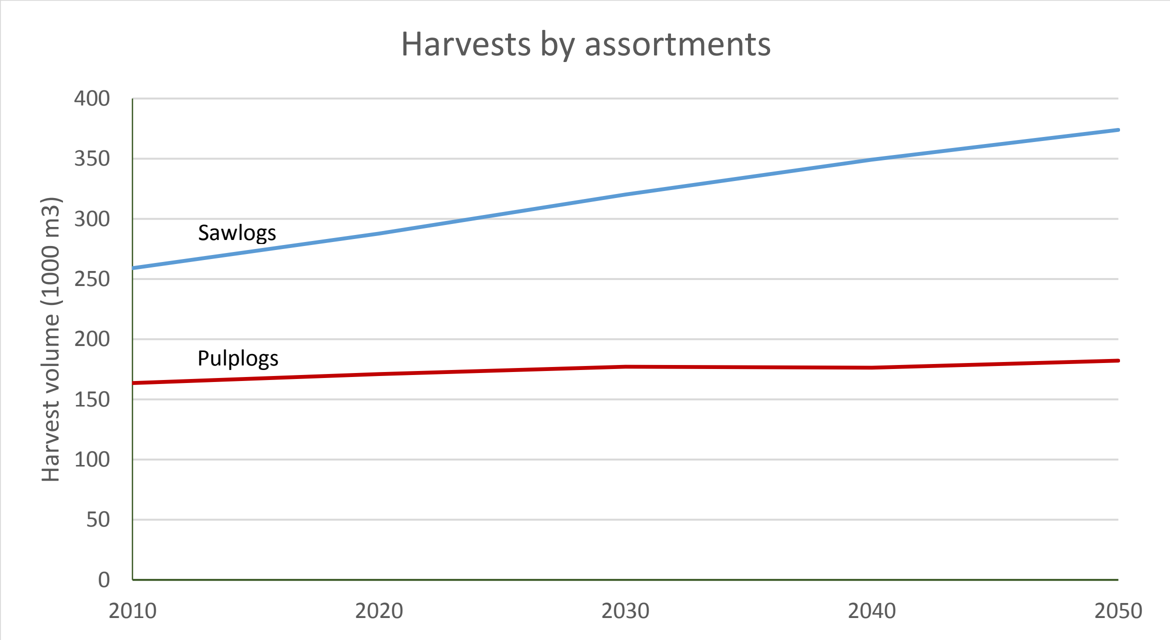
Figure 5. *Forest harvest removal* over time within the EU28.*



**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.

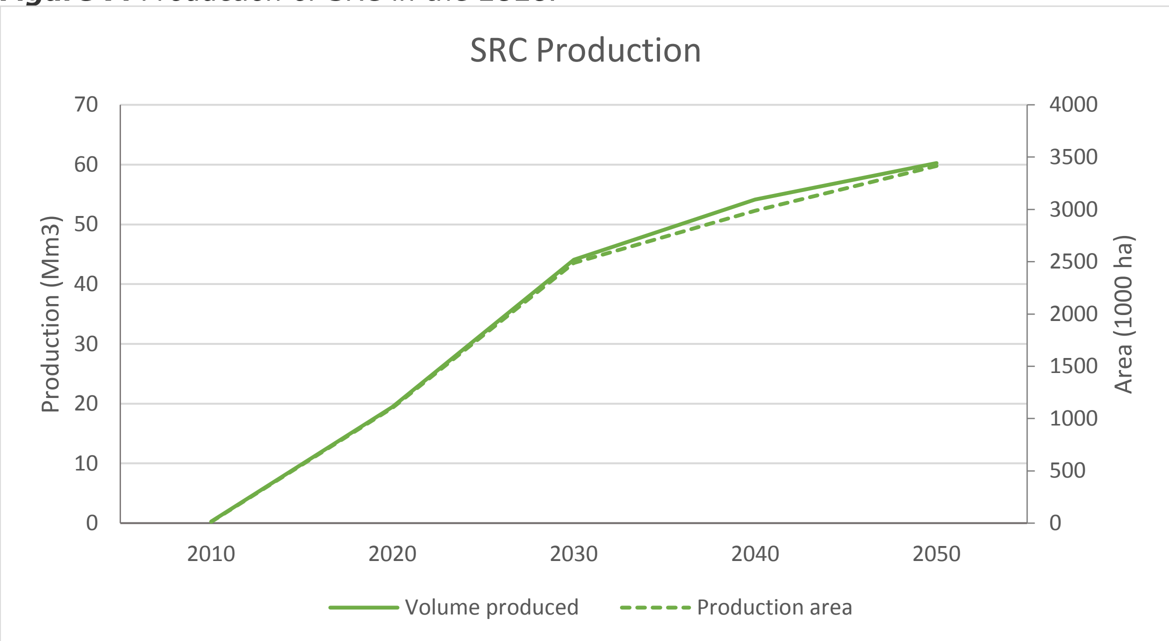
In opposite to EFSOS II, EUWood presents very different prospects for the development of EU harvests. In EUWood, stemwood harvests in 2010 are considered already very close to the theoretical potential (544 Mm^3 under bark) in the EU27. More biomass potential is assumed mainly from increased harvest 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[16].

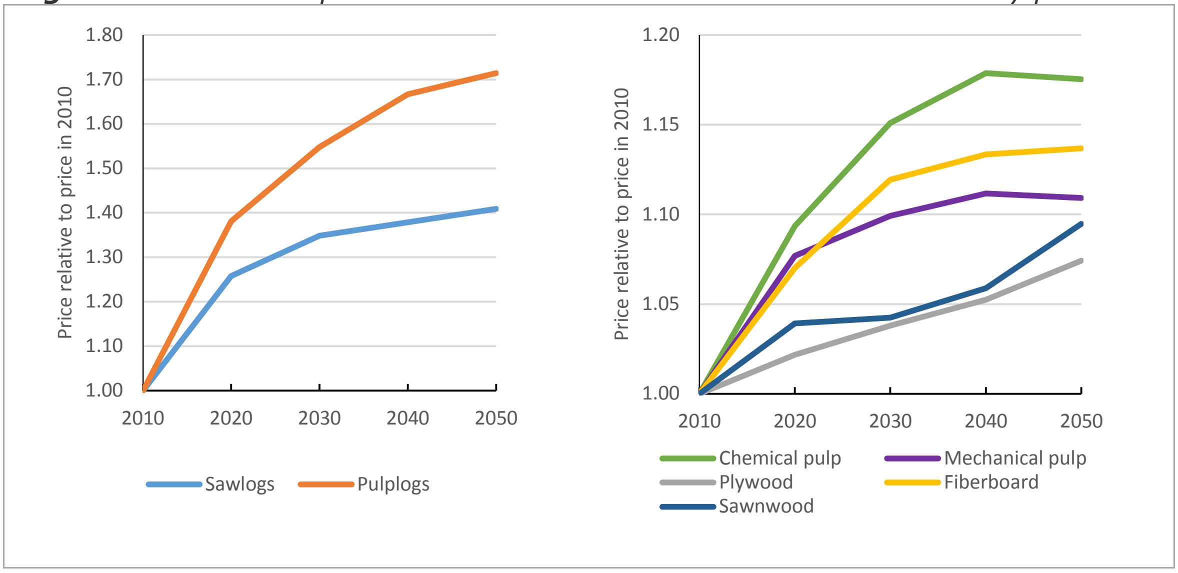
Figure 7. *Production of SRC in the EU28.*



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.*



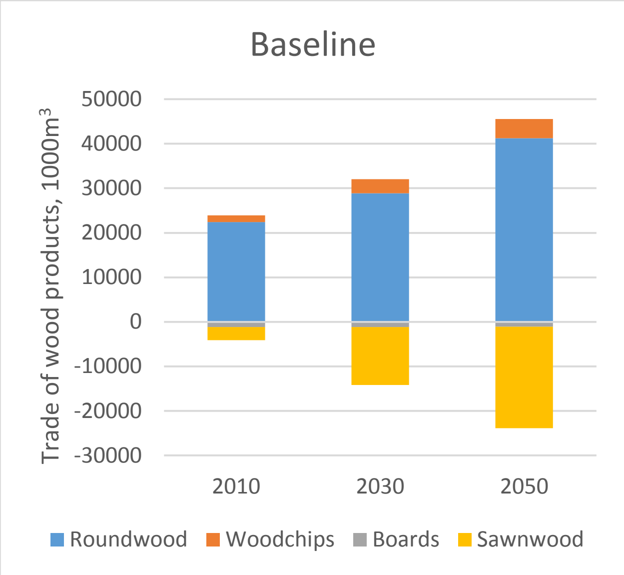
Trade of woody biomass and forestry products

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.*



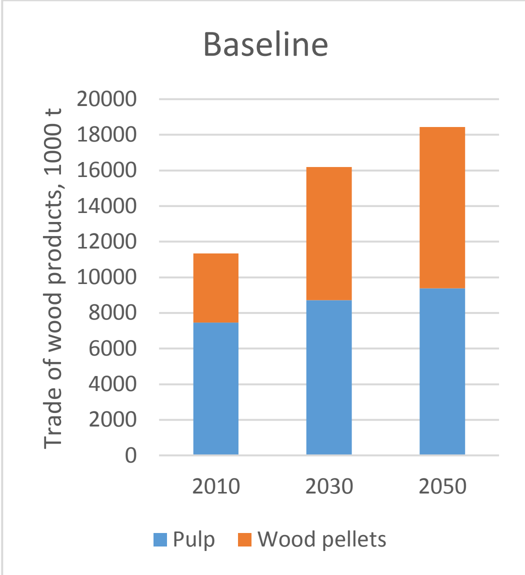
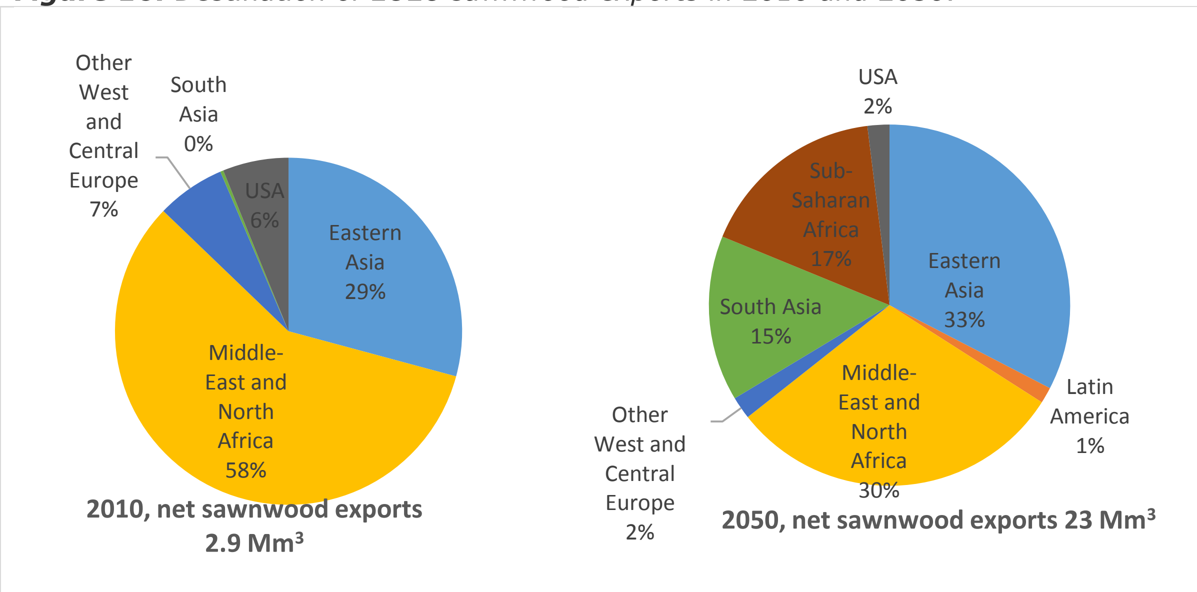


Figure 10. *Destination of EU28 sawnwood exports in 2010 and 2050.*



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

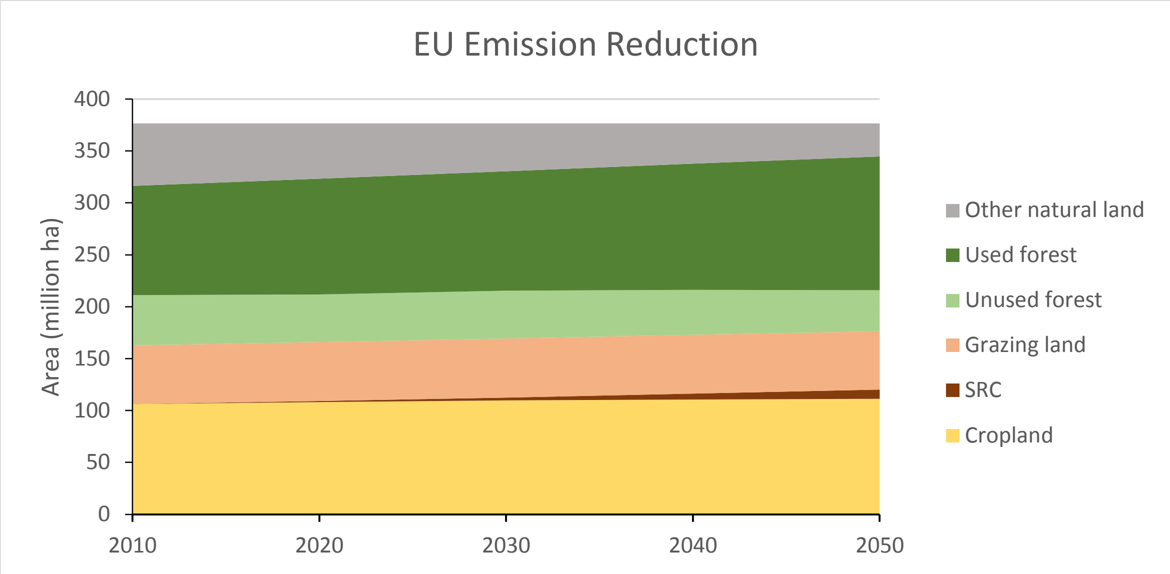
- The same assumptions as for the baseline scenario apply for all aspects as stated earlier for the baseline scenario (GDP projections, global population growth, etc.), except for:
- The bioenergy demand in EU28 evolves throughout the projection period in accordance with levels evaluated as for the GHG40/EE 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.*

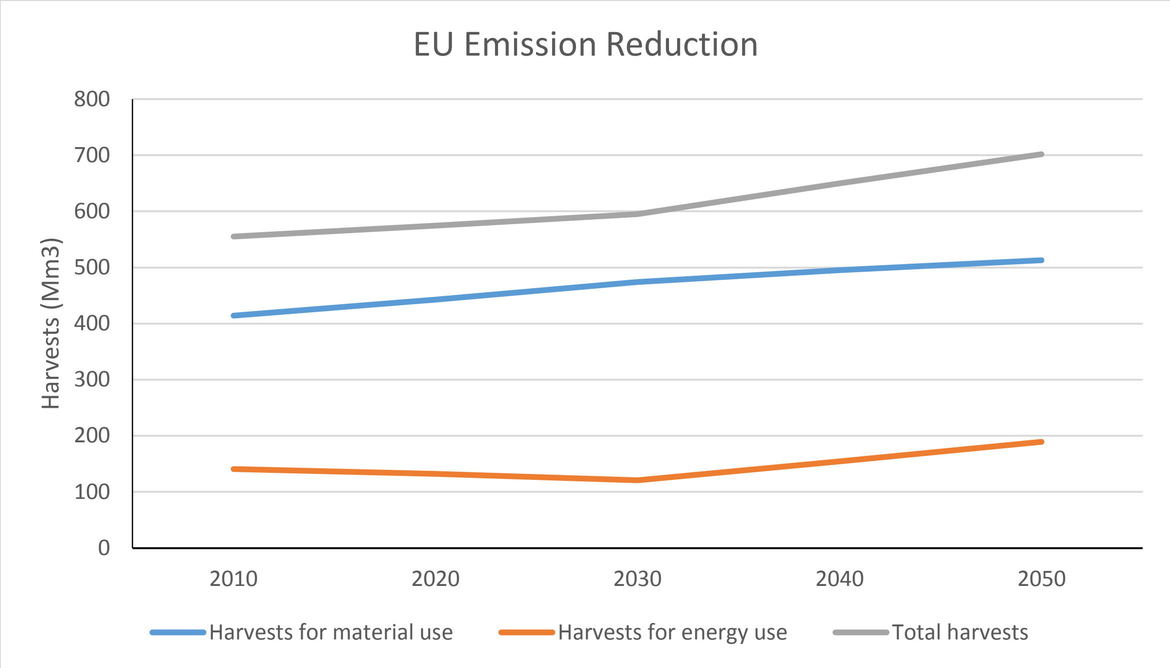


Forest harvests in the EU

The forest harvests in the EU Emission Reduction Scenario are expected to increase significantly over time, emphazising 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.**

