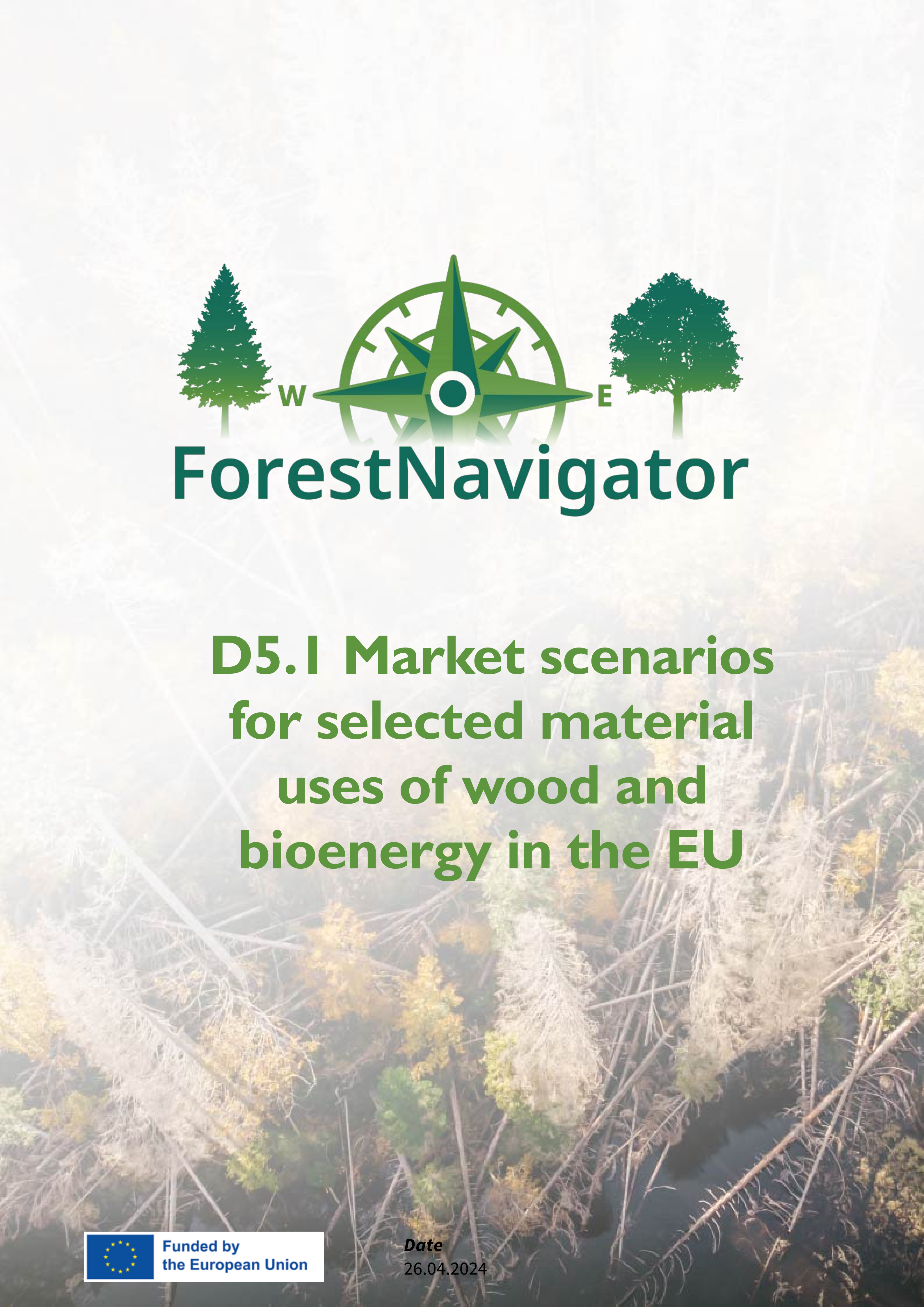

ForestNavigator

D5.1 Market scenarios for selected material uses of wood and bioenergy in the EU

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Abstract

D5.1 creates plausible scenarios and projections for selected material uses of wood (construction and textile fibres), as well as bioenergy and biofuels. The deliverable follows complementary approaches, including partial equilibrium modelling (PRIMES and GLOBIOM) and elicitation of expert views. The market scenarios feed into the quantification of climate change mitigation potential and socio-economic effects (WP 5), as well as into broader analysis of synergies and trade-offs between forest ecosystem services (WP 6-7).

Keywords

Market scenarios, Forest products, Wood uses, Energy mix, Bioeconomy, Construction, Textiles, Bioenergy, Biofuels

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Nature of the deliverable * **R**

Table of Contents

List of figures

List of tables

Abbreviations

a	annum (year)
BECCS	bioenergy with carbon capture and storage
CAGR	compound annual growth rate
C	coniferous
CLT	cross-laminated timber
D	deliverable
EC	European Commission
EJ	exajoule
EU	European Union
FAOSTAT	statistics service of the United Nations Food and Agriculture Organization
G4M	Global Forest Model
GHG	greenhouse gas
GDP	gross domestic product
GLOBIOM	Global Biosphere Management Model
HTL	hydrothermal liquefaction
HWP	harvested wood products
LCA	life cycle assessment
LCI	life cycle inventory
LULUCF	Land Use, Land Use Change, and Forestry
LVL	laminated veneer lumber
Mm^3	million cubic metres
Mt	million tonnes
Mtoe	million tonnes of oil equivalent
NC	non-coniferous
PRIMES	price-induced market equilibrium system model
R	recycled
RCF	regenerated cellulosic fibre
RCP	representative concentration pathways
ROW	rest of the world
SSP	shared socio-economic pathway
TRL	technological readiness level
WP	work package

Executive summary

This deliverable assesses the demand side of the forest-based sector. The market outlook is pivotal for assessing the state of forests and the ecosystem services they provide. The aim of the report is to create plausible scenarios and projections for selected material uses of wood (construction and textile fibres), as well as bioenergy and biofuels. The deliverable follows complementary approaches, including partial equilibrium modelling (PRIMES and GLOBIOM) and elicitation of expert views.

The created scenarios are grouped into material uses, energy uses, and combinations of material and energy uses. The scenarios portray i) baseline developments following business-as-usual, ii) scenarios depicting a realistic increase in the market share of wood, and iii) "what if" scenarios for examining the sector level responses to structural changes of unprecedented scale.

In the construction sector, market experts expect the overall construction volume to remain close to the current level in the EU toward 2050. Wood is likely to gain only minor share in multi-storey buildings, with the greatest potential related to hybrid construction and mixed materials. Even notable change in the market share of wood in construction is unlikely to have major consequences for the level of harvest, as the amount of wood required to build residential buildings from wood is relatively small (0.1-0.3 m^3/m^2). The "wood increase" scenario expecting a few percent increase in the market share of wood in building construction would result in less than 1 Mm^3 difference in the supply of intermediate wood products compared to baseline in 2050.

In the textiles sector, the total textile market globally varied in the scenarios from 176Mt to 350Mt, and wood-based market share was assumed to increase from around 6% to 8%-14%. Wood-based textile fibres are expected to substitute cotton only partially: Most of the substitution is expected to occur between different wood-based fibres rather than between wood-based fibres and non-wood fibres. This is because the properties of each textile fibre are somewhat different, so they serve partly different markets and applications. However, the "high consumption" scenario would indicate a strong increase in the global demand for wood-based textile fibres, suggesting major structural changes for the EU pulp industry.

Wood-based bioenergy supply increases in all scenarios in the EU to 2050 in support of the net zero climate target. The increase in wood-based bioenergy supply compared to 2020 ranges from 7% to 60%, depending on the possible limits for primary biomass use for energy. Imposing limits on forestry feedstock owing to sustainability considerations primarily affects the availability of forestry residues for bioenergy rather than fuelwood harvest.

In the GLOBIOM scenarios exploring combined material and energy use assumptions, the EU woody biomass harvest increased by up to 38% or decreased down to 13% during the period 2020-2050. The maximum harvest results from high bioenergy demand, very high demand for wood in building construction, low rate of construction product reuse, and high demand for wood-based textiles. The minimum harvest results from current level of construction material demand, low textiles demand, a decrease in bioenergy demand, and high rate of construction product reuse.

As the expectations for an increase in the market share of wood construction and the rate of recycling were low among the interviewed market experts, the most influential factor for the harvest rate is the bioenergy demand. Most of the increase in demand for domestic construction uses could be satisfied with reduced net exports. In theory, a high rate of reuse and recycling can avoid any increase in harvest and improve the forest industry competitiveness, but the techno-economic feasibility of such a scenario has not been assessed in this report.

Preliminary wood-based textiles scenarios were included in the GLOBIOM model, however, streamlined approaches for a more integrated assessment of the combined effects of all studied markets will be addressed in later deliverables (D5.2-D5.4).

The next steps within the WP5 will be to quantify the effect of the scenarios on harvested wood product (HWP) pool emissions and removals (D5.2), substitution effects (D5.3), and socio-economic effects (D5.4). The analyses and projections from WP5 will be further utilized in WP6-7 for more encompassing analysis of synergies and trade-offs between forest ecosystem services.

1. Introduction

1.1. Background

The ForestNavigator project aims to evaluate the climate change mitigation potential of the forest-based sector in the EU. In the pursuit of a comprehensive assessment, Work Package 5 (WP 5), assumes an important role by delving into the demand side of this sector, as the outlook for the forest-based sector is pivotal for assessing the state of forests and the ecosystem services they provide. Specifically, this report presents the development of wood use scenarios, which will be used to quantify plausible future forest product and bioenergy market trajectories and their implications for roundwood demand. In later deliverables, the scenarios will be used for quantifying the climate change mitigation potential of the material and energy uses of wood and the related harvest needs and carbon sink in forests.

The European economy has seen major disruptions in the early 2020s, such as the covid-19 pandemic, the conflict in Ukraine, and the peak in inflation and interest rates, which have caused major fluctuation in the supply and demand for wood-based products. These can be considered as short-term and mid-term business cycles affecting overall economic activity, and not necessarily the structures of the industries. As the timeframe of the market scenarios extends to 2050, this deliverable focuses on long-term structural changes, i.e., permanent major changes in the product portfolios of the wood-based industries. Formulating an understanding of structural changes requires screening the plausible changes in the operating environment affecting the demand for wood-based products as well as emerging opportunities created by innovative wood-based products.

During the second half of the 20th century – a period characterized by stable growth – wood demand for forest products was primarily driven by gross domestic product (GDP) and population growth. Since the turn of the century, the forest-based product market has become more diverse, posing a challenge to reliably quantify future market projections (Hurmekoski et al., 2021). For example, the demand for bioenergy has exceeded GDP growth due to energy policy, while the demand for communication papers has declined despite increasing GDP, due to substitution for electronic media. As a result, population and available income are no longer the sole driving factors for the future demand of forest products.