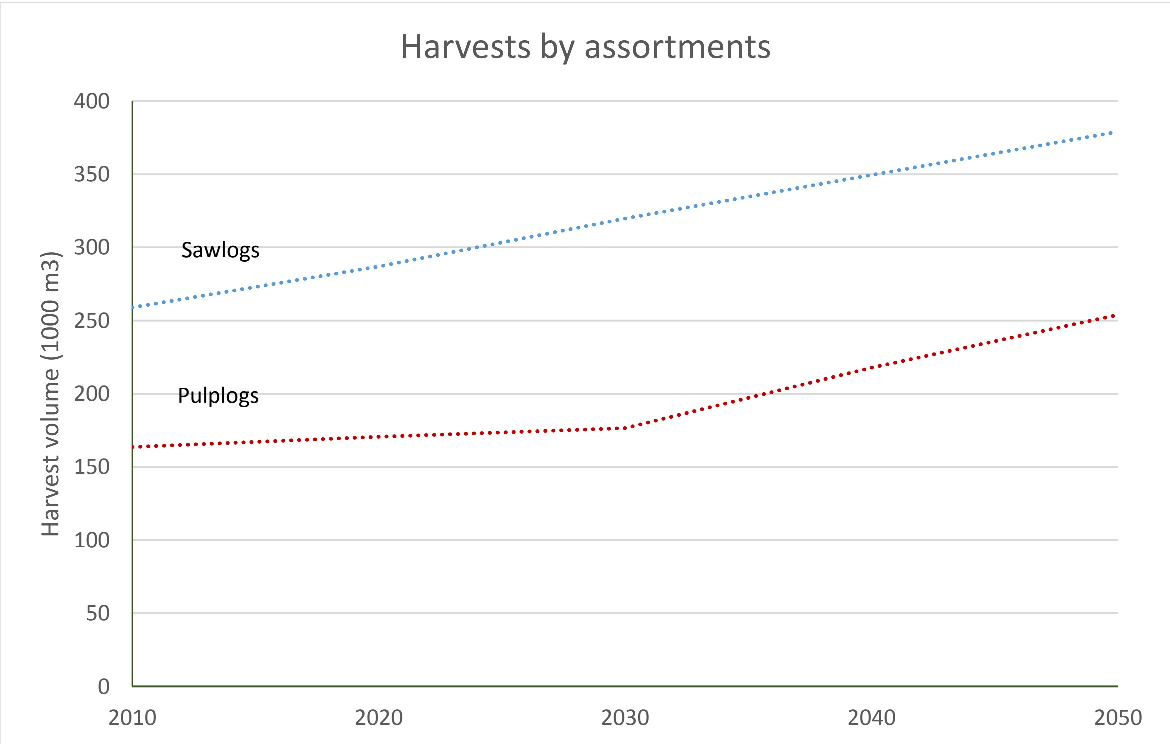
The higher demand for bioenergy after 2030 (compared to the baseline) is reflected clearly also in the development of the relative shares of harvest assortments (Figure 13), where the harvest of pulplogs increases strongly after 2030. Until 2030, the harvests for direct energy use decrease slightly, 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.*

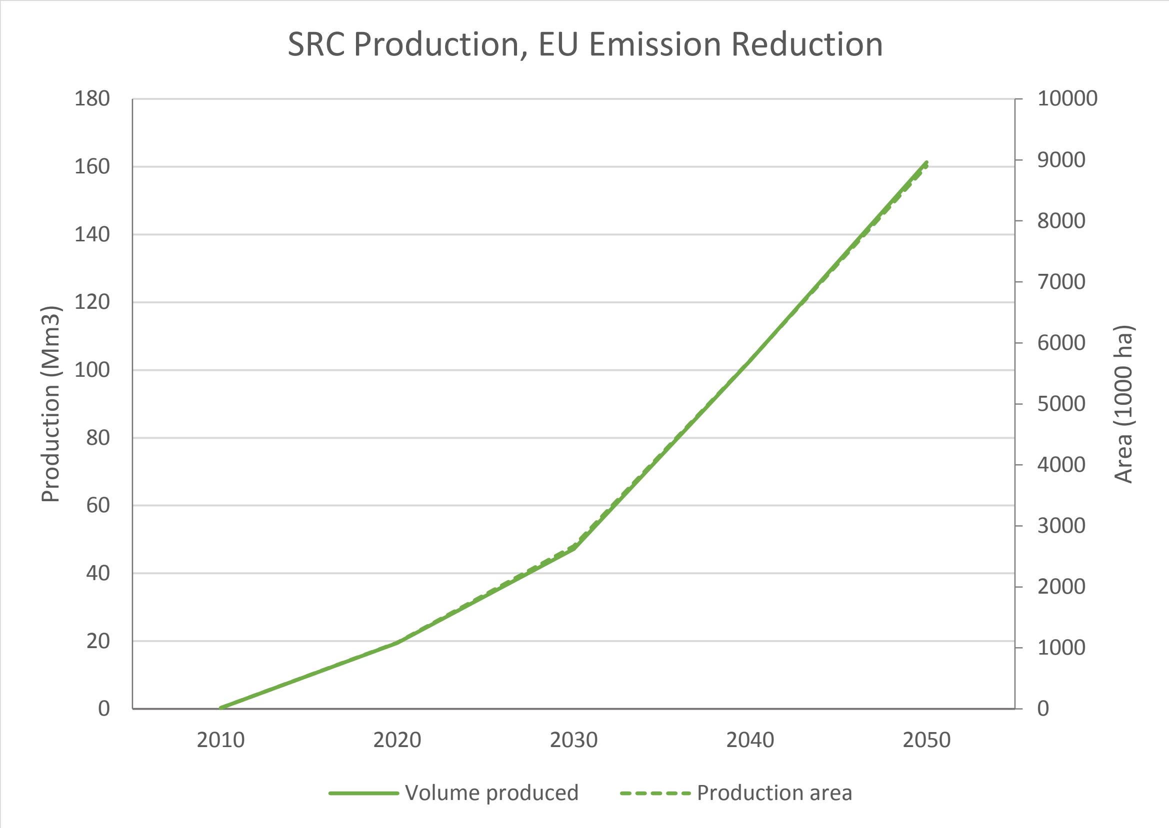
Figure 13. *Development of the harvest of sawlogs and pulplogs for EU28 in the EU Emission Reduction Scenario.*



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.

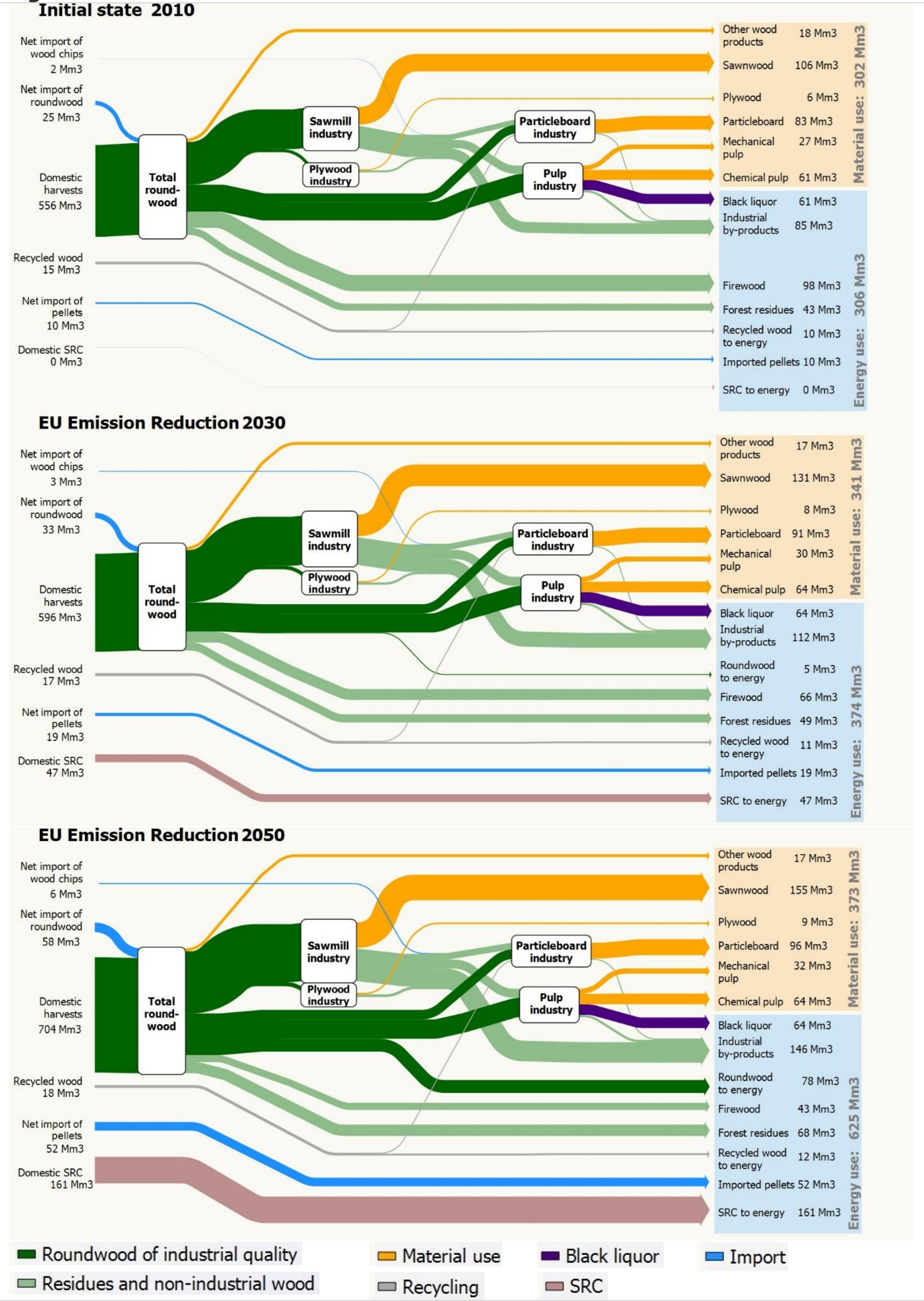
Figure 14. *Production of SRC in the EU 28 in the EU Emission Reduction scenario.*



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:

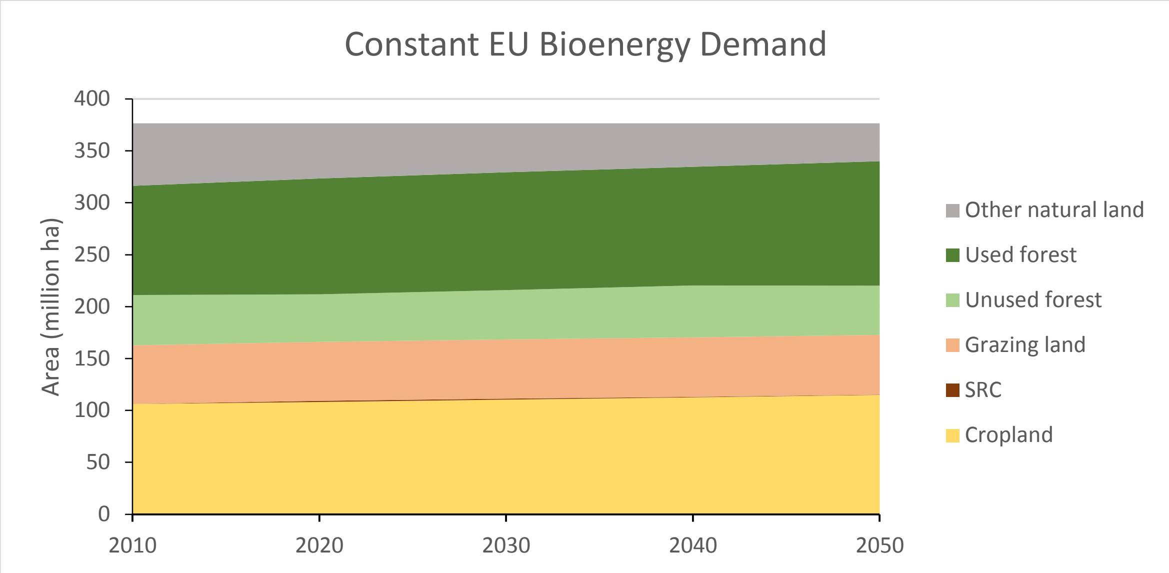
- The demand for bioenergy in EU28 evolves until 2020 in accordance with assumptions for the GHG40/EE scenario in the 2014 IA report. This applies also for the energy savings, where the development follows GHG40/EE scenario until 2020, but no energy efficiency improvements are assumed thereafter.
- From 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.

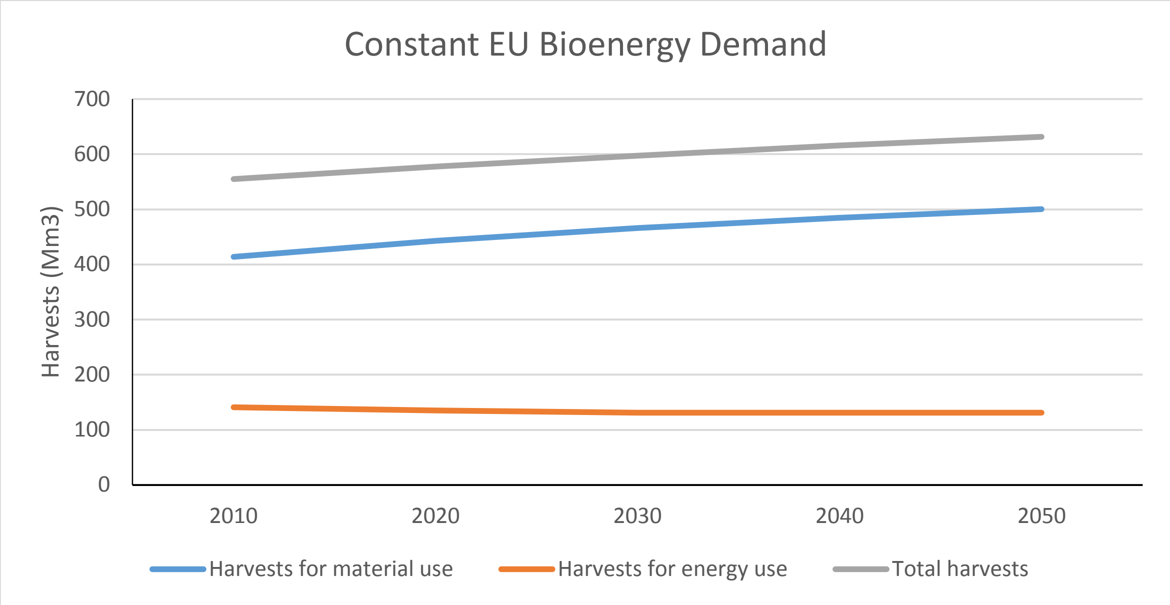
Figure 16. *Land use development in the LULUCF sector in the EU28 in the Constant EU Bioenergy Demand scenario.*



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.*

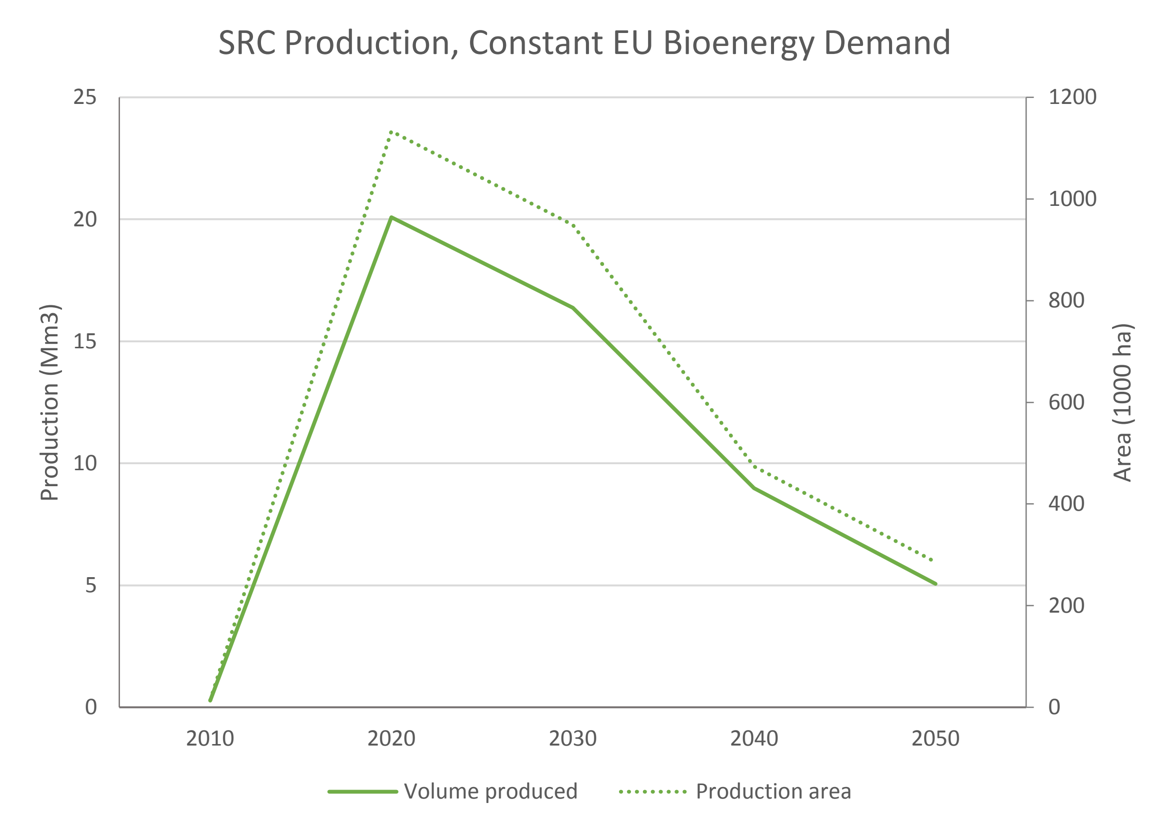


**The category "Harvests for direct energy use" combines harvests of forest residues, firewood, sawlogs and pulplogs that are used for energy as such, or after chipping and/or pelletization. "Harvests for material use" shows the harvested amount of wood that is used for material production in the forest 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.*

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.

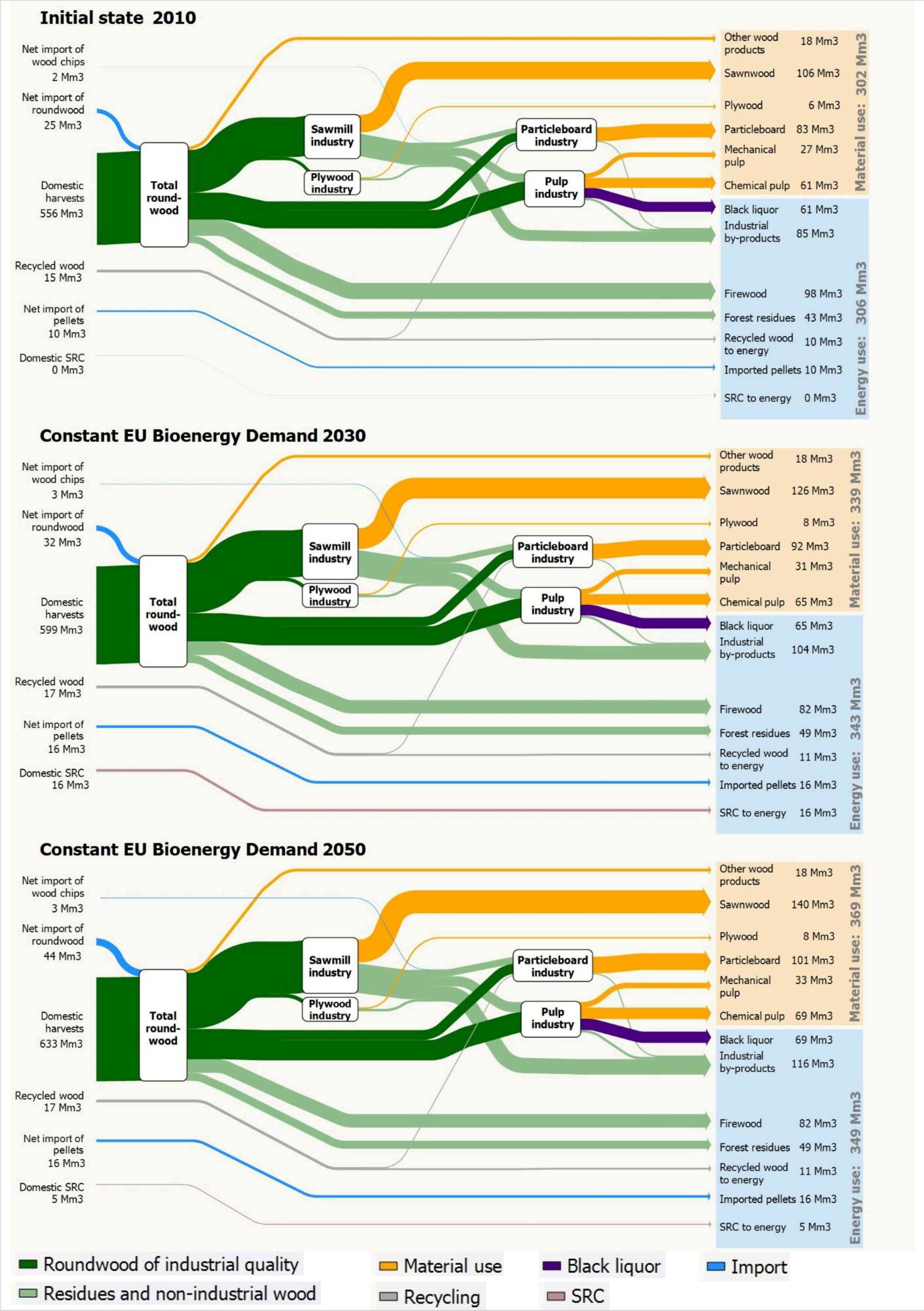
Figure 18. *Production of SRC in the EU28 in the Constant EU Bioenergy Demand scenario. Note that the scale of this figure is not the same to the corresponding figures for the other scenarios.*



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[7] 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 GECO2015[7].

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.

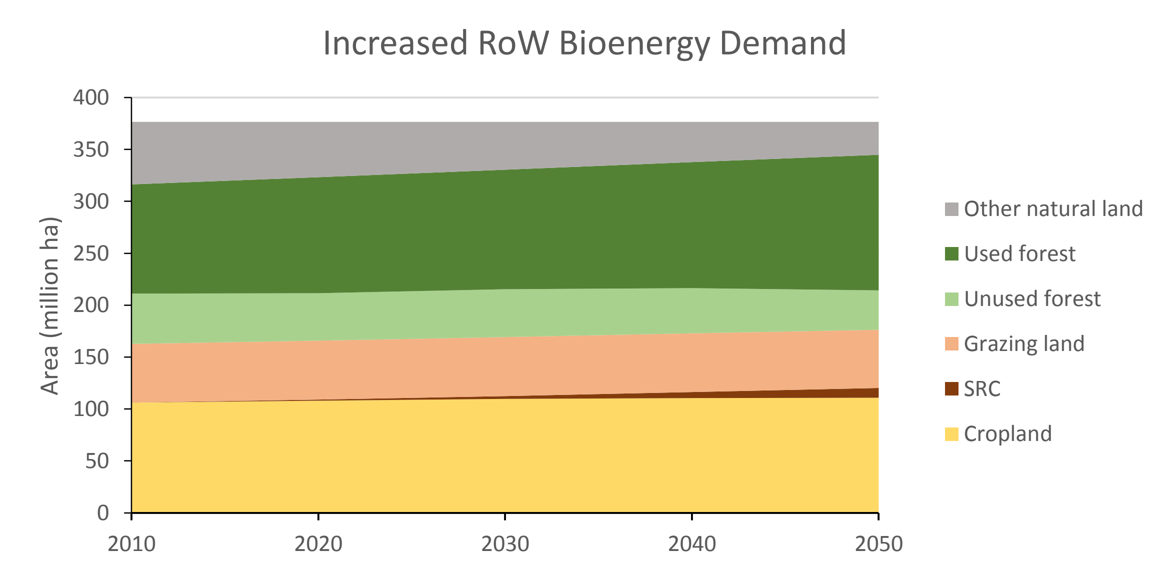
It should also be noted that the use of a "carbon value" as of the Global Mitigation scenario is not reflected within the Increasing RoW Bioenergy Demand scenario. This implies that land use emissions within the Increasing RoW Bioenergy demand scenario are not taxed nor taken up by carbon markets associated 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.**

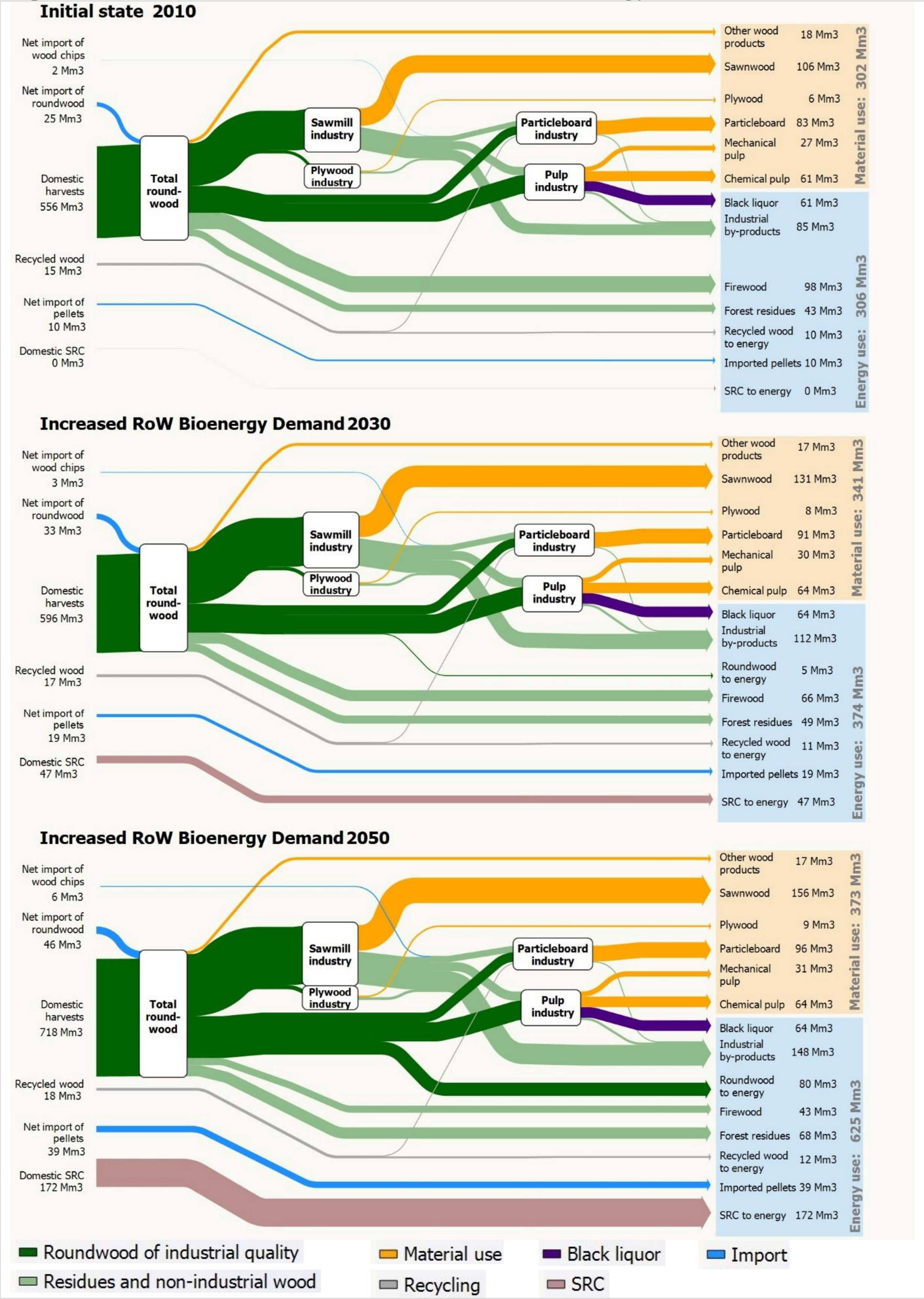
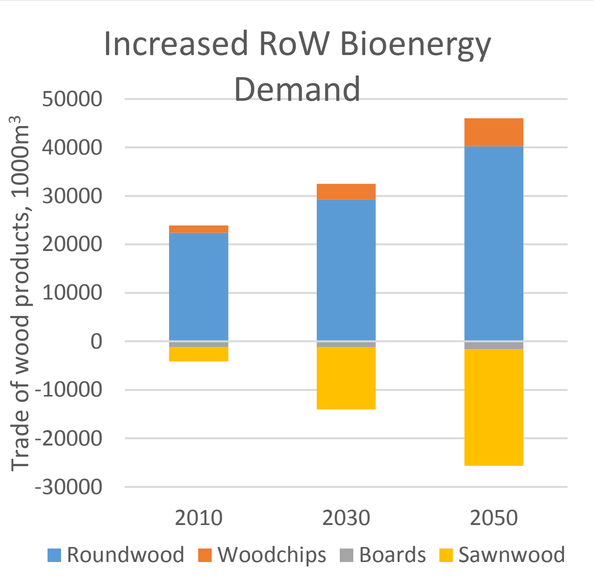
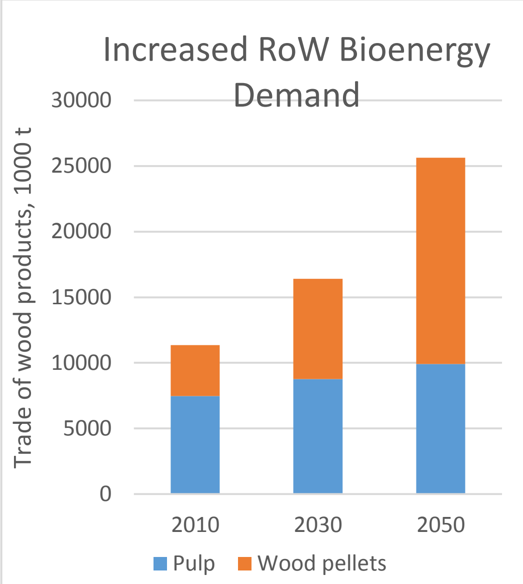


Figure 22. *EU28 net trade of wood products in the "Increased RoW Bioenergy Demand scenario". Positive figures denote EU net imports, negative figures EU net exports.*