The diversification of the sector makes quantitative projections of wood-based products markets challenging, due to lack of consistent data or mature models for each end use sector. In contrast, the outlook for the energy sector can be seen to be driven by more consistent energy and climate policy. Thus, the material use scenarios developed in this deliverable are based on an expert stakeholder process, while energy mixes are based on the PRIMES energy model (E3M-Lab, 2018). Additional material, and integrated energy scenarios are using the GLOBIOM land use model (Havlik et al., 2011; Lauri et al., 2019; Lauri et al., 2021) to derive the supply of intermediate wood-based products by country from the global or regional demands and present different approaches to explore changes in the markets.

1.2. Objectives

D5.1 describes the methodology and data sources, and reports the outcomes of i) market scenarios for selected material uses of wood co-created by researchers, market experts and other stakeholders, ii) energy sector model (PRIMES) projections for bioenergy demands, and iii)

GLOBIOM model projections showing impacts on wood supply under varying scenarios combining material and energy uses. Together, these projections form the forest sector market outlook, which will be used in subsequent deliverables to calculate marginal changes in harvested wood product (HWP) pool emissions and removals (T5.2), substitution effects (T5.3), and socio-economic effects (T5.4). The market scenarios will also be utilized in the scenario analysis in WPs 6-7.

D5.1 explores a plausible range of change for the demand for wood-based products in selected end use markets including both material and energy uses. The deliverable portrays a set of scenarios describing both quantitatively and qualitatively shifts in wood-based product end-uses in 2050 as well as their impacts on production structure and harvest in the EU. The scenarios are formed with a view on giving insights particularly for the analysis of substitution impacts, by considering also changes in product portfolios and not only production volumes. Thus, the selection of products and markets were driven by market volume and prospects, as well as data availability.

2. Material and methods

2.1. Methodology

2.1.1. Material use scenarios

The main objectives of the scenario exercise were to i) explore future market development for wood-based products and their equivalent non-wood substitutes, which includes market shares and related quantities in 2050, ii) evaluate and specify, which products substitute for which products, and iii) determine the subsequent implications for raw material needs and demand for wood harvests, with emphasis on the distinction between shifts in the end uses of intermediate wood-based products and increase in the level of harvest.

The scenario process was carried out separately for three main intermediate product groups: i) wood-based textiles (e.g., regenerated textile fibres (RCFs)), ii) biofuels and biochemicals, and iii) wood construction (see section 2.2). The selection was based on two criteria: 1. Large enough volume and growth prospects to affect EU forest product markets, and 2. availability of LCA and market data necessary for quantifying the impacts of the scenarios in reference to T5.3.

Although the geographic scope of the market analysis is the EU, for wood-based textiles, and -biofuels & -biochemicals, the markets are global, necessitating to explore global demand scenarios. The effects on the harvest and production in the EU are obtained partly from the interviews (the ratio of increase in harvest vs. shift in end uses) and partly from partial equilibrium analysis with GLOBIOM (allocation of harvest per region given global demand). For wood-based construction, the scenarios were formed separately for Northern, Central, Southern, and Eastern EU, utilizing local background data of the current markets to support experts forming their views on the future. This is because the building types and competing products can vary considerably across regions.

In the scenario formation we used an established 'expert judgement' process to create estimations of the future markets shares for selected products. Expert judgement is utilized, when there is no available data (Hughes 1996), which is often the case in long-time frame projections. Expert judgement methods can provide data for example to models. They should not replace traditional data sources but instead, complement or support the existing data (Krueger et al., 2012). Probably the most important step of the expert judgement process is to identify the relevant experts regarding the topic in question. We selected the experts who most likely create or use future projections in their work within the selected sectors, or who have personal interest otherwise towards the sectoral long-term development (e.g., investments or strategy development as a motivation). The selected experts consisted of researchers, industrial actors from companies, and other experts from interest organizations focusing on, e.g., forest management, wood products or fashion. The second most important part of the process was to provide enough background material and baseline data for the experts to support their estimations. Statistical data of the sectoral development (selected wood-based product groups and the main products within the relevant sector) over the past 5 years was compiled as background material for the experts. We also provided future projections of the sectoral development if they were available.

The scenario development process consisted of three stages. First, the experts were shown data of the current and historical market developments regarding selected wood-based product groups, and then asked to define the future markets shares for wood-based final products and their end-uses in an excel-based survey. The interviewee filled in the survey together with the interviewer, who carefully explained each section, including background. The experts gave short qualitative justifications for their answers and assessed the main advantages and disadvantages and main drivers and barriers of the assessed market development. Second, the numerical answers of the experts were clustered into homogeneous groups based on their similarity, which was defined subjectively by the researcher based on both quantitative and qualitative responses. Therefore, in the beginning, each single opinion of the expert represented an individual data point, which were then combined into bigger clusters based on their similarity assessed by the researchers based on both, qualitative and quantitative data. The final scenarios were based on arithmetic average values within each cluster. Finally, qualitative storylines were combined to the scenarios for added insight on, e.g., trade and substitution patterns and raw material sources and recycling practices.

2.1.2. The PRIMES energy system model

The main objective of this task is to quantify bioenergy demand scenarios covered by biomass of forestry origin and other biomass resources. The bioenergy demand scenarios are quantified using the PRIMES energy system model and the different biomass supply configurations derived using the PRIMES Biomass supply model, both developed by E3-Modelling.

PRIMES is a structural partial equilibrium model that quantifies the capacity and the fuel mix in each end-use sector for the EU and each of its Member States (E3M-Lab, 2018) up to 2070 in a 5-year timestep. It simulates the responses of energy consumers and suppliers to different economic, policy, and technology developments. The model treats the decision making of various stylized actors as a fully-fledged microeconomic problem, including its structural details, often embedding both engineering and economic features. PRIMES represents the energy demand, supply, and emission abatement technologies in an explicit and detailed way. The model is composed of several modules, with each one representing a specific supply sector, such as power and district heat and demand sector, namely households, industry, transport, and international bunker fuels. Every scenario is represented as complex decision problem that is solved using non- linear and inter - temporal optimization or simulation of each sector formulating a typical decision problem expressed structurally based on microeconomics theory, embedding engineering details and technical restrictions in the economic behavioural problem. The model is calibrated with Eurostat energy balances. A detailed description of the model can be found in the literature (E3M-Lab, 2018; Capros, 2019; Capros, 2018).

Biomass supply is quantified with the PRIMES Biomass Supply model, which projects the optimal use of biomass and waste sources in related production pathways into the future, to meet a given demand for bioenergy products provided by PRIMES model (Capros. 2012). The model solves a minimization problem for long-term supply costs, subject to equilibrium constraints stemming from biomass feedstock cost-supply curves and cost structures of conversion technologies. The problem is solved for all EU Member States and the entire time horizon, up to 2070 in a 5-year timestep. It assumes perfect participation of, and competition among, all market actors, namely, the biomass producers and consumers. The market equilibrium is formulated by Member State requiring for each bioenergy commodity to be met through domestic production and/or imports from intra-EU and extra-EU countries in each period.

The supply of primary feedstocks is simulated through time-dependent cost-supply curves that are specific to each EU Member State. The supply potential incorporated in PRIMES Biomass Supply represents biomass available for bioenergy production; biomass potential for other uses (e.g. material, biochemicals) is not part of the available supply. The cost-curves representing primary feedstock availability have been developed through cooperation with other models that cover land use (Global Biosphere Management Model; GLOBIOM), waste and non-CO2 (Greenhouse Gas – Air Pollution Interactions and Synergies; GAINS) and agricultural projections (Common Agricultural Policy Regionalised Impact Modelling System; CAPRI) (IBF & IIASA, 2023; IIASA, 2021; CAPRI, 2022).

Primary feedstock and their categorization in food and feed crops, energy crops, agricultural residues, forestry biomass and waste, is presented in Table 1. Specifically, forestry-based feedstock includes harvested stem wood and primary and secondary forestry residues.

The model includes both overarching constraints stemming from policy restrictions (e.g. sustainability criteria) or, for example, technical constraints that are fuel specific (e.g. biofuel blending ceilings).

Table 1. Biomass feedstocks incorporated in PRIMES Biomass Supply model and their categorization.

Biomass Category	**Feedstock**	**Description**
Food & feed crops	Starch crops	Maize, wheat, barley, etc.
	Sugar crops	Sugar beet, sweet sorghum, etc.
	Vegetable oil crops	Rapeseed, sunflower, etc.
Energy crops	Annual crops	Herbaceous crops (miscanthus, switchgrass, etc.)
	Perennial crops	Wood crops (willow, poplar, etc.)
Agricultural residues	Agricultural residues	Field residues, husk, chaffs, cobs, etc.
Forestry biomass	Harvestable forestry	Stemwood, fuel wood from logging, managed forests etc.
	Primary forestry residues	Thinning and logging residues, branches, tops, etc.
	Secondary forestry residues	Sawmill residues and post-consumer wood waste categories
	Black liquor	Papper and pulp industry residues
Biomass of waste origin	Animal manure	Animal dung (cattle, poultry, pigs)

	Animal waste	Animal fats from food industry and food processing
	Used cooking oil	Used cooking oil from food processing
	Industrial solid waste	Food, meat, fat, beverages, tobacco etc. manufacturing
	Landfill gas	Gas generated from landfills
	Municipal solid waste	Household waste
	Sewage sludge	Wastewater treatment sludge

Bioenergy commodities incorporated in PRIMES Biomass Supply include solid biomass for heat and power generation, biofuels used in the transport sector derived both from food and non-food biomass and gaseous bioenergy described in Table 2. Detailed descriptions of the model and further applications can be found in the literature (Capros, 2012; Tsiropoulos, 2022).

Table 2. Bioenergy commodities incorporated in PRIMES Biomass Supply model.

Bioenergy type	Bioenergy commodity
Liquid bioenergy (Biofuels)	Biodiesel
	Biogasoline
	Bioethanol
	Bio-kerosene
	BioHeavy
Gaseous bioenergy	Biogas
	Biomethane
	Waste gas
Solid bioenergy	Solid waste
	Small scale solids
	Large scale solids

2.1.3. The GLOBIOM economic land use model

A further objective was to assess the future demands for semi-finished wood products and bioenergy for the entire forest sector according to overarching scenarios simulated in the Global Biosphere Management Model (GLOBIOM). This task aimed to reconcile under a common set of scenarios the final demands for final products and bioenergy presented in the previous sections of this document and to translate them into semi-finished wood products production and trade volumes as well as wood assortments harvest volumes, ensuring the sustainability of the biomass supply in the reconciled scenarios.

GLOBIOM is a global spatially explicit agricultural and forest sector partial equilibrium economic model (Havlik et al., 2011, 2014). GLOBIOM includes forestry, forest industry and bioenergy modules as described in Lauri et al. (2021). The model is solved recursively for each 10-year period by maximizing the economic surplus (societal welfare).

The supply side of the model is based on the 0.5° to 2° grid resolution while the demand side and trade are based on 59 economic regions.

The forestry module includes five harvested products: pulpwood, sawlogs, other industrial roundwood, fuelwood, logging residues and one non-harvested product (deadwood).

The forest industry module includes:

- four paper and paperboard grades: newsprint, printing and writing papers, packaging materials, other papers
- four pulp grades: chemical pulp, mechanical pulp, recycled pulp, other fiber pulp
- three mechanical forest industry products: sawnwood, plywood, fiberboard
- four forest industry by-products: woodchips, sawdust, bark, black liquor
- two recycled products: recycled paper, recycled wood

The bioenergy module includes two final products: traditional bioenergy, modern bioenergy and one intermediate product (wood pellets).