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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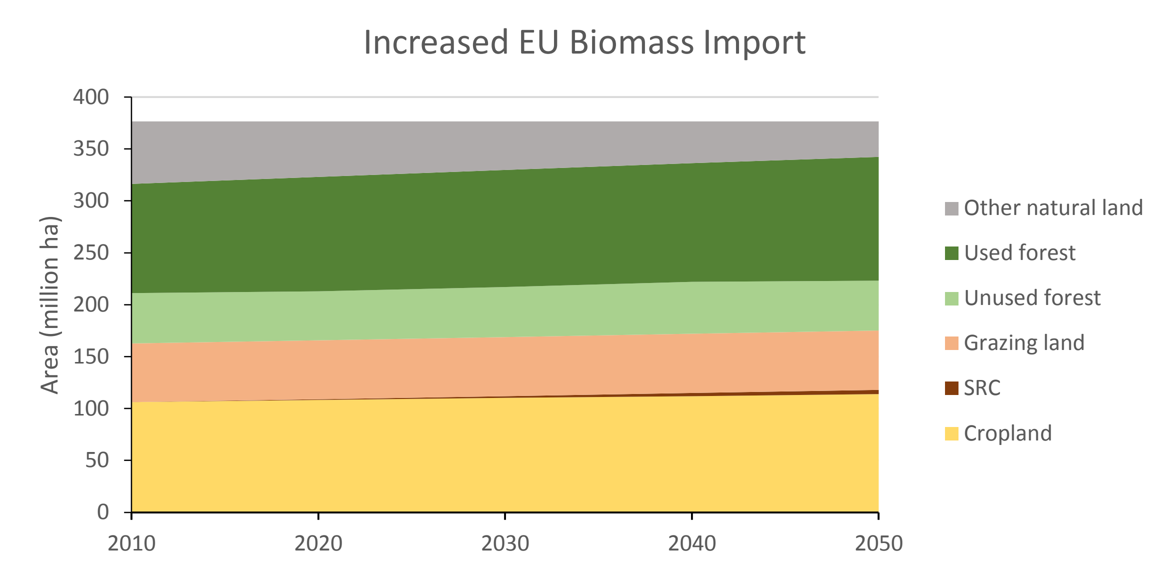
[27] *The change in trade cost is implemented in the model through a change of two parameters in the trade cost function, the reference trade cost and the price elasticity. The reference trade cost value specifies the starting cost of trade for a specific trade quantity, while the price elasticity influences 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.*

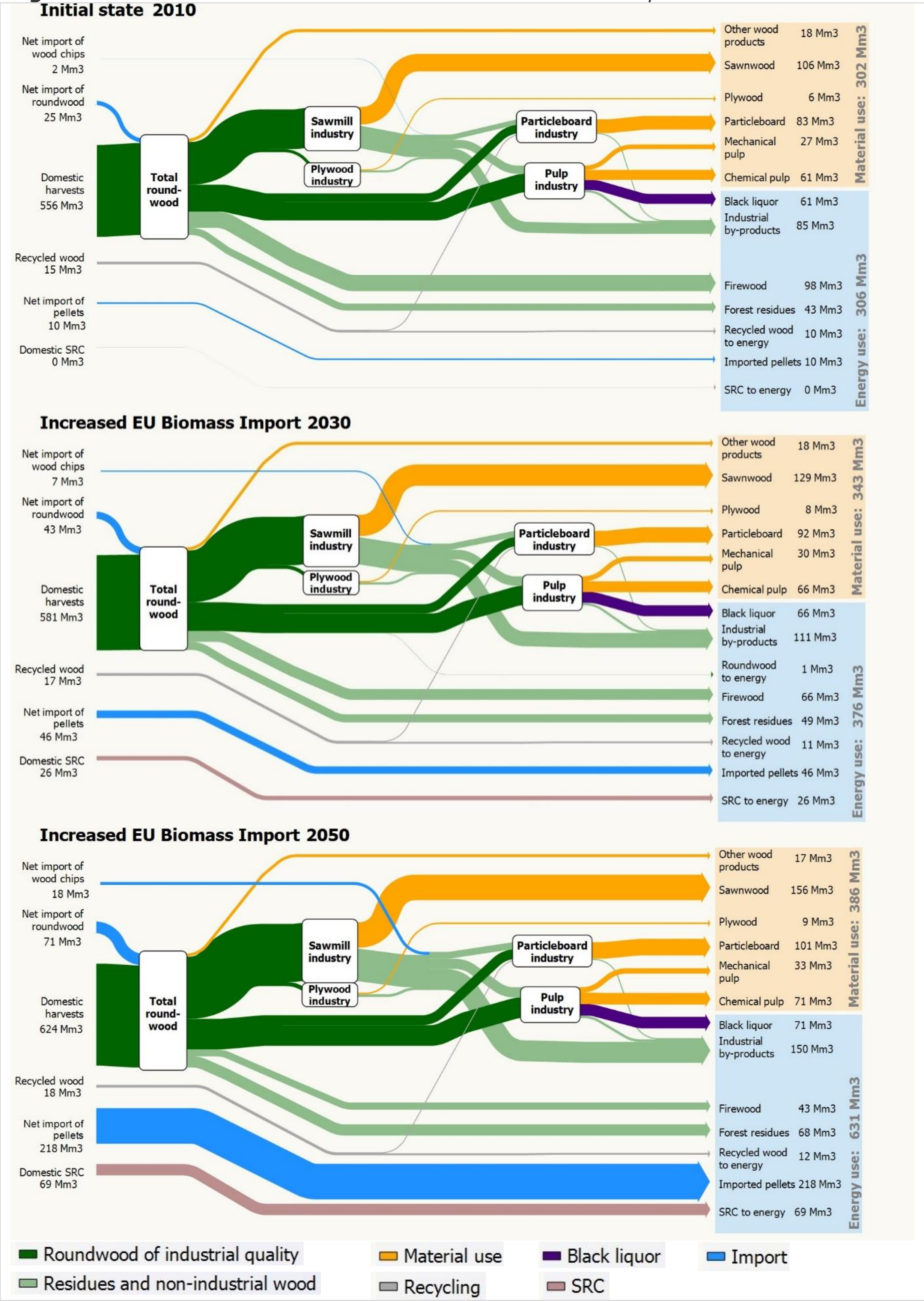
Figure 23. *Land use development in the LULUCF sector in the EU28 in the Increased EU Biomass Import scenario.*



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.

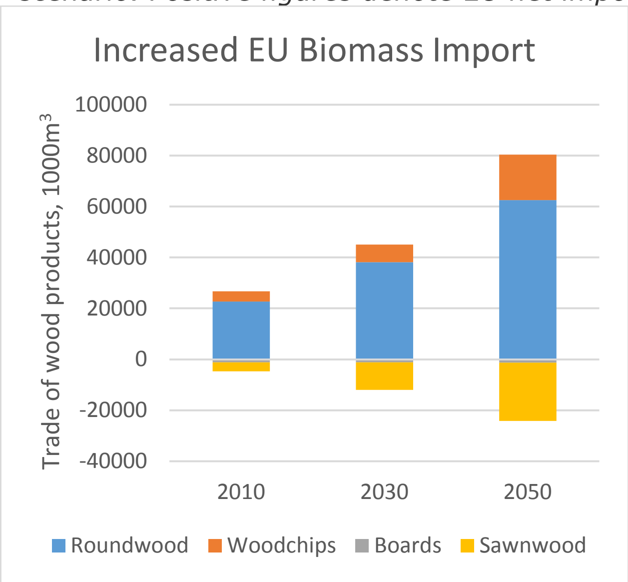
The largest differences to the EU Emission Reduction scenario are seen in the increased amount of imported wood pellets, which leads to a much lower production of SRC for bioenergy purposes than in the EU Emission Reduction scenario, and removes the need of using roundwood directly for energy. That is, **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.*



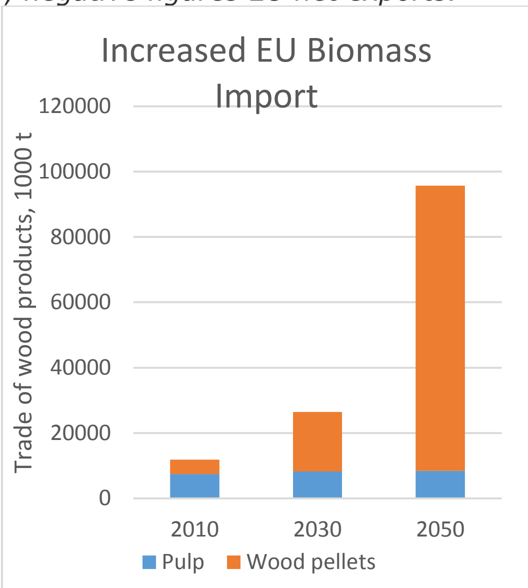
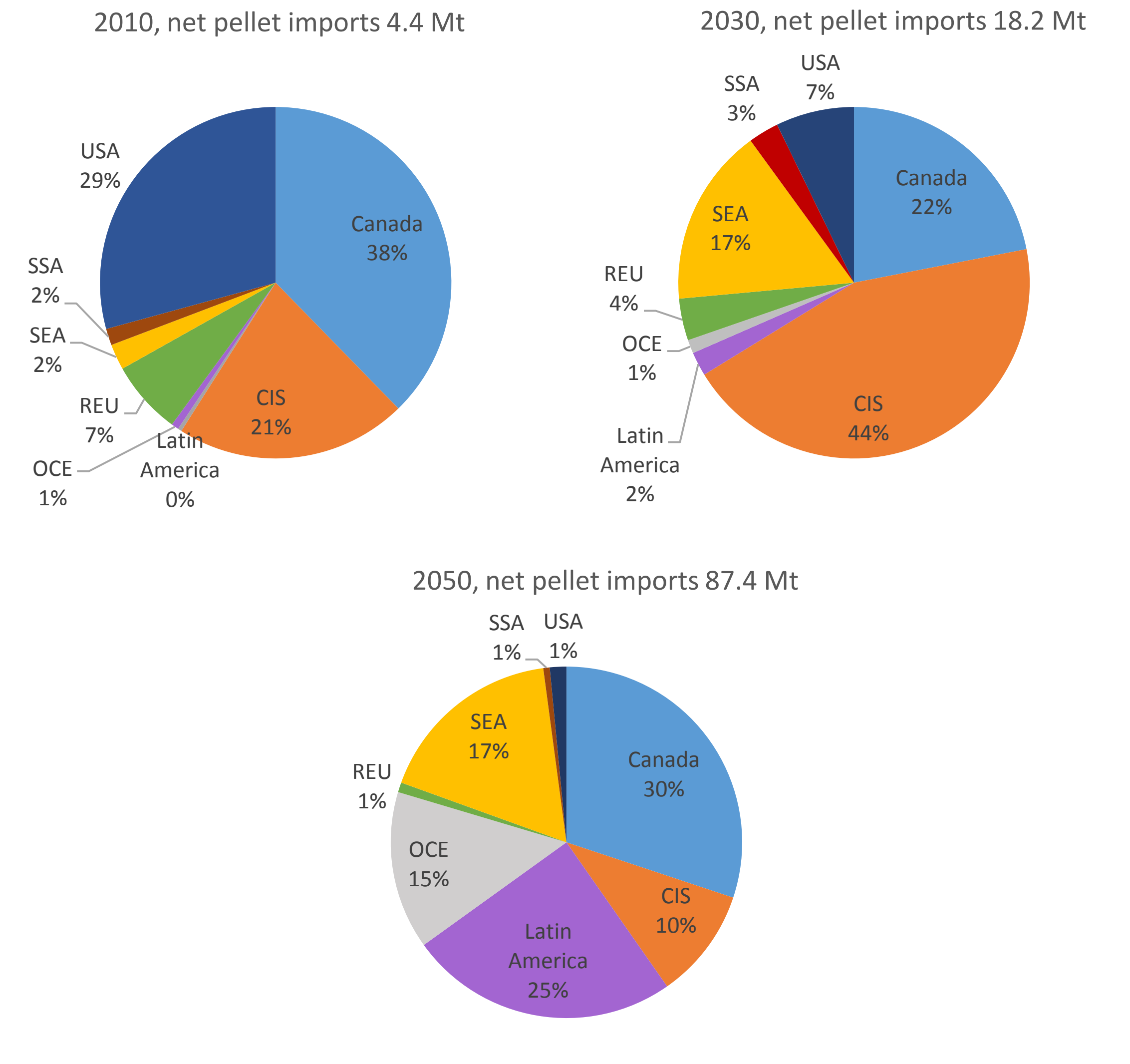
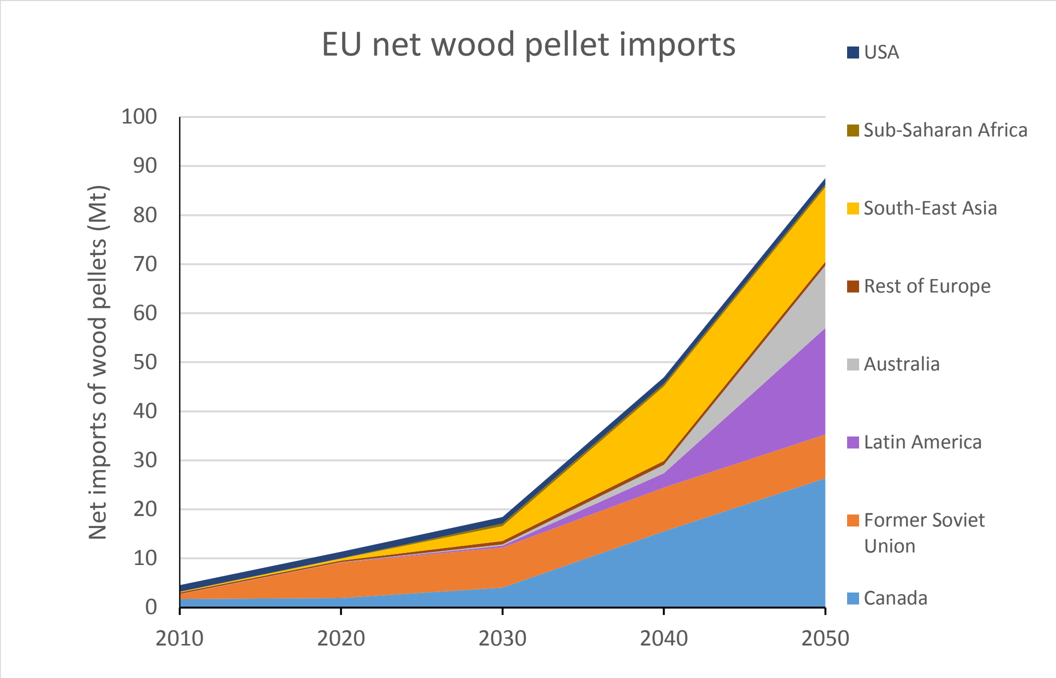


***Figure 26.** Origin of EU28 pellets imports in 2010 and 2050.**



**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.*

			2010	**2030**	**2050**
			Mill. ha		
ReceBio modelling results	**Baseline**	**Total forest area**	**154**	**161**	**167**
		Area of used forest	**105**	**116**	**124**
		Afforestation (since 2000)	**6**	**15**	**22**
	EU Emission Scenario	**Total forest area**	**154**	**161**	**168**
		Area of used forest	**105**	**115**	**129**
		Afforestation (since 2000)	**6**	**15**	**22**
	Constant EU Bioenergy Demand	**Total forest area**	**154**	**161**	**167**
		Area of used forest	**105**	**113**	**120**
		Afforestation (since 2000)	**6**	**15**	**22**
	Increased RoW Bioenergy Demand	**Total forest area**	**154**	**160**	**169**
		Area of used forest	**105**	**115**	**131**
		Afforestation (since 2000)	**6**	**15**	**22**
	Increased EU Biomass Import	**Total forest area**	**154**	**161**	**167**
		Area of used forest	**105**	**113**	**119**
		Afforestation (since 2000)	**6**	**15**	**22**

Figure 28. *Area of used forests in the EU28 in the different scenarios.*

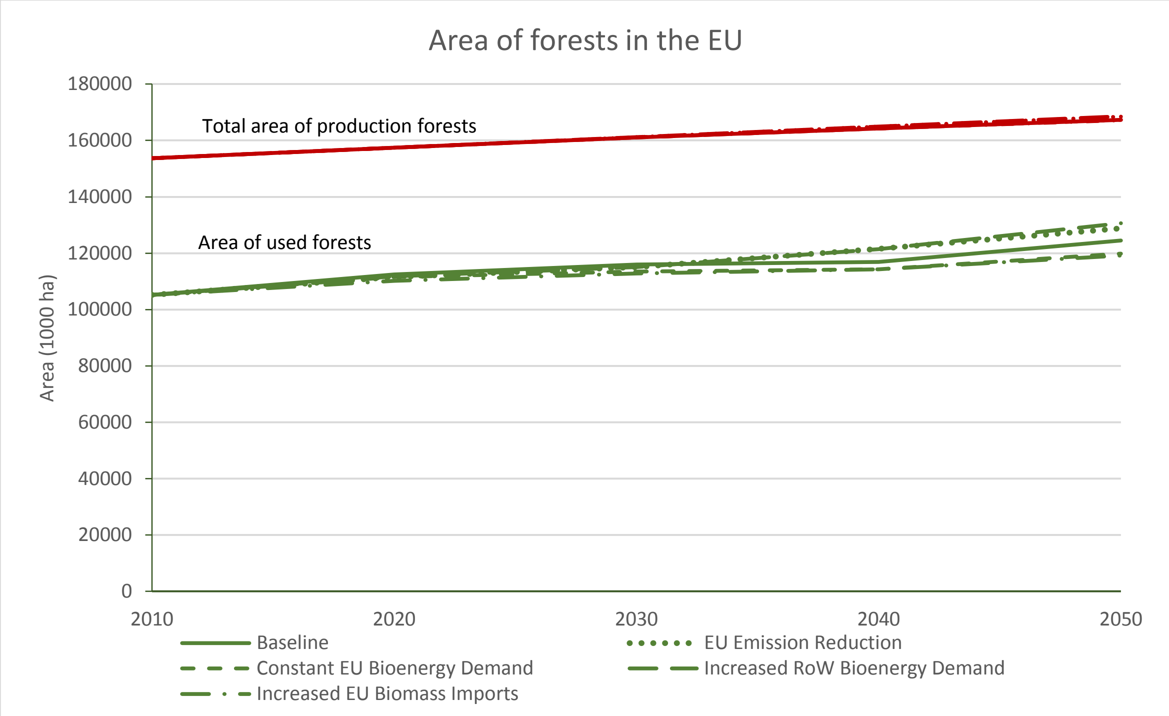
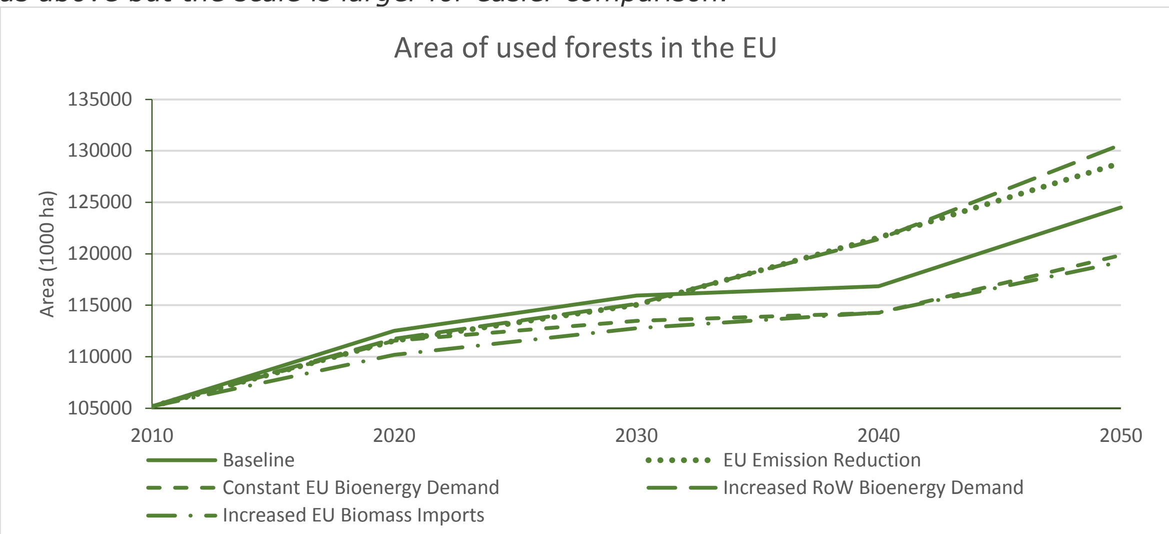


Figure 29. *The area of used forests in the different scenarios. Here, the data is same as above but the scale is larger for easier comparison.*



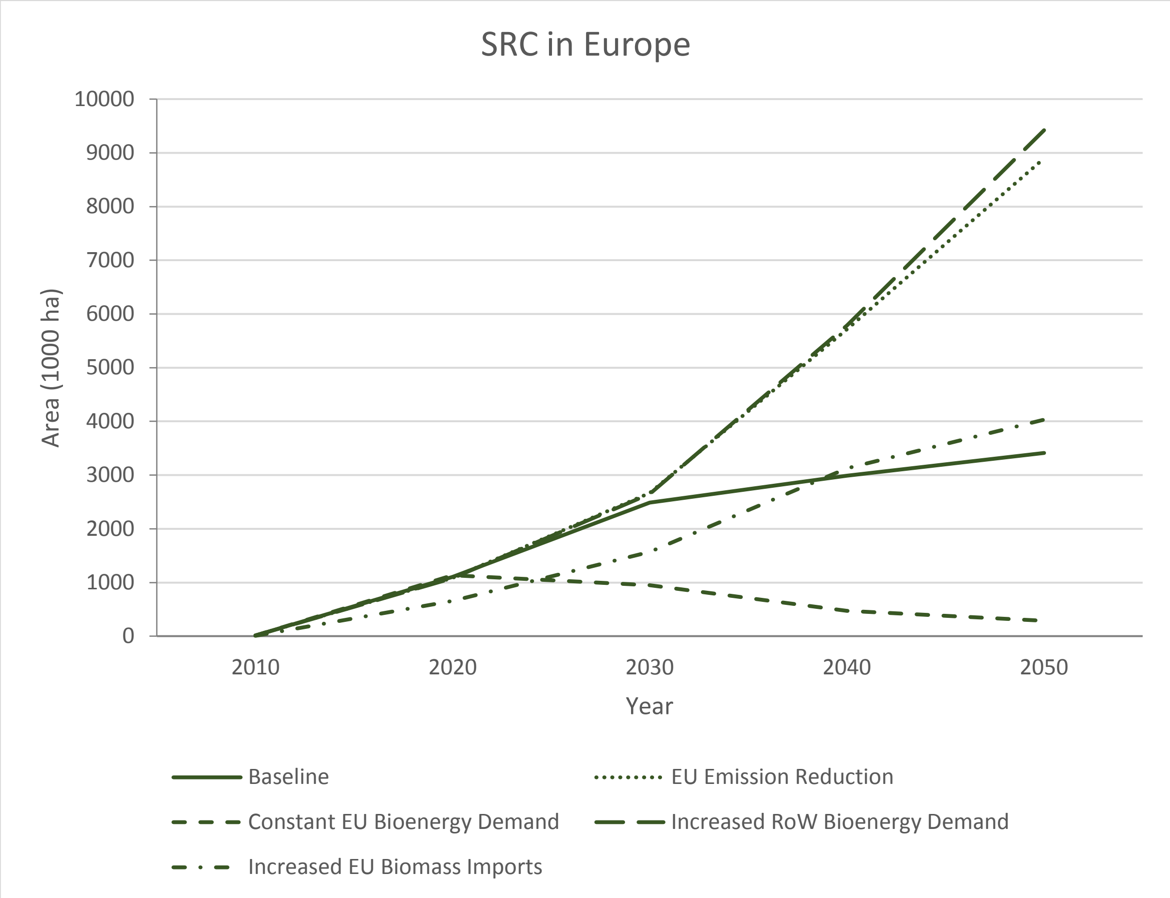
A notable difference in land use between the scenarios developed within this project are seen in the areas of short rotation plantations (SRC and lignocellulosic perennials grown on cropland) (Table 5 and Figure 30). Among short rotation plantations, this study focuses on the analysis of SRC as it is 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).*

			2010	**2020**	**2030**	**2050**
			Mill. ha			
ReceBio modelling results	**Baseline**	**SRC***	**0.01**	**1.1**	**2.5**	**3.4**
		Perennial lignocellulosic crops**	**0.02**	**2.0**	**2.8**	**3.1**
	EU Emission Scenario	**SRC**	**0.01**	**1.1**	**2.7**	**8.9**
		Perennial lignocellulosic crops	**0.02**	**1.7**	**2.3**	**6.1**
	Constant EU Bioenergy Demand	**SRC**	**0.01**	**1.1**	**0.9**	**0.3**
		Perennial lignocellulosic crops	**0.02**	**2.0**	**2.0**	**2.0**
	Increased RoW Bioenergy Demand	**SRC**	**0.01**	**1.1**	**2.7**	**9.4**
		Perennial lignocellulosic crops	**0.02**	**1.7**	**2.3**	**6.1**
	Increased EU Biomass import	**SRC**	**0.01**	**0.7**	**1.6**	**4.0**
		Perennial lignocellulosic crops	**0.02**	**1.7**	**2.3**	**6.2**

**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.*

Figure 30. *Area of cropland dedicated to production of short rotation coppice (SRC) in EU28 in the different scenarios.*

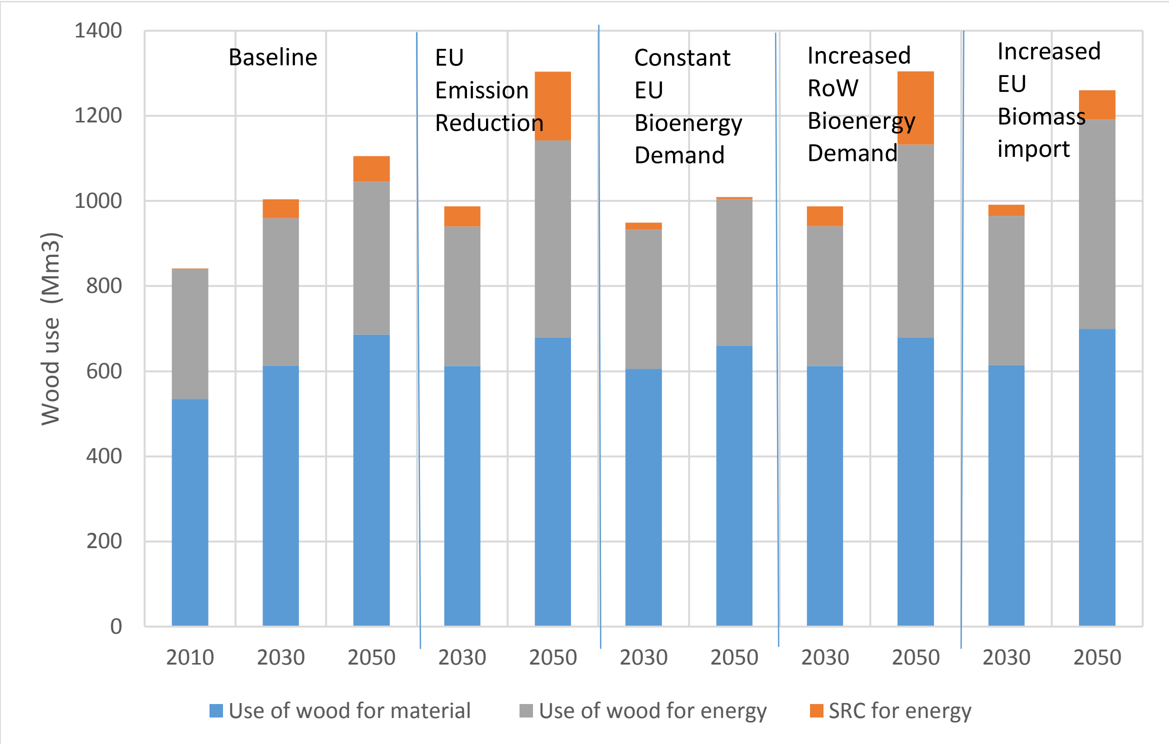


When comparing the cropping area of SRC and perennials in 2010 shown in Table 5, some deviations can be noted between the baseline scenario and the data collected within the Task 1 of this study, which reported 0.5 million hectares of willow and poplar as of 2011. This is due to the fact that the model 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.*



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.

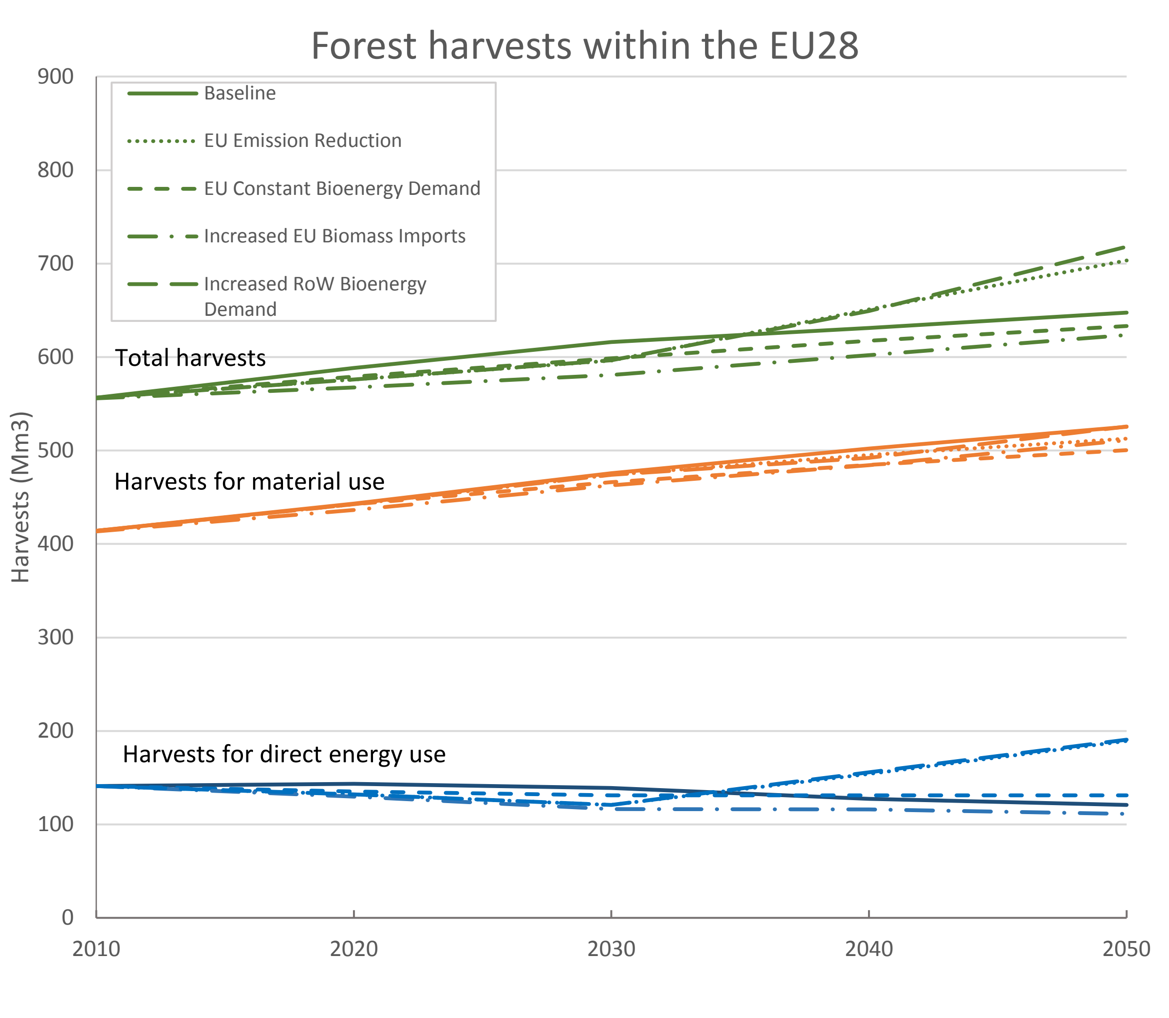
Table 6. *The share of wood used for material and energy production in the different scenarios.*

Scenario		2010	2030	2050
Baseline	Energy use	*36%*	*39%*	*38%*
	Material use	*64%*	*61%*	*62%*
EU Emission Reduction	Energy use	*36%*	*38%*	*48%*
	Material use	*64%*	*62%*	*52%*
Constant EU Bioenergy Demand	Energy use	*36%*	*36%*	*35%*
	Material use	*64%*	*64%*	*65%*
Increased RoW Bioenergy Demand	Energy use	*36%*	*38%*	*48%*
	Material use	*64%*	*62%*	*52%*
Increased EU Biomass Imports	Energy use	*36%*	*38%*	*45%*
	Material use	*64%*	*62%*	*55%*

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.