The alignment of the forestry module, the industry module and the bioenergy module is achieved by a material mass balance in the model calibration according to Fig. 1.

Forest industry and wood pellets production capacities are based on FAOSTAT production data for 2000–2020 (FAO, 2020). After 2020, production capacities evolve according to investment dynamics, where investment decisions are made by comparing the current period income and annualized investment costs. Forest industry and wood pellets production is modelled by using Leontief production technologies, which have fixed input-output coefficients. Leontief production technologies can be combined, which allows imperfect or perfect substitution between the inputs. The substitution between inputs can be further controlled by defining minimum/maximum shares for their use.

Final products demands are based on constant elasticity demand functions, which are parametrized by reference volumes, reference prices and elasticity coefficients. Exceptions are modern bioenergy demand that are exogeneous and conventionally based on the SSP-RCP scenario data (IIASA, 2020) or specific exogenous demands aligned to SSP-RCPs from energy sector models (MESSAGE, PRIMES, POLES). Traditional bioenergy demand is assumed to stay constant over time.

Reference prices are based on the world export prices and transport costs, so that net exporters face world prices, and net importers face world prices plus transport costs (Buongiorno et al., 2003). For simplicity, preference prices are assumed to stay constant over time.

Reference volumes are based on FAOSTAT for 2000–2020 (FAO, 2020). After 2020, the reference volumes are shifted over time based on GDP and population growth according to SSP-RCP scenario data (IIASA, 2020). The elasticity parameters of the demand functions are based on econometric estimates from Buongiorno et al. (2003), Buongiorno, 2015) and Morland et al. (2018). Income-elasticities lie between 0 and 1, and differentiated for low, middle-and high-income regions. Newsprint and printing and writing papers are assumed to have 0 income elasticity for all regions. Price-elasticities lie between 0.1 and 1. Population elasticity is generally assumed equal to 1.

Trade is modelled by using bilateral trade flows. Bilateral trade volumes are based on BACI trade data for 2000–2020 (Gaulier and Zignago, 2010). After 2020, trade volumes evolve according to endogenous trade dynamics, which depend on constant elasticity trade-cost functions that are parametrized by historical trade volumes and transport costs. Transport costs are estimated from the difference between world import and export values similar to Buongiorno et al. (2003). The share of transport costs in the value of the product is higher for raw materials such as roundwood, woodchips and recycled paper than for forest industry products.

Including coniferous (C) and non-coniferous (NC) biomass separation in the model increases the number of wood-based products from 26 to 38. The separation is applied for all products except fiberboard, paper and paperboard and bioenergy products. The separation is not applied for these products, because they are often produced from a mixture of C and NC biomass. The separation is based on FAOSTAT data where available (FAO, 2020), or when FAOSTAT data is not available, the separation is approximated by using regional C and NC biomass resource balances. For fiberboard, newsprint, printing and writing papers and bioenergy production C and NC biomass are assumed to be perfect substitutes, which implies that the share of C and NC biomass can vary between 0 and 100%. For packaging materials and other papers production the minimum share of C biomass is assumed to be 75%.

Recycled (R) biomass can be used to substitute virgin fibers in wood-based products production. Due to material losses and the ageing of recycled biomass it is not possible to substitute all virgin fibers with R biomass, but there are maximum technical shares for R biomass use. The model includes three R products: R wood, R paper and R pulp. R wood is recovered from mechanical forest industry products, which are re-used as a raw material in fiberboard production or burned for energy. R paper is recovered paper and paperboard, which is re-used for R pulp production. R pulp is used as a raw material in paper and paperboard production. The supply of R wood is based on the final consumption of mechanical forest industry products and on R wood collection rates. The maximum R wood collection rate is assumed to be 50% based on Leek (2010). The supply of R paper is based on FAOSTAT statistics for 2000–2020. After 2020, R paper supply is endogenous and is determined by paper and paperboard consumption and R paper collection rates. The maximum R paper collection rate is assumed to be 80% based on observed maximum national collection rates (CEPI, 2019). The supply of R pulp depends on the supply of R paper and R pulp yield from R paper. R pulp yield from R paper depends on the filler content of R paper, and the ageing effect of R biomass (Stawicki and Read, 2010; Van Ewijk et al., 2017). The average R pulp yield with the ageing effect is about 90%. Connecting this to the filler content of different paper grades (packaging materials 0%, newsprint 10% and printing and writing papers 20%) gives recycled pulp yield of 70–90% depending on the paper grade. Other papers are assumed to have zero yields, since they mainly include sanitary papers, which are usually not recycled. Connecting the R pulp yields to maximum collection rates and the consumption shares of different paper grades implies that the maximum technical share of R pulp varies from 60% to 65% at the global level.

Biomass supply is based on spatially explicit harvest potentials, spatially explicit harvest costs, spatially explicit transportation costs and forest/management type specific land-use change costs. Harvest potentials are based on increment data from the Global Forest Model (G4M) (Kindermann et al., 2006, 2008; Gusti and Kindermann, 2011).

In long-rotation forestry, the whole increment (excluding harvest loss) can be used for pulpwood, but only part of the increment can be used for sawlogs. This is due to the joint- production of sawlogs and pulpwood, which implies that part of the harvest potential is biomass from thinning, which does not qualify as sawlogs. The joint-production increases the relative price of sawlogs and makes pulpwood a by-product of sawlogs production. In short-rotation forestry, sawlogs and pulpwood are produced separately, and the whole increment (excluding harvest loss) can be used for pulpwood or sawlogs. Short-rotation forestry can be used only in the tropical zone, while long-rotation forestry is possible in all regions.

Harvest potential separation for C and NC biomass is based on the FRA (2015) country level growing stock data. For the EU, we use a separate spatially-explicit tree species dataset (Brus et al., 2012). Tree species distribution is assumed to stay fixed over time, with C trees dominant in the boreal zone and NC trees in the tropical zone. In the temperate zone, C trees are dominant in some regions, and NC trees in other regions.

The harvest costs are based on G4M data. Transportation costs are based on Di Fulvio et al. (2016). Land-use change costs are linearly increasing, and are based on historical land-use change patterns. The purpose of land-use change costs is to control the transition between different forest and management types. The model includes three forest types (primary forests, secondary forests, managed forests) and three management types (low intensity, multifunctional, high intensity). Primary forests are forested land that has not been used historically for production. Managed forests are forested land that is currently actively used for production while secondary forests are abandoned managed forests. Management types differ in the proportion of increment that can be harvested. In high intensity management, the whole increment can be harvested while in multifunctional and low intensity management, only part of the increment can be harvested. Consequently, harvest volumes can be increased by increasing the managed forest area or by intensifying forest management within the managed forest area, i.e., changing the management type.

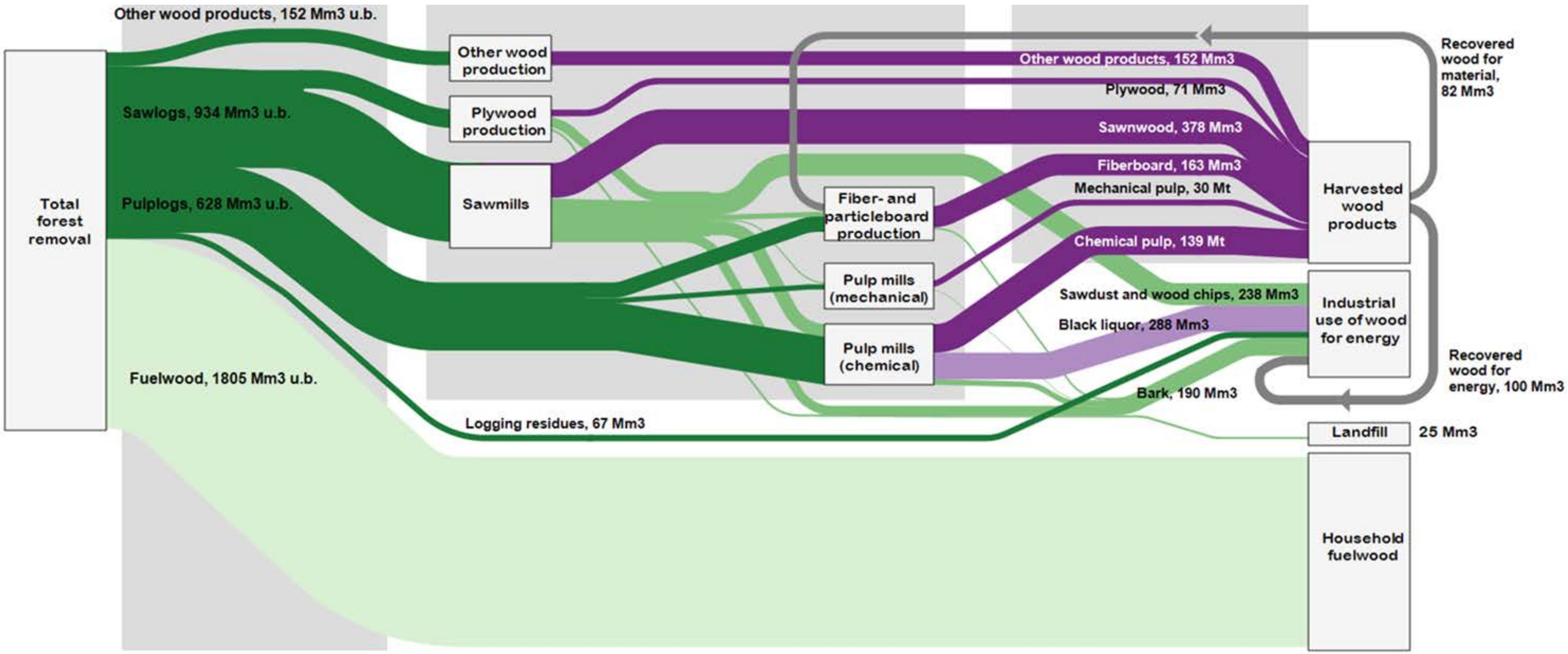

Figure 1. Schematic representation of global wood flows (Sankey diagram) in GLOBIOM for year 2010: from forest feedstocks to semi-finished wood products.

2.2. Data collection and scenario formation

2.2.1. Selection of experts and interview structure for material use scenarios

The selection of experts focused on the downstream of the value chain, i.e., end-users and intermediate producers. The experts consisted of industrial actors, interest group representatives and other experts (e.g. researchers) that hold knowledge relevant to the research questions. The core expert focus was on the end use markets & competing products (substitution). We carefully studied the backgrounds and assessed the suitability of each expert we invited, and contacted altogether over 60 experts personally by email phone, of which 16 experts were interviewed. Due to the method, the number of experts is less relevant than their background and expertise.

The textile scenarios were formed by 6 international experts, consisting of two (pulp) industrial actors, 2 researchers specialized in wood-based textiles, and 2 textile/fashion market experts. The opinions of these experts converged, despite that they were unaware of the answers given by others. The construction scenarios were formed by 6 Finnish experts, consisting of 3 (sawnwood/panel) industrial actors, 2 construction market experts, and 1 architect specialized in wood construction. The data for biochemicals- and fuels was collected from 4 international experts, consisting of 2 advanced biofuel- and 1 wood-based industry -industrial actors and 1 biochemical expert (industrial background). Regarding biochemicals and -fuels, many of the suitable experts refused to participate due to confidentially reasons, even though we clarified that the aim was not to collect sensitive or company-specific data.

The experts had first a possibility to familiarize themselves with the collected background data, introduced by the interviewer. Next, we asked for quantitative estimations of the market structure regarding the product group in question in 2050, as well as qualitative justifications and any additional information. The interviews were designed to collect the following information:

1. The market shares of different end-products within selected product groups, which can be converted into cubic metres/tonnes. This allowed calculating the volume demanded for end products.

2. The information of the feedstocks and intermediate products used for wood-based final products (e.g. overall wood-based raw materials vs non wood raw materials, dissolving pulp vs craft pulp, etc.). This allowed calculating the volume demanded for intermediate products.

3. The information of the substitute products (which products substitutes for which product in which end-use and to what extent (%)). This allowed calculating weighted displacement factors for each intermediate product (D5.3).

4. How much the increased/decreased market share of the specific wood product affect the i) harvest levels (in the EU), ii) end-uses distribution of the intermediate products (or export rates). This allowed making more detailed and realistic assumptions for the steps 2-3 above.

After the interviews, we grouped the responses into scenarios by their similarity (considering both quantitative and qualitative data). The quantitative responses within the same group were combined by calculating their group averages and qualitative responses were compiled into scenario storylines.

The interview questions for textiles, construction and chemicals and fuels are provided in Annexes 1-3. The Interview structure for biochemicals and -fuels was different from interview structure used for other product groups since we used experts to define, which of those wood-based products identified in the initial desktop study phase as climate beneficial and market feasible, have the most market potential in 2050. In addition, we asked if there were other potential products missing from the initial screening.

2.2.2. Background data collection for material use scenarios

Wood-based regenerated cellulosic fibres

The total textile fibre production was around 113 million tons globally in 2021 (Textile exchange, 2022). The volumes and market shares for most important textile fibre types including polyester, cotton, and RCFs were derived from market reports of Textile exchange (2018, 2019, 2020, 2021, 2022) for the years 2017-2021. The analysed fibres were selected based on the market shares and long-term prospects. Polyester covered 54% of the total production in 2021 and was estimated to steadily increase its market share towards 2030 (Textile Exchange, 2022) (Figure 2). As the total production of textiles was assumed to continue its increasing trend, production volume of Cotton was assumed to increase as well although its market share has been slowly decreasing (from 26% in 2017 to 22% in 2021) and dropping to 20% by 2030. Global RCF market share has remained at 6% from 2016 to 2021, and it was assumed to increase to 7% by 2030 (Textile Exchange, 2022) (Figure 3). Despite the moderate percentual increase, in terms of volume the growth represents 3.35 Mt more production annually.

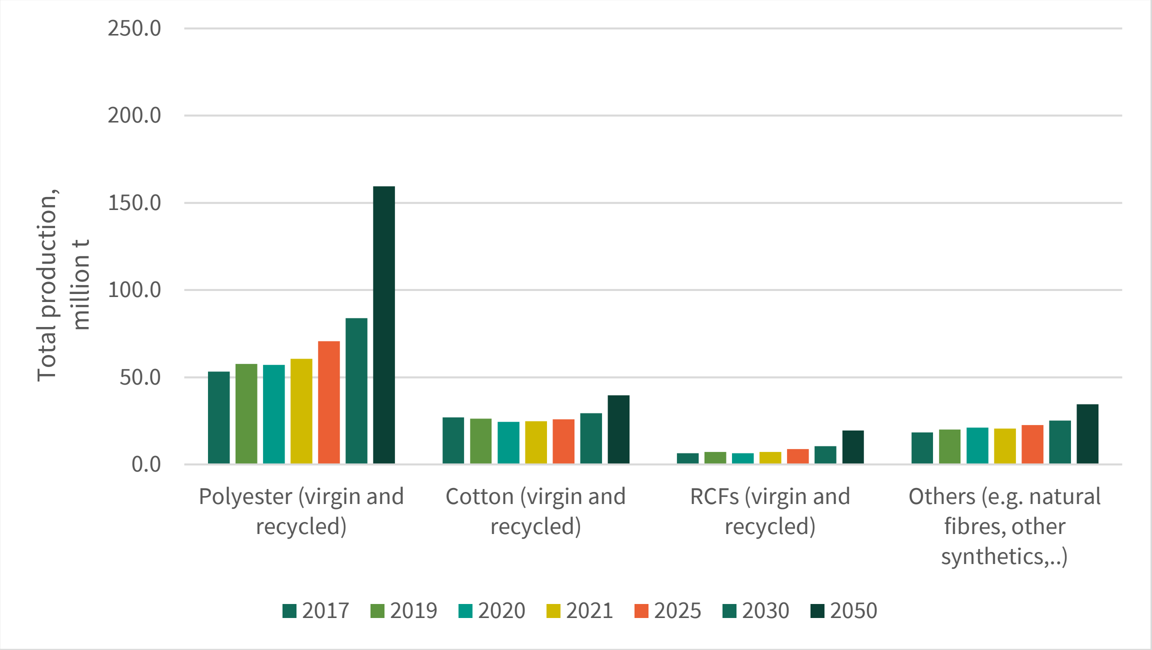

Figure 2. Global textile fibre production by fibre type.

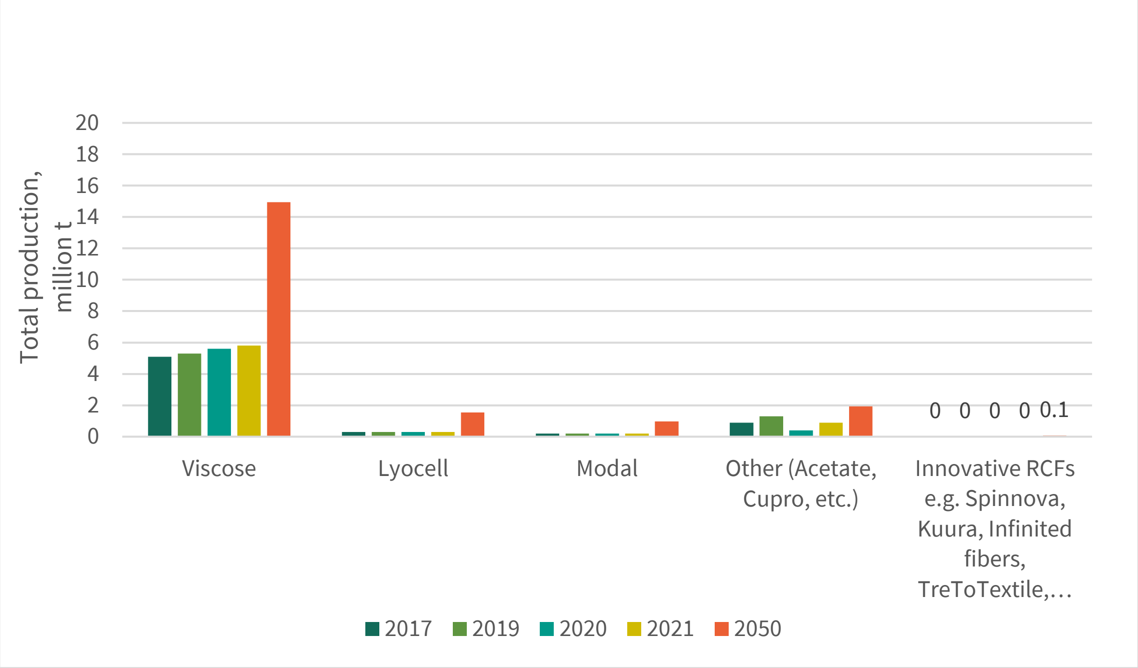

Figure 3. Global production of RCFs.

For RCFs, we determined market shares by individual fibre types including viscose, Lyocell, and others consisting of mostly acetate and Cupro. Although acetate has relatively large share in total RCFs, most of the production is used for other end uses than textile garments (Textile exchange 2022). Therefore, acetate will be excluded from the substitution analysis in the D5.3, as it is not typically substituting non-wood fibers. We also included new RCF types that have future potential in terms of production volumes (e.g. Spinnova, Kuura, Infinited fibres), but their production volumes remain too small (i.e., single pilot scale factories) to be included in the current statistics. Based on the report of JRC (2019), the production of bio-based RCFs in the EU was roughly 600 kt.

The “Baseline scenario” estimates for 2050 were formed by the researchers, using existing literature and additional information gained from the interviews. For the baseline, the income elasticity of textile consumption was assumed to be unit elastic, meaning that when GDP increases by 1%, the textile consumption increases by 1%.

To estimate baseline values in 2050, we used Compound Annual Growth Rates (CAGR) (Eq. 1):

$$CAGR = \left(\frac{V_{t1}}{V_{t0}}\right)^{\frac{1}{t}} - 1 \qquad \textit{Equation 1}$$

where V_{t1} stands for the volume estimate in year t, V_{t0} is the current volume, and t is the number of years between the estimate year and the current year.

The values were found from literature and consultation company estimates. CAGR typically refers to monetary values instead of production volumes, but the same equation applies when estimates of the future volumes in the given year are available. In some cases, the estimates were missing, and we had to rely on monetary CAGR values. Since there exist no CAGR estimates until 2050, we used estimates made for 2030 (see Table 3) and modified them to fit better 2050 estimations. The rates decrease towards 2050 since the GDP growth is higher until 2030 than until 2050. Therefore, we manually modified the CAGRs of main textile types (polyester, cotton, RCFs, and other) to correspond to slowing GDP growth by multiplying them with a correction factor (GDP growth per annum 2050 divided by GDP growth per annum 2030) of approximately 0.80. The GDP growth estimates were retrieved from Capital Economics Ltd (2024). For individual RCF types CAGR 2030 values were used as such to form shares of the total RCF fibre amount, and the total amount of RCFs was calculated based on the corrected CAGR value of 2050.

Table 3. Compound annual growth rates of textile fibres.

Header	Header	CAGR (2021-2030)	Source
Textile fibre types (all)	Polyester (virgin)	3.69 %	Textile exchange, 2022
	Recycled Polyester	3.20 %	Spinnova, 2023
	Recycled cotton	3.72 %	Newsnet, 2023
	Cotton(virgin)	1.97 %	Textile exchange, 2022
	RCFs	4.34 %	Textile exchange, 2023
	Others	2.26 %	Textile exchange, 2024
RCF types	Viscose	5.40 %	Fortune Business Insights, 2023
	Lyocell	8.20 %	Allied Market Research, 2022
	Modal	7.45 %	Dataintelo, 2023
	Acetate, Cupro, etc.	4.70 %	MarketsandMarkets™, 2023
	New RCFs	1.60 %	Spinnova, 2023

Wood-based construction

Unlike wood-based textiles and –biofuels and chemicals, construction markets are more local. Thus, we focused on the EU and divided the assessment into four regions: Northern-, Central-, Southern-, and Eastern EU. For further analysis and GLOBIOM modelling, also country-level data was required. However, since detailed construction data by housing type and materials used was limited, we selected four case study countries to represent each region where data on wood construction was sufficiently available, and generalized the market allocation to different housing types and materials for the whole region. The case study countries were Finland, Spain, Poland and Germany. Market shares of alternative construction materials for selected countries were collected from variety of sources (Table 4) to be presented as a background data for the experts. The scenarios were formed by using Finland as a case study, since Northern EU has long traditions in the wood construction and therefore some further growth potential can be expected. The experts were asked to give estimates of the market shares of alternative construction materials regarding new buildings in 2050, with their justifications. The expert scenarios were given in number of new buildings, and percentual distribution into different housing types by material.