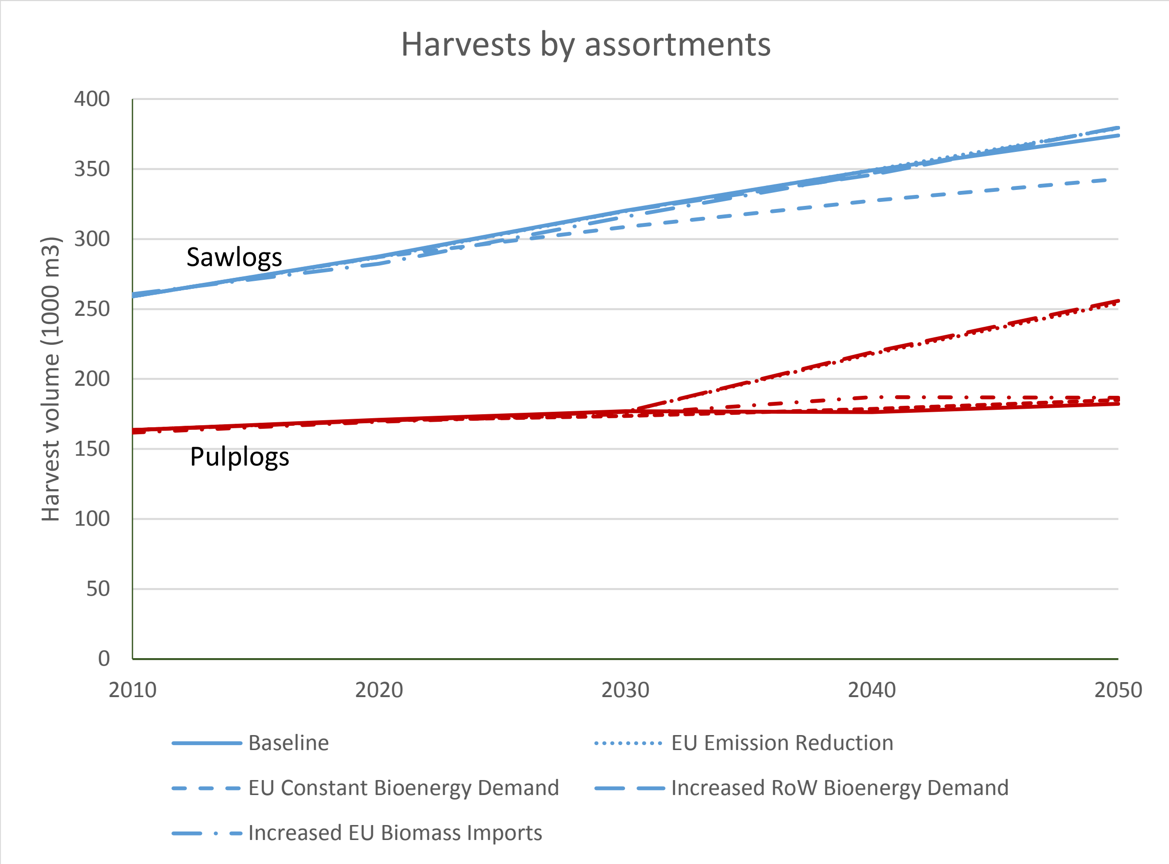
Figure 32. *Total forest harvest* in solid wood equivalent, measured over bark (SWE o.b.) in the EU28 in the different scenarios.*



**The category "Harvests for direct energy use" combines harvests of forest residues, firewood, sawlogs and 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 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 pulplogs, and the development of sawlog harvests follows the trends seen in the harvests for material. The harvest of pulplogs 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.*



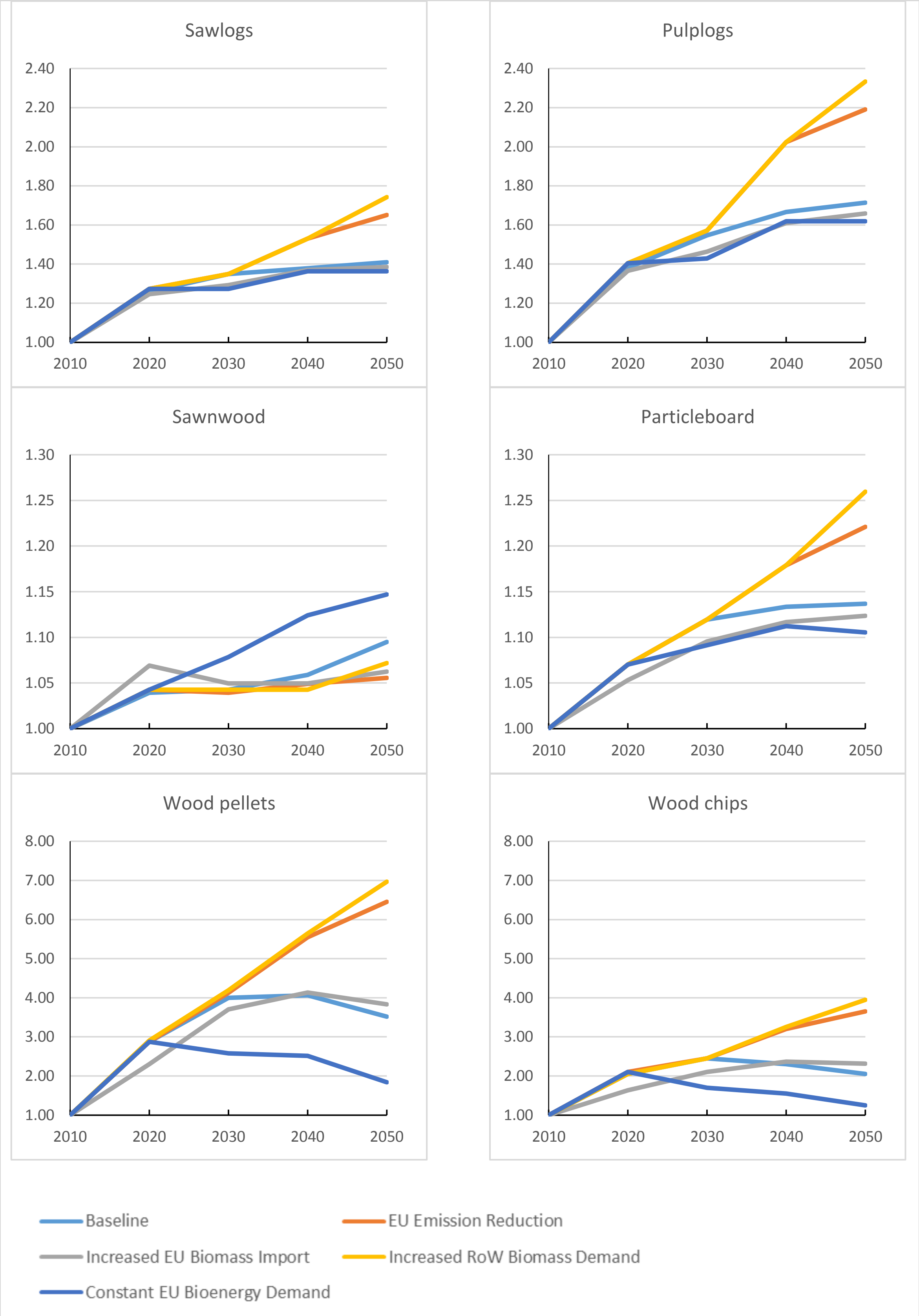
Price of wood and wood products in the EU

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.*



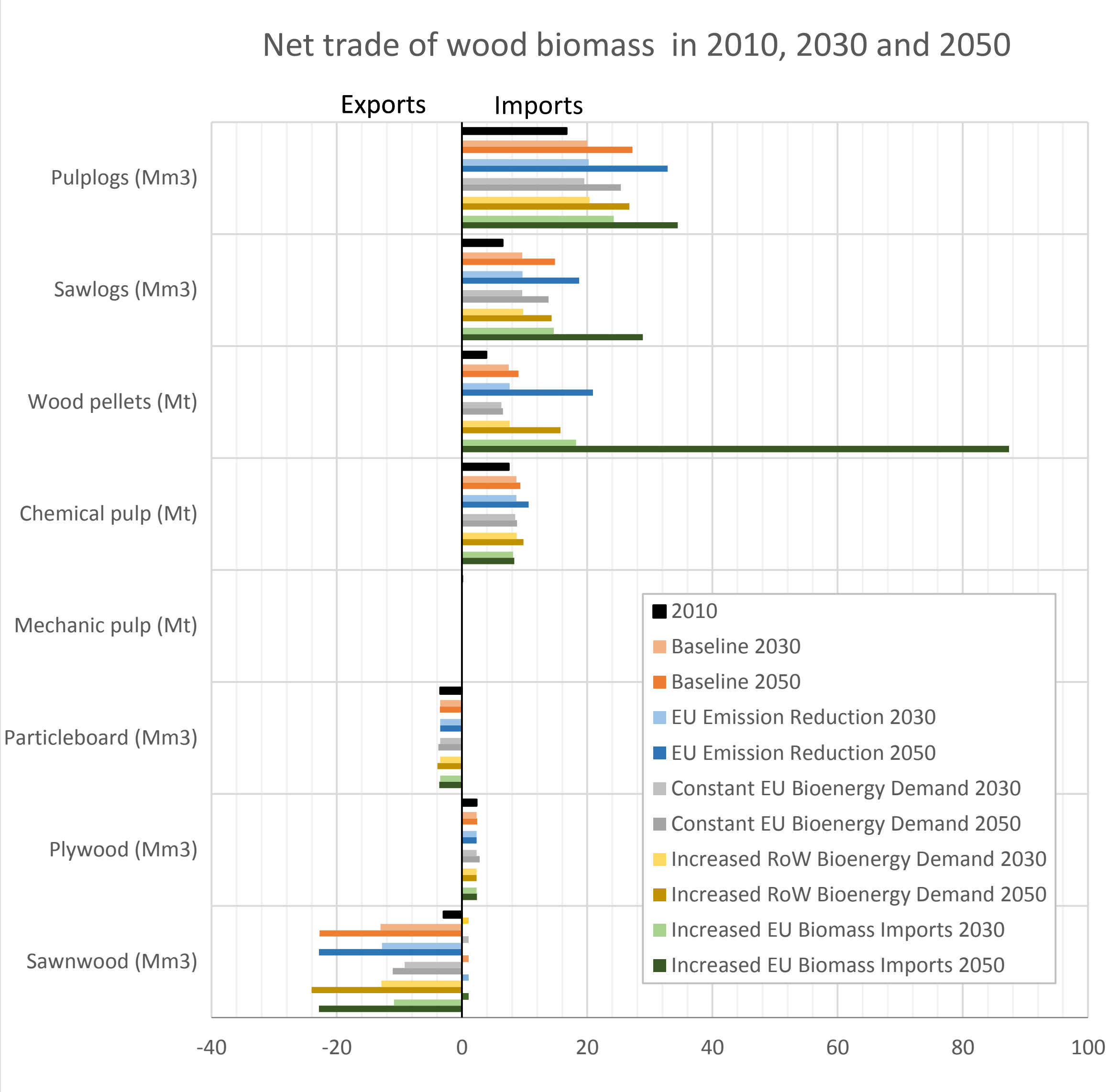
Trade of wood biomass

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.

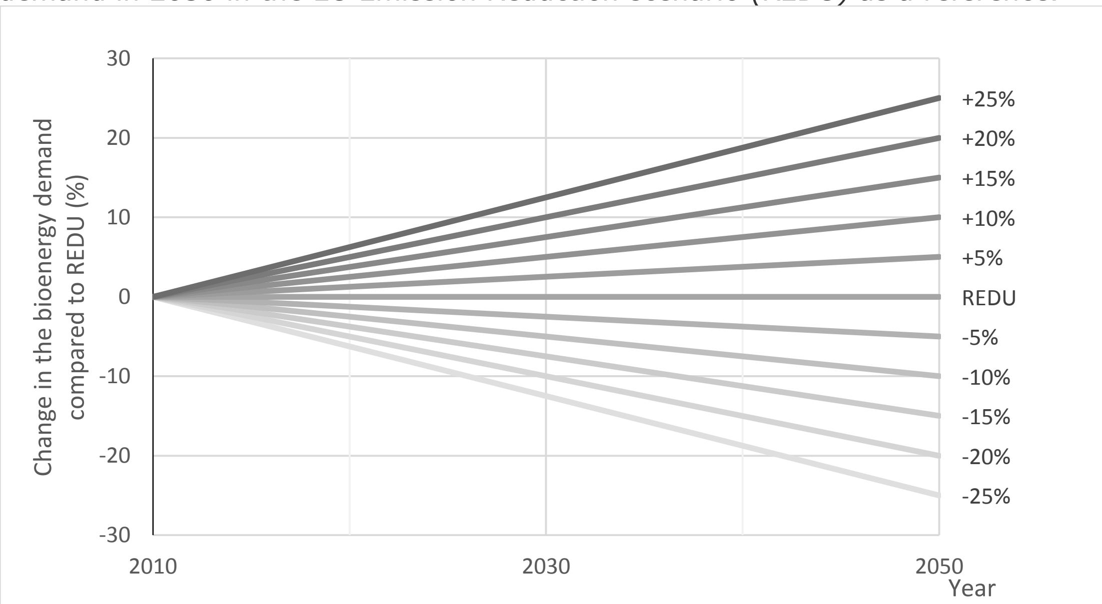
The results are compared to the scenario results of the EU Emission Reduction scenario, abbreviated as REDU throughout this chapter. This policy scenario depicts increased demand for bioenergy and was chosen for this analysis as it also serves as the basis for the other policy scenarios.

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.

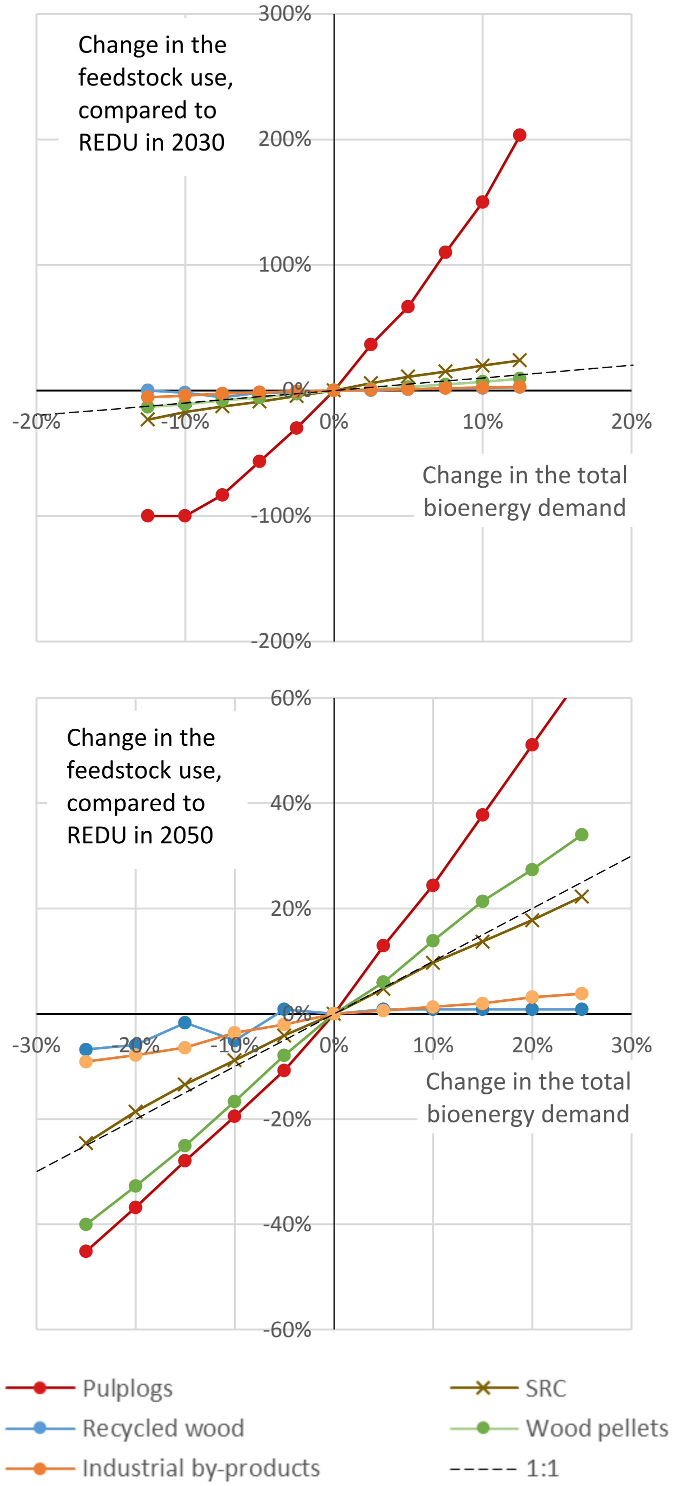
Figure 36. *The projected change in the EU bioenergy demand, using EU28 bioenergy demand in 2050 in the EU Emission Reduction scenario (REDU) as a reference.*



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.