The selected housing types were generalized as much as possible to keep the scenario process manageable, since the experts were asked to give numerical estimates and too many or detailed housing types would have made the process too complex. In addition, more detailed analysis would not have been possible due to lack of data regarding detailed house types. The selected housing types were wood-based-, concrete-, brick- and stone- multi-storey buildings (residential and non-residential separated), and wood-based- and brick and stone residential detached and semi-detached residential houses.

As a basis, we used Eurostat (2021) statistics to compile useful floor areas of new buildings built in the EU27 in 2020 by country. This floor area distribution was used as a basis to transform expert scenarios from market shares into square meters. To transform number of houses into square meters of useful floor area, we used Nordic average of useful floor areas in multi-storey- and detached houses (Official Statistics of Finland, 2022). This technique was used since detailed floor area information regarding different house types by material was missing in most of the cases. The total floor area regarding scenarios was calculated similarly, comparing the difference of 2050 market shares to market shares calculated for 2020. The Baseline scenario (2050) was formed based solely on the interview results, since the assumptions made were conservative and based on current development. The responses of the five remaining experts were used to formulate the second market scenario (slight wood increase).

Table 4. Market shares of alternative construction materials for selected countries.

Country	Year	Buildings constructed (total N)	Concrete multi-storey buildings		Brick and stone		Wood structured multi-storey buildings		Wood structured (semi-) detached buildings	Other (%)
			Residential (%)	Non-residential (%)	Multi-storey buildings (%)	Single family (semi-) detached residential houses (%)	Residential (%)	Non-residential (%)	Residential (%)	
Finland	2017	49,509	61.81 %	0.26 %	0.00 %	0.00 %	4.44 %	0.20 %	16.97 %	16.32 %
	2018	44,386	66.02 %	0.00 %	0.03 %	0.18 %	3.85 %	0.00 %	22.11 %	7.82 %
	2019	39,126	70.29 %	0.31 %	0.00 %	0.00 %	5.62 %	0.43 %	26.07 %	0.00 %
	2020	41,373	67.68 %	0.36 %	0.00 %	0.00 %	7.73 %	0.00 %	24.17 %	0.06 %
Spain	2017	24,823	47.91 %	10.89 %	11.51 %	4.03 %	1.13 %	0.73 %	0.64 %	23.16 %
	2018	29,959	52.57 %	9.98 %	10.17 %	4.34 %	1.07 %	0.73 %	0.67 %	20.47 %
	2019	33,095	50.16 %	8.19 %	9.37 %	4.83 %	1.06 %	0.82 %	0.63 %	24.94 %
	2020	35,473	51.45 %	8.74 %	9.99 %	5.64 %	1.13 %	0.82 %	0.56 %	21.68 %
	2021	29,885	50.53 %	8.12 %	12.33 %	4.12 %	1.59 %	1.08 %	0.93 %	21.31 %
Poland	2017	104,565	0.23 %	10.66 %	2.14 %	72.56 %	0.00 %	0.00 %	0.43 %	13.97 %
	2018	113,676	0.45 %	9.41 %	1.91 %	66.81 %	0.00 %	0.00 %	0.58 %	20.84 %
	2019	124,025	0.56 %	7.70 %	1.81 %	66.16 %	0.00 %	0.00 %	0.65 %	23.11 %
	2020	121,767	0.41 %	7.47 %	2.04 %	72.93 %	0.00 %	0.00 %	0.74 %	16.40 %
	2021	130,000	0.30 %	7.54 %	1.98 %	80.96 %	0.00 %	0.00 %	0.89 %	8.33 %
Germany	2020	125,313	3.81 %	6.17 %	10.29 %	31.21 %	0.45 %	3.68 %	15.61 %	28.6 %

Sources: Finland: Official statistics of Finland (2023), Spain: Spanish Ministry of Transport, Mobility, and Urban Agenda (2023), Poland: Statistics Poland (2023), Germany: Statistisches Bundesamt (2023)

Wood-derived chemicals and fuels

The scenario analysis focused on bio-based chemicals and –fuels which show the largest potential for substitution. Therefore, the selected products had to fulfil the following criteria to be selected for further analysis: i) There is market growth potential, ii) the selected product can substitute fossil-based equivalent products, iii) there is existing comparative LCA and/or LCI literature to define the unit emissions, and iv) wood-based feedstocks are economically feasible and realistic for the production.

Figure 4 summarizes the current production of bio-based chemicals in the EU. In terms of market growth potential, the CAGR (2025) was estimated to be highest, 10% annually, for bio-based platform chemicals and adhesives, whereas other types of chemicals such as polymers for plastics, solvents, paints & coatings, cosmetics & plasticisers it was estimated to be around 1-4% (JRC, 2019). The production of bio-based polymers for plastics were anticipated to increase from 268 kt/year (2019) to 353 kt/year, and the production of bio-based platform chemical production was assumed to increase from 181kt/year to 353 kt/year in 2025 in the EU (JRC, 2019). The technological maturity level is low-medium for the majority of chemical types, except for lubricants and cosmetics which have been utilizing bio-based raw material already in a higher rate (JRC, 2019). However, most of the bio-based chemicals did not offer much potential in terms of wood substitution for two reasons. One is that, when the market share is already 100% or close to 100% (such as propanediol (1,3-), lactic acid and wood turpentine (JRC, 2019)), no substitution can occur if extra units are produced. Secondly, most of the chemicals that do hold potential in terms of substitution, are not likely based on wood-based feedstocks but agriculture -based feedstocks in the future. The main reason is the poor efficiency of the conversion process—biochemical production from wood-based lignocellulosic feedstocks requires typically high volumes of raw material as input, which results in very low volumes of output product. One example presented in the JRC (2019) report is vanillin, where the production of a tonne of vanillin requires 333 tons of wood as an input. Thus, even considering coproduction avenues, a more economically feasible solution is to utilize agricultural side streams as a raw material, such as orange peel, or fast-growing sugar cane which do not contain large amounts of lignin.

Biodiesel and ethanol consumption is assumed to remain approximately the same or even slightly decrease (biodiesel) by 2031, based on global projections of OECD/FAO (2022). This is mainly caused by the electrification of the transport sector. In the EU, the consumption of ethanol was estimated to decrease 12,5% by 2031 from the 2022 level (5442 kt) and the production was assumed to decrease around 2% from the 2022 level (4806 kt) (OECD/FAO statistics, 2022). The same trend was assumed for biodiesel, whose consumption was respectively assumed to decrease 12% from the 2022 level (17423 kt) and production around 9% (15371 kt in 2022). However, biofuels will be needed more in the maritime and aviation sectors in the future, since larger maritime bunkers and long-distance flights are not feasible to operate fully with electricity. Yet, this does not create market potential for ethanol and biodiesel, since they cannot substitute aviation petroleum (aviation) and heavy fuel oil utilized in high-capacity freight load maritime bunkers. Advanced liquid biofuels have potential to substitute heavy fuel oil in the maritime sector, but higher substitution rate would require substantial engine changes (IRENA, 2021).

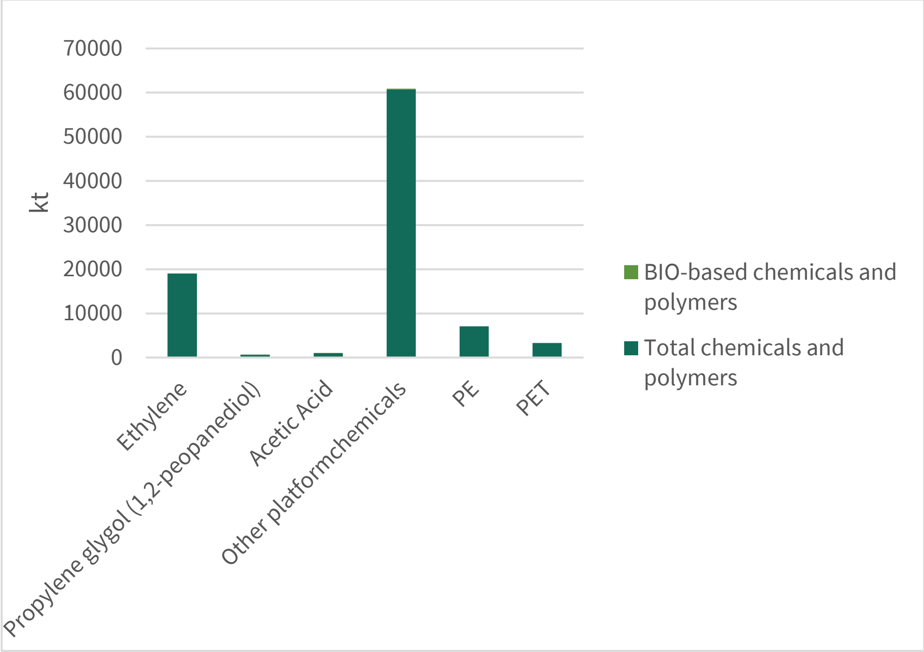

Figure 4. Current chemical and polymer production in EU-28. (JRC, 2019)

2.2.3. Energy use scenarios (PRIMES)

In this task two bioenergy demand scenarios and one bioenergy supply variant were developed, differing in the contribution of bioenergy in the final energy mix and in biomass supply availability for bioenergy, respectively. The scenarios are developed under the same policy framework, assuming the implementation of policies that contribute to the attainment of EU Green Deal (European Commission, 2019) targets stipulated in the EU Climate Law (European Commission, 2020). In particular, at least 55% reduction of net GHG emissions by 2030, compared to 1990, including emissions and removals and climate neutrality for the EU by 2050. To achieve these targets, the scenarios are aligned with the EC’s Fit for 55 policy proposal package (e.g. RED revision (European Parliament, 2023a), EU ETS extension (European Parliament, 2023b), EU ETD (European Parliament, 2003), transport-related initiatives (European Parliament, 2023c)). The designed scenarios are described in Table 5.

Based on the projected bioenergy demand, the scenarios are divided into (a) a high bioenergy demand scenario (BioEnerHigh) and (b) a low bioenergy demand scenario with two variants.

In the BioEnerHigh scenario biomass is an option so as to also deliver negative emissions by utilizing carbon capture technologies in bioenergy production that are necessary to achieve the EU Green Deal net zero emission target in 2050, mainly through bioenergy carbon capture and storage (BECCS).

In the low bioenergy demand variants, demand for bioelectricity and for district heat is lower compared to BioEnerHigh as it is met primarily by solid biomass both of forestry and waste origin. An overall supply constraint of 9 EJ is applied on EU domestic biomass supply with simultaneous limited contribution of primary feedstock or final commodities imports. The two low bioenergy demand variants differ in the utilisation of forestry resources. BioEnerLow assumes similar availability of forestry biomass resources as in BioEnerHigh. LimForestry applies a constraint on the use of forestry feedstock based on sustainability considerations, in line with assumptions of GLOBIOM for the period after 2030. Specifically, the constraint was applied on harvestable stemwood, primary and secondary forestry residues to levels similar to 2030. Finally, an additional exploratory variant scenario was built on the basis of LimForestry to explore the additional space for reduction of forestry biomass feedstock. This variant, while exploratory in nature, can be used as a starting point for new scenario development in the context of other WPs.

Table 5. PRIMES Biomass Supply scenarios and variants.

PRIMES scenario	**PRIMES Biomass Supply**	**Storyline**
High bioenergy demand	BioEnerHigh	High bioenergy penetration in the final fuel mix, especially in power sector
Low bioenergy demand	BioEnerLow	Low bioenergy demand with a limit of 9 EJ on domestic biomass supply
	LimForestry	Same bioenergy demand as in BioEnerLow with an additional constraint on forestry biomass utilization.

2.2.4. GLOBIOM scenarios

General scenarios assumptions

The semifinished products consumption is based on FAOSTAT calibration in the historical period 2000-2020. After 2020 the consumption is shifted by Population and GDP growth and by using history-based income-elasticities.

The development in population and GDP for the EU was derived from the EU Reference 2020 Scenario (EC, 2021), for the rest of the word the alignment of the demands was obtained by consider the SSP2 (IIASA, 2020).

The derived final products consumption is based on the semifinished products consumption and a country level share of final products use according to Mantau et al. (2010) (Annex 4).

The bioenergy demand is exogenous to the model and based on the PRIMES scenarios for EU, for the rest of the world (ROW) countries an alignment to the energy model MESSAGE RCP1p9 scenario was considered, as a pathway to climate neutrality. Given that the PRIMES scenarios are aligned with EU climate neutrality.

The recycled biomass use is allowed to increase up to technical upper bound consistent with current production technologies and recovery rates, according to different scenarios.

In the scenarios, we have changed EU parametrization (i.e. bioenergy demand, final products consumption, recovery rate) according to the scenarios specifics, while ROW parameters remained unchanged independently from the EU specific EU scenario.

High/Base/Low Bioenergy scenario

Two forest bioenergy scenarios were derived directly from the PRIMES scenarios data, as the demand for bioenergy is exogenous in GLOBIOM. The “HighBIOEN” corresponds to forest biomass demands for energy aligned to the PRIMES “BioEnerHigh”. The “BaseBIOEN” corresponds to the PRIMES low scenario “LimForestry”.

The woody biomass use for energy in GLOBIOM included the PRIMES categories ”Harvestable stemwood”, ”Primary forest residues”, ”Secondary forest residues”, ”Black liquor”, ”Solid biomass import”. The unit conversion from energy content to wood volumes assumed 1 Mtoe= 4.9 Mm^3, based on woody biomass density 0.45 ton/m^3 and heating value 19 GJ/ton[i] and 1 Mtoe=4.19 MJ.

PRIMES has higher share of stemwood and forest residues for bioenergy compared to GLOBIOM that has a higher share of by-products (Fig. 5). The difference is due to the reason that GLOBIOM has additional sustainability constraints that decreases industrial roundwood and forest residues use for energy compared to PRIMES. A consequence of this divergence is that in GLOBIOM there is a higher by-products use for energy, which increases profitability of forest industry net exports.

In the GLOBIOM “BaseBIOEN” scenario, woody biomass energy use is lower relative to “HighBIOEN” and the same biomass could be used for material products. However woody biomass energy use is based mostly on residues which cannot be used for material use replacement, hence material use does not necessary increases with low bioenergy demands. The relatively lower woody biomass use for energy (in BaseBIOEN) decreases forest-industry by-products demands and prices which decreases EU forest industry competitiveness and net exports compared to the HighBIOEN.

An additional exploratory “what-if” bioenergy scenario was created in GLOBIOM for exploring the effect on harvest level of decreasing 20% forestry biomass supply for bioenergy purposes. In this scenario, named “LowBIOEN”, there is a decrease over time of by-products and forest residues for bioenergy, if compared to current levels. This additional scenario was modelled only in GLOBIOM and there were no explicit assumptions on imports of wood pellets. Given the demand for solid biomass either as feedstock for biofuels and biomethane production or for use in BECCS, and the structure (i.e. bioenergy fuel types) of bioenergy demand, it is likely that under this exploratory scenario the demand for lignocellulosic types of biomass will remain. The reduction of forestry feedstock as envisaged in LowBIOEN may come with an increase of either annual and/or perennial lignocellulosic crops, given that the potential of agricultural residues is largely exploited. In energy terms, a 20% reduction of forestry feedstock for bioenergy compared to 2020 levels, entails a reduction of about 14.5 Mtoe of forestry residues and by-products in 2050 (compared to the LimForestry scenario). These quantities would need to be compensated by additional use of agricultural land for energy crops. Considering yields of about 5 ktoe/ha for production of annual and perennial lignocellulosic crops, this could entail additional 2.9 Mha of agricultural land (compared to what is used in LimForestry). For such expansion, sustainability considerations from expansion of agricultural land should be further explored. Alternatively, to retain agricultural land at levels similar to the LimForestry scenario, further intensification of agricultural practices so as to increase yields, the feasibility of which also needs to be assessed, as there may also be sustainability trade-offs (e.g. fertilizer runoff to soils and waterbeds) or diminishing returns. As the results of PRIMES Biomass Supply are an outcome of optimization, switching to agricultural land is expected to push bioenergy prices higher, across all major bioenergy categories (liquid biofuels, solid biomass and biomethane) owing to the increase in land rent (owing to land expansion) and agricultural inputs (e.g. fertilisers, energy for irrigation, machinery). The shift to different feedstock is not expected to alter the conversion technology portfolio, as the conversion of energy crops and forestry to bioenergy products have comparable yields. Another possible outcome is some increase to the level of wood pellet imports. It should be noted, that under LimForestry there is some potential for further increasing imports without altering the dependency of the EU to non-EU countries. The implications for such supply alternatives, coupled with a potential further reduction

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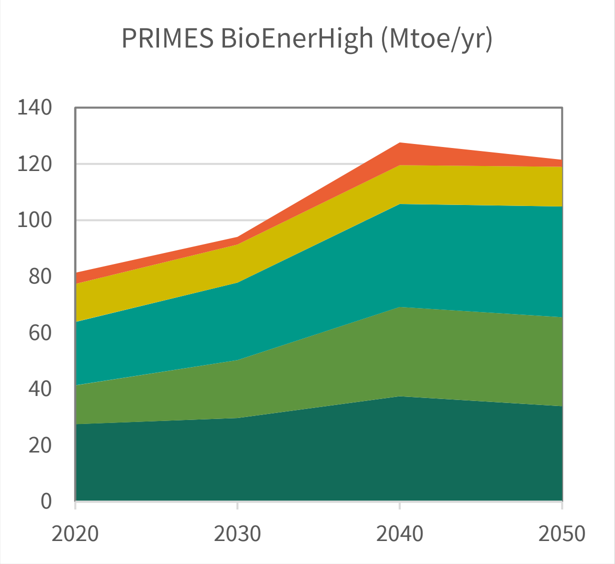
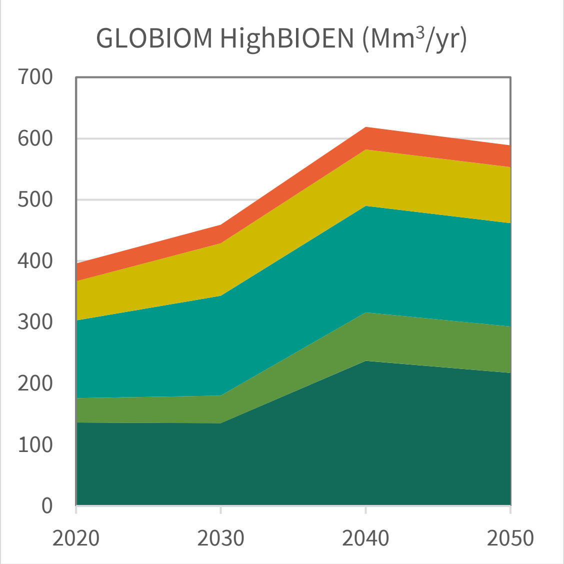
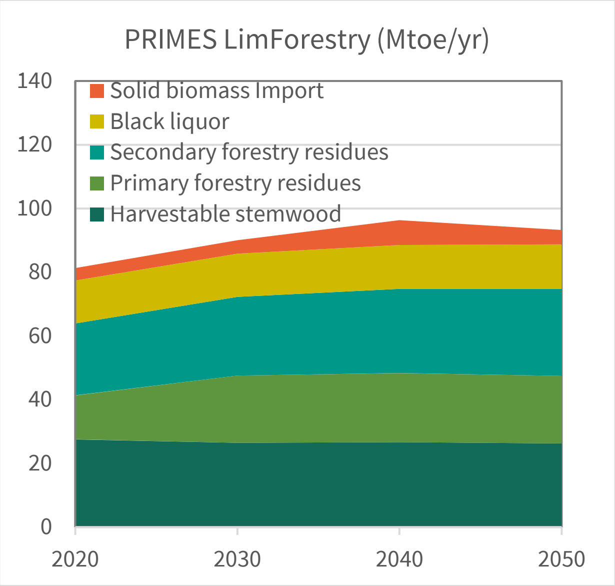
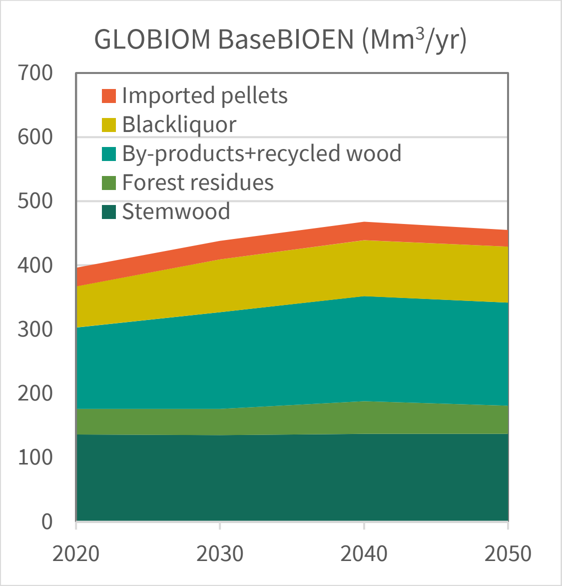
[i] GLOBIOM commonly assumes air dry wood heat value 16 GJ/ton instead own dry wood heat value 19 GJ/ton, however with 16 GJ/ton (or 1 Mtoe=5.8 Mm3) PRIMES data would imply too high woody biomass use for energy in 2020 relative to FAOSTAT statistics.

of bioenergy demand (e.g. due to drivers from the demand sectors) require further exploration from the energy systems perspective.