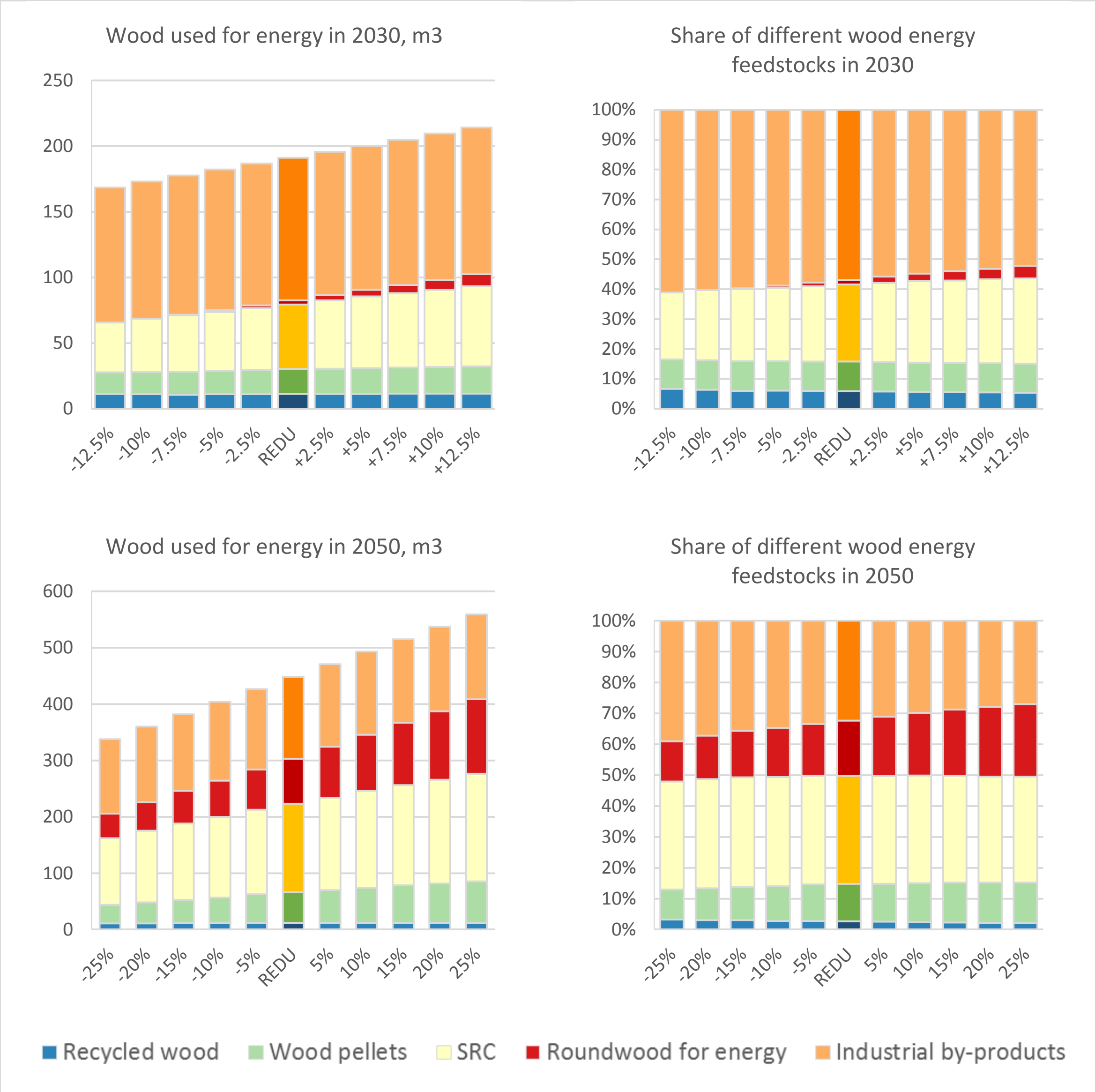
By 2050, there is more time for the markets to adapt, leading to especially a relative increase in the use of imported wood pellets compared to 2030. This releases the pressure to use roundwood directly for energy, and although they still increase and decrease relatively more than the total bioenergy 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.*

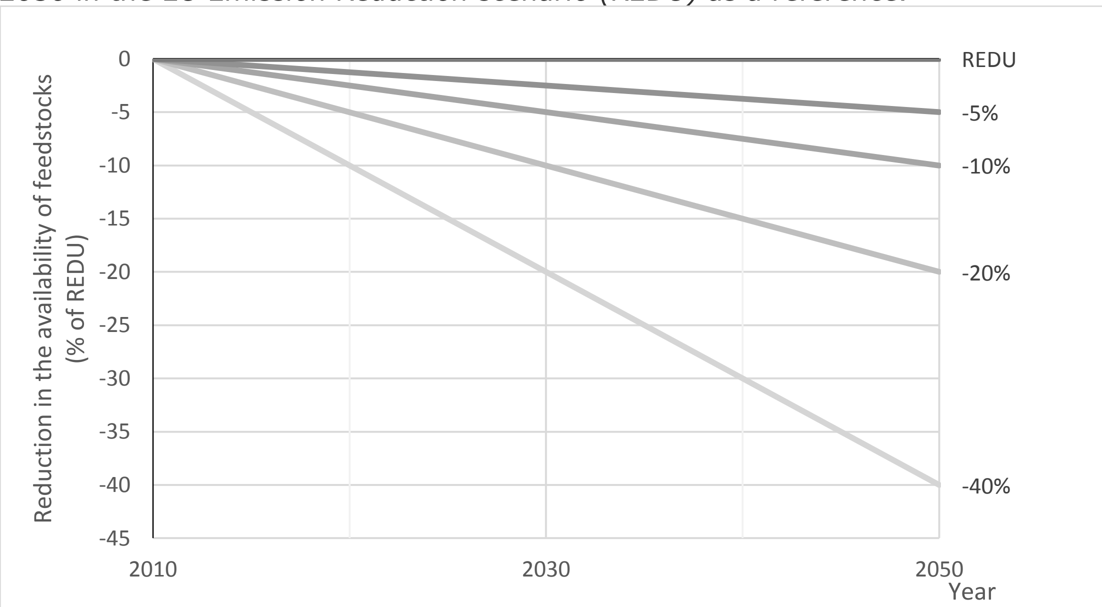


8.2. Availability of biomass feedstocks for energy

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.*

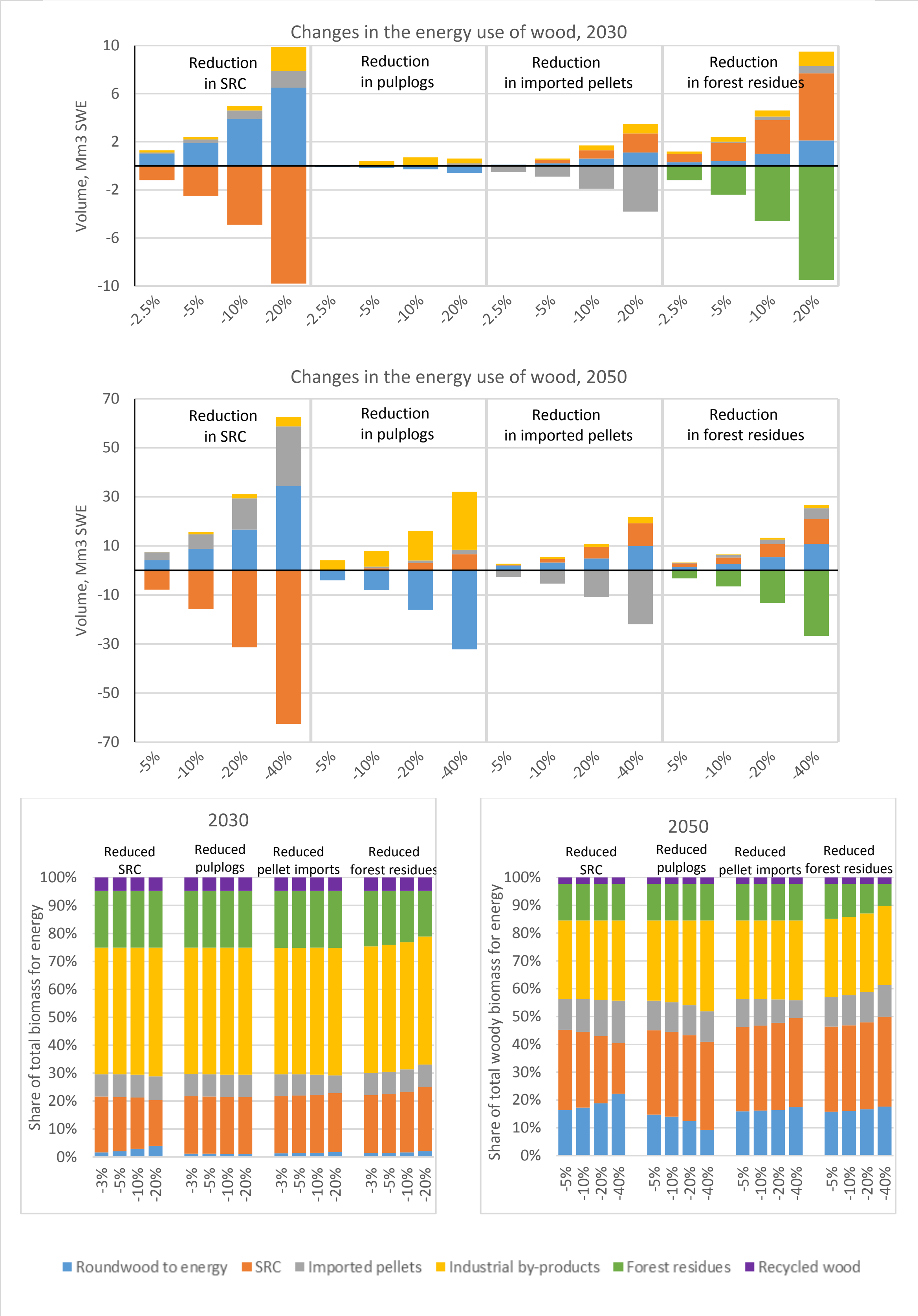


It was seen that in the short run (between 2010 and 2030), a reduction of one of the feedstocks generally increases the uses of roundwood and SRC for energy. However, in the long run (by 2050), increasing use of industrial by-products and imported wood pellets becomes more prominent. In other words, 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 imports decrease, 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[28]. 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)[29] 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[30] 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,

[28] *See Task 2 Report for a more thorough description of cascading use.*

[29] *"A simple "cascade factor" is the ratio between the total wood raw material supply, expressed as "roundwood equivalent" (RWE), and the fraction of it which is "roundwood" (from the forest and other wooded land, parks, etc.). It indicates the extent to which that roundwood has its use multiplied throughout the various value chains. A total cascade factor is the ratio of the total wood raw material supply (RWE) to all fresh wood (roundwood + forest residues) has its use multiplied throughout the various value chains."* Indufor (2013).

[30] RWE (overbark) refers to roundwood equivalent which is a measure used by Indufor to make all wood-based raw materials comparable. Indufor (2013).

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.*

Study	Indufor		ReceBio EU Emission Reduction scenario		
Reference year	2011	2016	2010	2030	2050
	RWE*		Million m^3		
Bioenergy consumption**	293	360	297	306	413
Material consumption	648	679	529	607	671
Roundwood consumption***	454	495	539	578	694
Cascade factor	2.07	2.10	1.53	1.58	1.56

** 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.

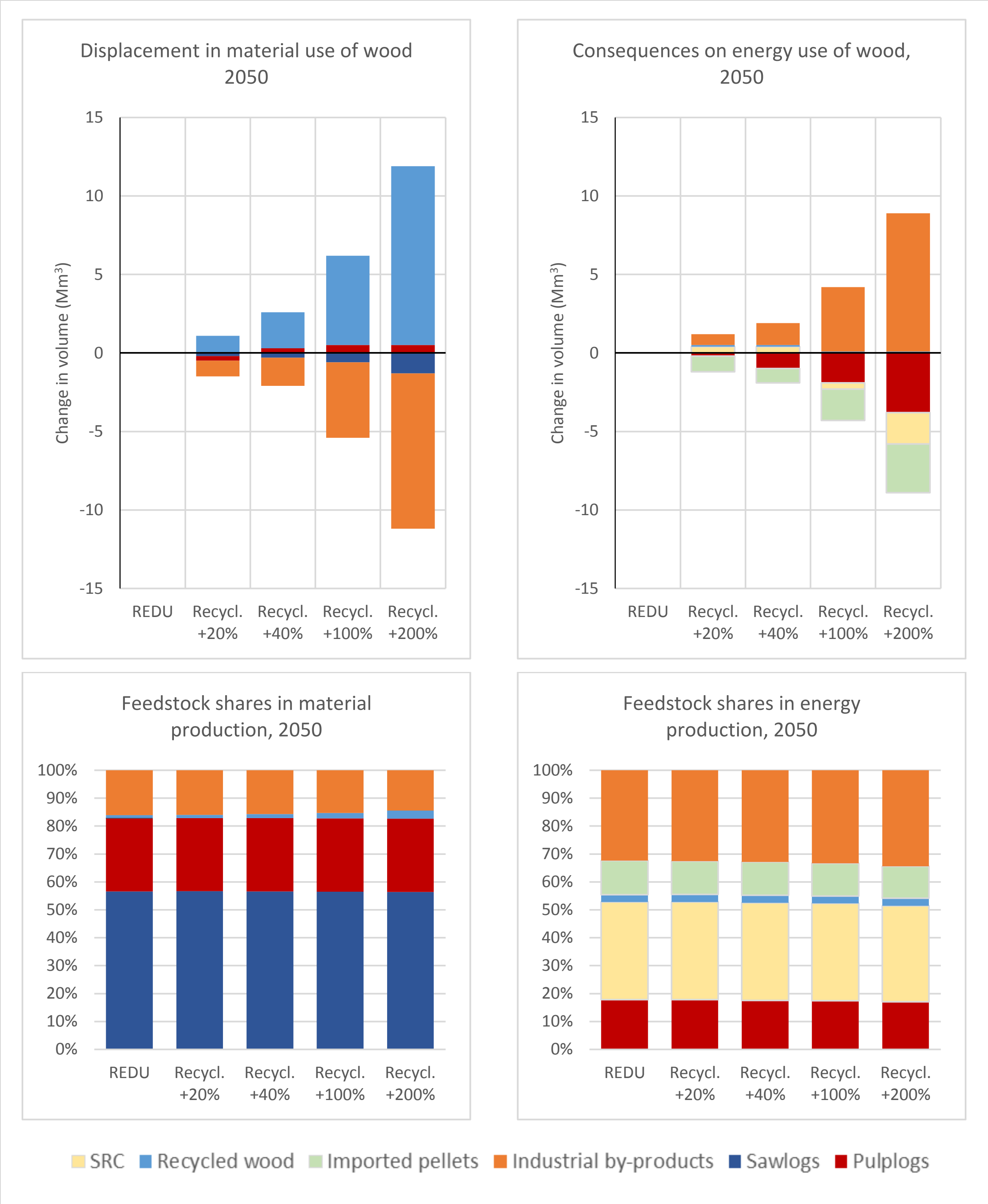
Most of the industrial residues replaced by recovered wood in material production will be instead used for energy production. This, in turn leads into a decrease in the energy use of virgin raw materials: in 2030, the main reduction is in imported wood pellets and roundwood to energy when recovered wood 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 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.*