PRIMES BioEnerHigh (Mtoe/yr)


GLOBIOM HighBIOEN (Mm^3/yr)


PRIMES LimForestry (Mtoe/yr)


GLOBIOM BaseBIOEN (Mm^3/yr)

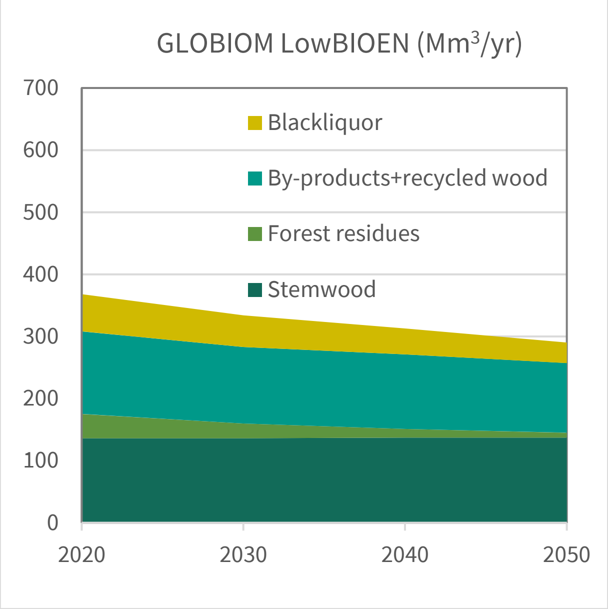

GLOBIOM LowBIOEN (Mm^3/yr)

Figure 5. Comparison of forest bioenergy for EU according to feedstock according to the PRIMES bioenergy content (left) and corresponding GLOBIOM volumes (right) and at the bottom the GLOBIOM exploratory “low ” forest bioenergy scenario).

Base/High Circular economy

Two scenarios assuming different recovery rate for recycled wood and wood reuse were created, to explore the impact of circular economy on wood demands. The “BaseCIRCU” is a scenario with low circular economy development, where the maximum recovery rate for recycled wood can reach maximum 50% over time (the maximum observed national recovery rate in EU). In this scenario, recycled wood can be used for fiberboard and bioenergy.

In the “HighCIRCU”, the EU max recovery rate for recycled wood can increase to a maximum 75%. The recycled wood use is extended from fiberboard and bioenergy also to sawnwood (that translates in a sawnwood reuse). This has a significant impact on the EU demand for virgin sawnwood that can decrease under 70% by 2050 (Fig. 6), given favourable market assumptions.

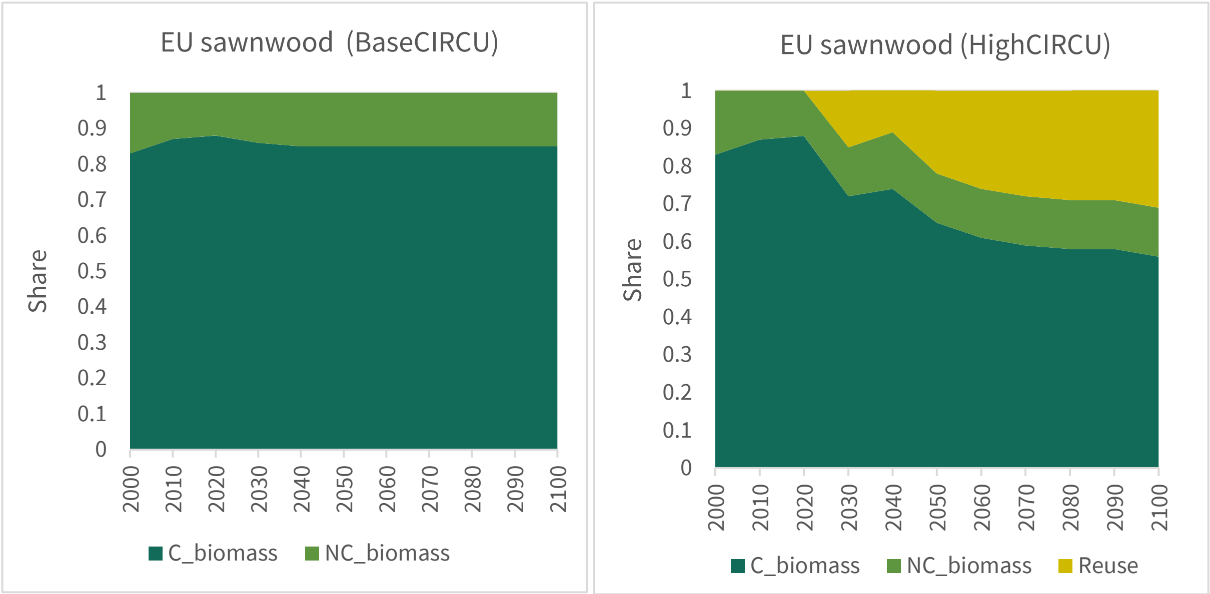


Figure 6. Impact of scenarios on the share of EU sawnwood consumption from Conifer (C), Non-Conifer (NC) and sawnwood Reuse.

Base/High Wood-based textile demands

Two scenarios were created assuming different levels of consumption of textiles. In both scenarios textiles are derived from dissolving pulp or chemical pulp.

In the “BaseTEXT”, wood-based textiles global demand follows the global demand for dissolving pulp with income-elasticity of 0.4, with a corresponding global demand of 15 M ton/year. This approximately follows the “Baseline 2050” scenario for textiles (see Section 3.1), though the demand of GLOBIOM “BaseTEXT” is somewhat lower than in the “Baseline 2050” in 2050.

In the “HighTEXT” scenario, the global wood-based textile demand is assumed to grow until reaching 3 x “BaseTEXT” demand by 2050, to approximately follow the “high consumption” scenario (see Section 3.1), with a global demand of 52 Mton/year (Fig. 7).

In both scenarios, a share of the global textile demand was allocated to EU according to the economic market dynamics in the GLOBIOM model. This resulted in a wood-based textile production of 2 Mton/year allocated to EU under the BaseTextile and 7 Mton/year under the HighTextile, with the rest of global demand being allocated in other regions outside the EU.

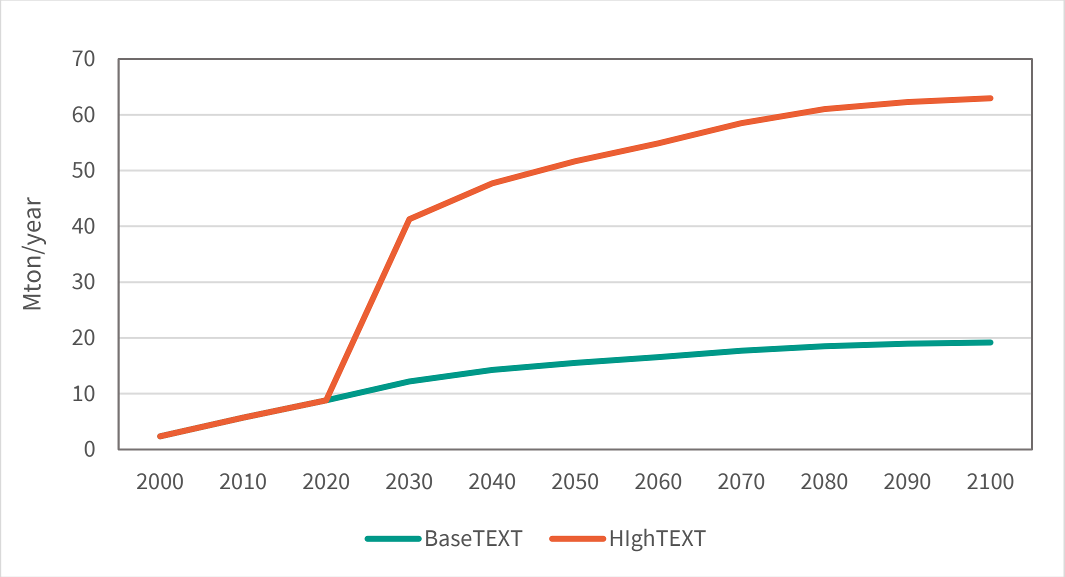


Figure 7.Global wood-based textile demand projections under the two GLOBIOM scenarios.

Base/Low/High wood-based construction materials

Three scenarios were created assuming a different amount of wood demand for construction materials (Fig. 8).

In the “BaseCONST”, the demand for wood-based construction products follows the same trend as the demand for all semifinished products, driven by population and GDP growth. In this scenario, the EU wood-based construction materials consumption increases by about 20% from 2020 to 2050. There is no corresponding scenario in the market construction scenarios (see Section 3.2).

The “LowCONST” assumes that the consumption of construction materials is fixed at the level of 2020, without any increase over time. This approximately follows the “Baseline 2050” construction scenario (see Section 3.2).

In the “HighCONST”, the EU wood-based construction materials use is assumed to increase by 1.33 x “LowCONST” in 2030, 1.66 x “Low const” in 2040 and 2 x “LowCONST” in 2050-2100. This means that the EU wood-based construction materials consumption increases by about 250% from 2020 to 2050. This approximately follows the “Major wood increase” construction scenario (see Section 3.2).

The GLOBIOM scenarios includes an 82% larger volume of construction wood compared to Section 3.2 market scenarios analyses for EU. This is due to the calibration of GLOBIOM to national wood use shares for final products, that are only partially represented by the market scenarios (accounting for 18% of GLOBIOM nationally-calibrated construction volumes). The demand for semi-finished products is translated into construction material consumption through best available country specific conversion factors (see Annex 4).

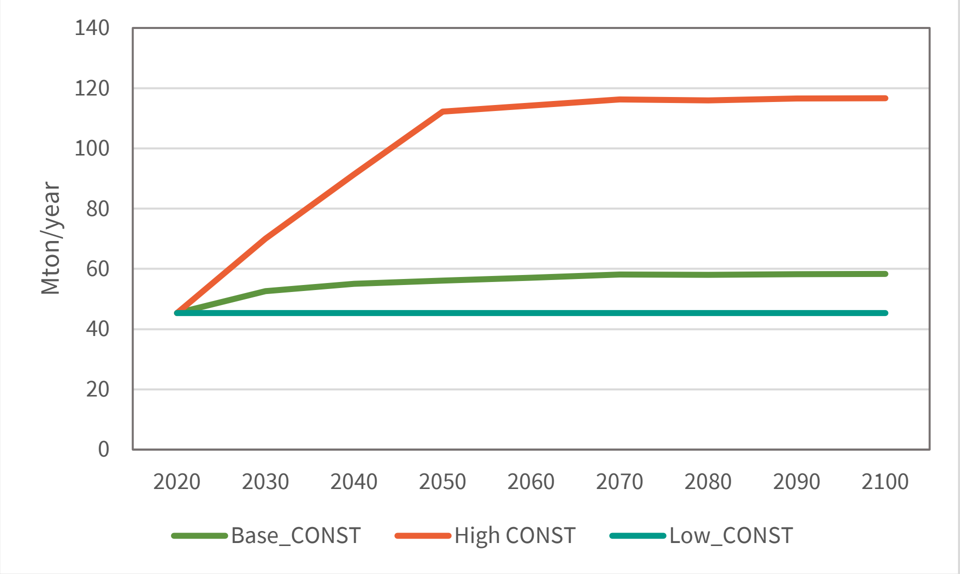


Figure 8. EU wood-based construction materials demand projections under the three GLOBIOM scenarios.