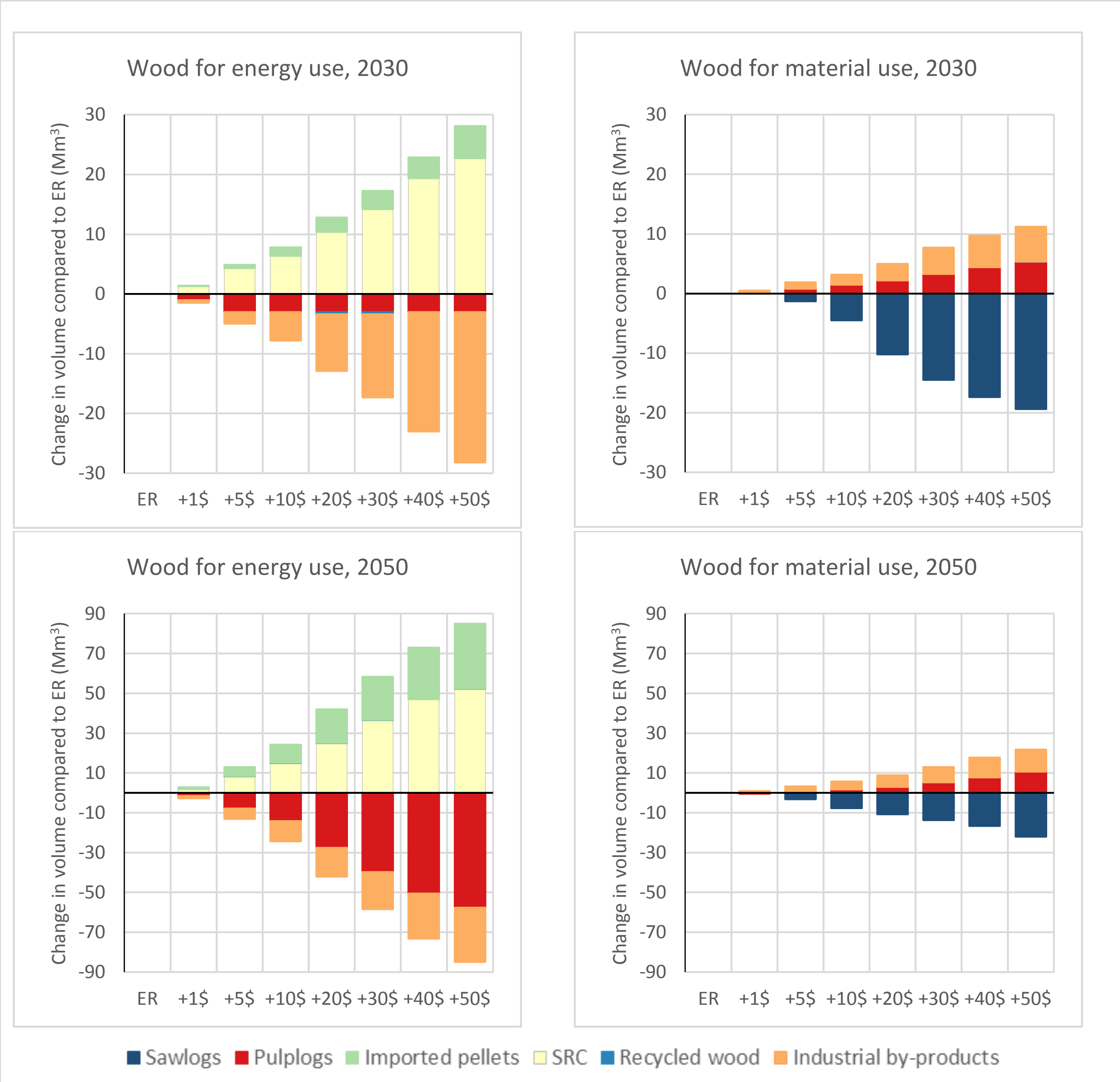
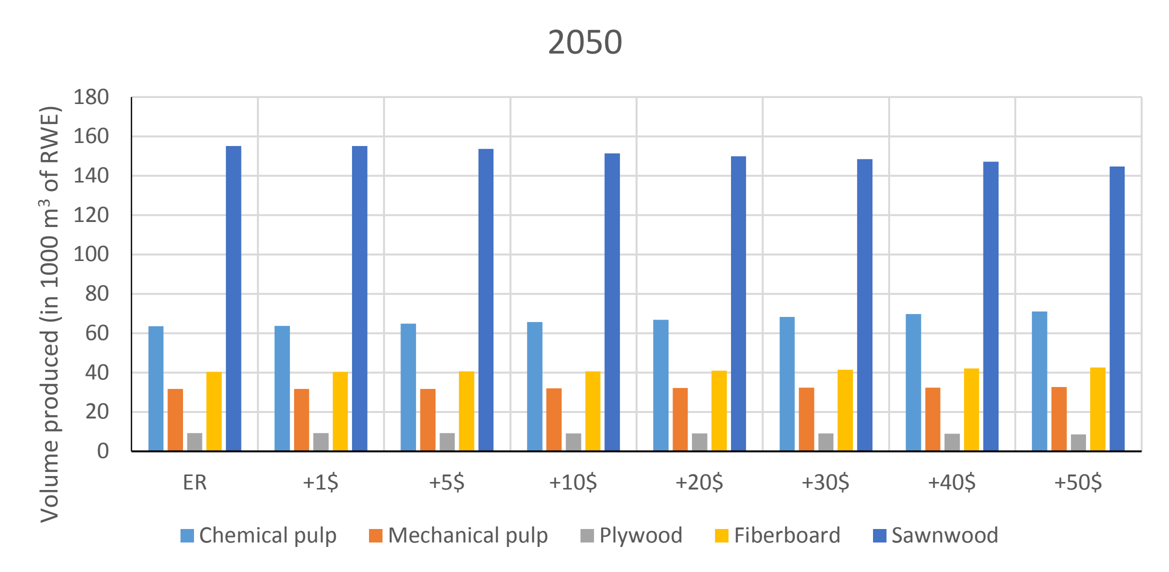


***Figure 44.** Amount of various material products produced under different tax levels for direct energy use of wood in 2050.*



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.

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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 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*

GLOBIOM feedstocks	POLES
• Wood from forest activites (stem wood and forest residues) • Short rotation tree plantations • Woody industrial by-products (sawdust, sawchips, bark, and black liquor)	• BIOINEL
• Wood from forest activities (stem wood and forest residues)	• BIOINBIOD
• Ethanol made from sugarcane, corn and wheat • Biodiesel made from rapeseed, palm oil and soybeans	• BFP1
• Wood from forest activities (stemwood and forest residues) • Short rotation tree plantations • Woody industrial by-products (sawdust, sawchips, bark, and black liquor)	• BFP2

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*

	2005	2030	
		Ref	GHG40/ EE
Domestic production biomass feedstock (Mtoe)	87	194	191
of which: forestry	33	48	48
of which: crops	4	65	59
of which: agricultural residues	12	16	16
of which: waste	28	47	47
of which: other (i.e. black liquor)	9	17	21

Source: European Commission. Impact Assessment: Accompanying the Communication A policy framework for climate and energy in the period from 2020 up to 2030. (2014).

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.

Table 10: *Mapping of the PRIMES bioenergy categories as of the 2014 IA report*

GLOBIOM feedstocks	PRIMES
• Stem wood from forest activites	• Stem wood from forest activities
• Wheat	• Wheat
• Sugar Beet	• Sugar Beet
• Sunflower • Rapeseed	• Sunfloweer / rapeseed
• Perennial lignocellulosic crops	• Perennial lignocellulosic crops
• Short rotation tree plantations	• SRC

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 11: *Mapping of the PRIMES bioenergy categories applied for this study*

GLOBIOM feedstocks	PRIMES
• Wood of industrial roundwood quality from forest activites • Short rotation plantations for energy use • Forest-based industrial by-products (sawdust, sawchips, and bark)	• Stem wood from forest activities • SRC • Solid waste portion corresponding to forest-based industrial by-products
• Residues from forest activities	• Residues from forest activities
• Wheat	• Wheat
• Sugar Beet	• Sugar Beet
• Sunflower • Rapeseed	• Sunfloweer / rapeseed
• Perennial lignocellulosic crops	• Perennial lignocellulosic crops

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.

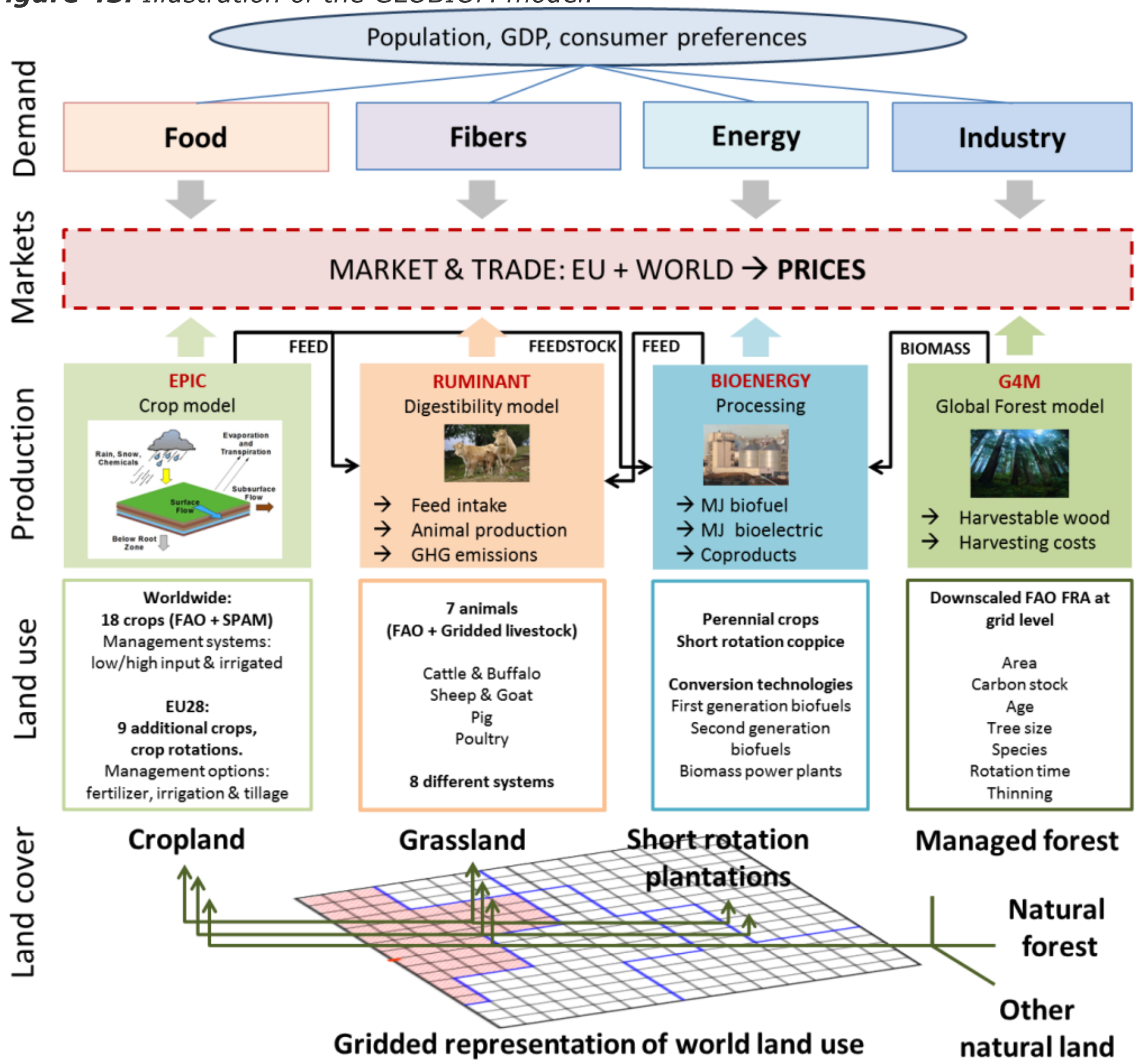
The model computes market equilibrium for agricultural and forest products by allocating land use among production activities to maximize the sum of producer and consumer surplus, subject to resource, technological and policy constraints. The level of production in a given area is determined by the agricultural 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.

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).

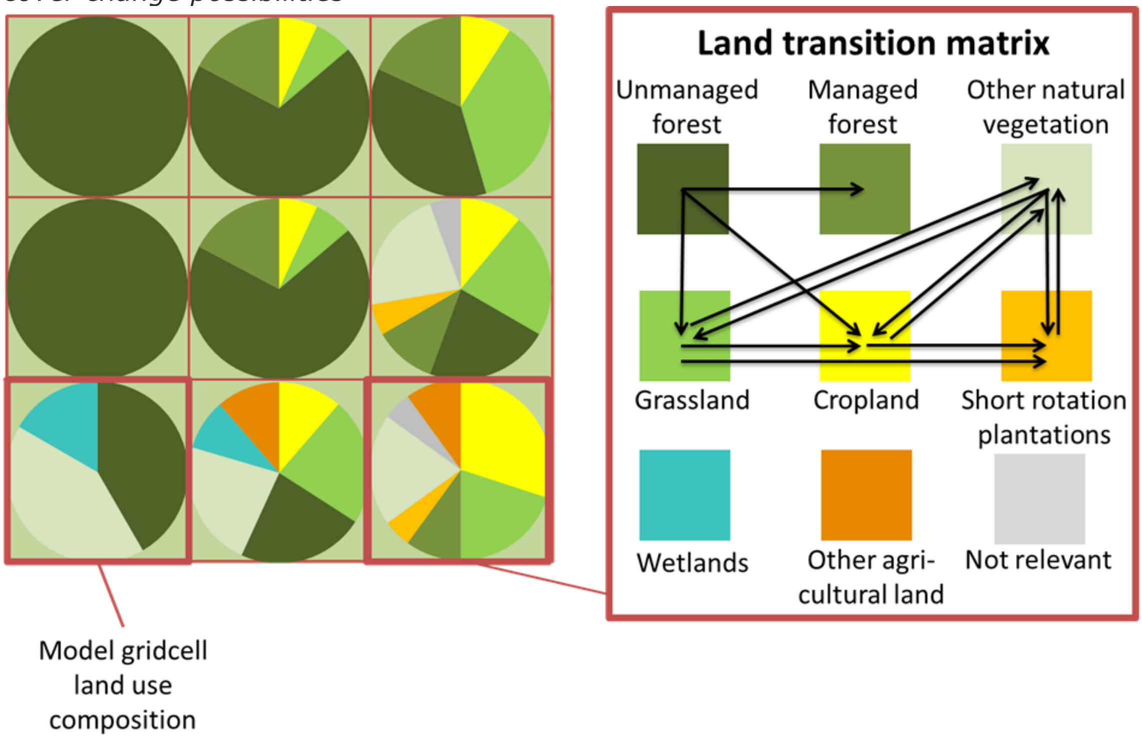
Figure 45. *Illustration of the GLOBIOM model.*



Representation of land use change

The model includes six land cover types: cropland, grassland, other natural vegetation land, used forests, unused forests, and plantations[33]. 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;

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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.[37] 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

[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 at 2014.

G4M model description

What is G4M?

The Global Forest Model (G4M)[38] 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 CO_2 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 CO_2 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 CO_2 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 CO_2 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).

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