GLOBIOM scenarios combining material and energy uses

The scenarios above were combined by including three levels of bioenergy demand, two levels of textile demands, three levels of construction materials demand, and two levels of wood recycling/reuse. We analyse the results for the most relevant combinations (20 scenarios) illustrated in Table 6. The scenario named "BaseBIOEN_BaseCIRCU_BaseCONST" is considered the GLOBIOM Baseline.

Table 6. GLOBIOM semifinished products demand scenarios and alignment to the final products demand scenarios.

GLOBIOM scenario name	Main demand assumptions
HighBIOEN_BaseCIRCU_BaseCONST (Baseline GLOBIOM)	High Bioenergy demand Baseline Circular economy Baseline Construction demand Baseline Textile demand
HighBIOEN_HighCIRCU_BaseCONST	High Bioenergy demand High Circular economy Baseline Construction demand Baseline Textile demand
HighBIOEN_BaseCIRCU_HighCONST	High Bioenergy demand Baseline Circular economy High Construction demand Baseline Textile demand
HighBIOEN_HighCIRCU_HighCONST	High Bioenergy demand High Circular economy High Construction demand Baseline Textile demand

BaseBIOEN_BaseCIRCU_BaseCONST	Baseline Bioenergy demand Baseline Circular economy Baseline Construction demand Baseline Textile demand
BaseBIOEN_HighCIRCU_BaseCONST	Baseline Bioenergy demand High Circular economy Baseline Construction demand Baseline Textile demand
BaseBIOEN_BaseCIRCU_HighCONST	Baseline Bioenergy demand Baseline Circular economy High Construction demand Baseline Textile demand
BaseBIOEN_HighCIRCU_HighCONST	Baseline Bioenergy demand High Circular economy High Construction demand Baseline Textile demand
HighBIOEN_BaseCIRCU_LowCONST	High Bioenergy demand Baseline Circular economy Low Construction demand Baseline Textile demand
HighBIOEN_HighCIRCU_LowCONST	High Bioenergy demand High Circular economy Low Construction demand Baseline Textile demand
BaseBIOEN_BaseCIRCU_LowCONST	Baseline Bioenergy demand Baseline Circular economy Low Construction demand Baseline Textile demand
BaseBIOEN_HighCIRCU_LowCONST	Baseline Bioenergy demand High Circular economy Low Construction demand Baseline Textile demand
HighBIOEN_BaseCIRCU_BaseCONST_HighTEXT	High Bioenergy demand Baseline Circular economy Baseline Construction demand High Textile demand

HighBIOEN_BaseCIRCU_HIghCONST_HighTEXT	High Bioenergy demand Baseline Circular economy High Construction demand High Textile demand
LowBIOEN_BaseCIRCU_BaseCONST	Low Bioenergy demand Baseline Circular economy Baseline Construction demand Baseline Textile demand
LowBIOEN_HighCIRCU_BaseCONST	Low Bioenergy demand High Circular economy Baseline Construction demand Baseline Textile demand
LowBIOEN_BaseCIRCU_HighCONST	Low Bioenergy demand Baseline Circular economy High Construction demand Baseline Textile demand
LowBIOEN_HighCIRCU_HighCONST	Low Bioenergy demand High Circular economy High Construction demand Baseline Textile demand
LowBIOEN_BaseCIRCU_LowCONST	Low Bioenergy demand Baseline Circular economy Low Construction demand Baseline Textile demand
LowBIOEN_HighCIRCU_LowCONST	Low Bioenergy demand High Circular economy Low Construction demand Baseline Textile demand

3. Results

3.1. Textile fibre market scenarios

A total of three scenarios were formed: “Baseline 2050”, “high consumption”, and “slowing consumption”. The quantitative projections of the textile fibre market scenarios are summarised in Figures 9 and 10, and characterized in the boxes below.

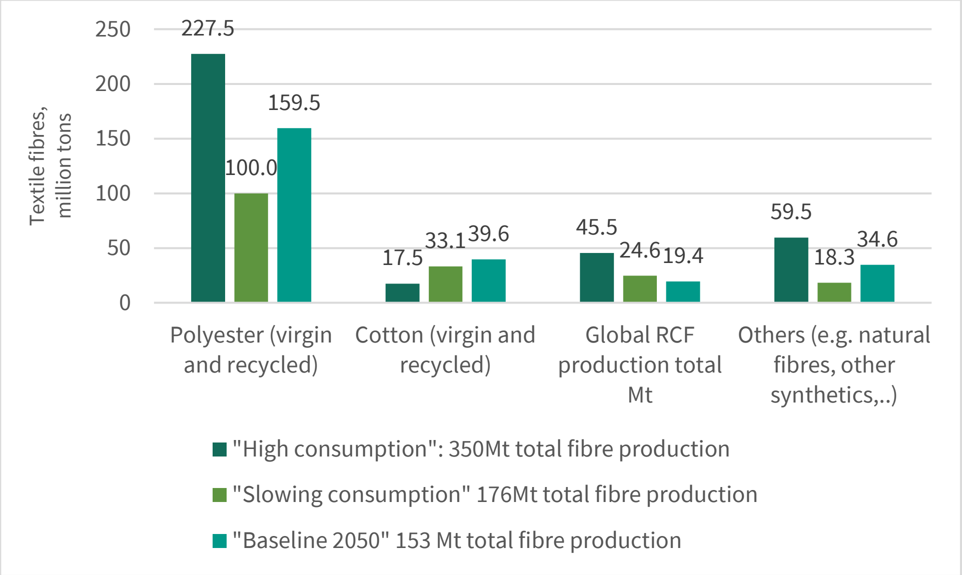


Figure 9. Production of main textile fibres in the three scenarios in 2050.

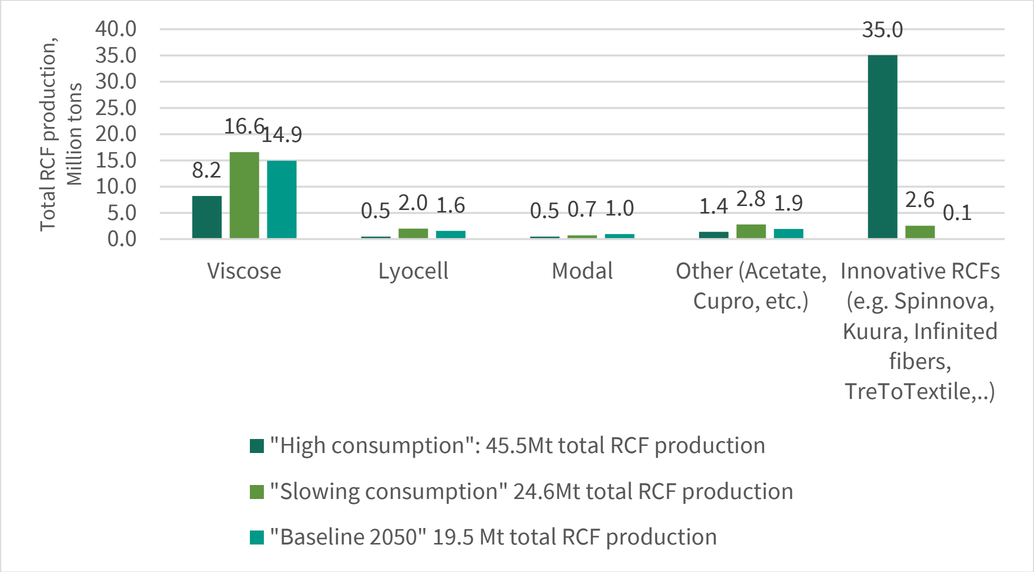


Figure 10. Production of RCFs in the three scenarios in 2050.

“Baseline 2050” scenario

The total fibre volume globally is estimated to reach 253 Mt, of which Polyester covers over a 60% share and cotton a 16% share. The RCFs cover around 8% of the total market, which is relatively close to today’s share (6%). Considering individual RCF types, viscose still has the largest share of the total production (77%) followed by other (mostly Acetate and Cupro) with a 10% share and Lyocell with an 8% share. The baseline expects conservative growth for innovative textile fibres, with an annual production of 0.1 Mt.

“High consumption” scenario

Textile production will continue to increase. This means an increase for polyester and other synthetics, and partially for RCFs as well. The most market feasible way to respond to the radically increased demand is to produce more products that are already in the markets. Therefore, polyester was assumed to respond to increased demand. The argument was that there are no efficient substitutes for polyester, but polyester production will be more based on recycled materials. At the same time, there is pressure not to increase cotton production. It was assumed that cotton production will be restricted and RCFs will partially fill the gap left by reduced cotton production.

RCF production will increase. It was assumed that the total production would amount in ten high-volume pulp factories on the global level. The supporting argument was that due to recent Lyocell patent release, there are already new factories arising in China. However, the main increment for RCFs comes from new types of RCFs, which can be produced based on multiple raw material sources including recycled paper.

It was assumed that around 50% of the increased raw material demand will be covered by shifts in end-uses, and 50% by extra harvests globally. Recycled raw materials would only be introduced to the production of new RCF types.

“Slowing consumption” scenario

It was assumed that since global population continues to increase, total textile demand increases accordingly. However, the share of recycled fibres will increase linearly, thus not all the production is virgin raw material based. Polyester continues to increase, and it will remain important in the future, since it's easy to produce. As in the “high consumption” scenario, here it was also assumed that recycled polyester will increase its share. It was assumed that there’s limitation for cotton production. However, since cotton fibres cannot be substituted entirely, some production will remain although it won’t be able to respond to increased demand. Also cotton recycling rate would increase.

RCFs were assumed to partially substitute cotton. RCFs could increase, but only slightly. The argument was that the availability of wood is not sufficient. Eucalyptus and plantation forests in general are needed to increase the volume of RCFs. It was assumed that RCFs cannot substitute synthetics, but they can be blended. RCFs would be covering increasing demand, but also cotton should be partially substituted. The experts stated that the difficult element will be to integrate recycling in the picture.

There were varying opinions what came to raw material supply for increased RCF demand. Some experts stated that 100% of the increased raw material demand will be covered by shifts in end-uses, since they argued there is not sufficient harvest opportunities available, and the shift would happen rather from paper products to textile fibres. They argued that forest industry side stream utilization would also not cover increased demand since there is so much competition regarding side stream uses in the future. Others however stated that some (around 10%) of the increased raw material demand should be covered by extra harvests, but the most will be covered by shifts in end-uses. They agreed that if there will be increase in new RCFs, it could be away from paper production in case the value added would be higher for them than for paper. If the increase would not be away from paper, their production would be anyway based on more sustainable raw material sources (e.g., side streams from agriculture). There could also be more planted eucalyptus forests.

All agreed that paper production will continue to decrease (shift to textiles), production efficiency will increase in general, and utilization of recycled fibres will increase. There might be still some increase in harvest levels, but the main contribution would be based on shifts in end-uses.

3.2. Construction market scenarios

Two scenarios were formed based on expert interviews: “Baseline 2050” and “Wood increase”.

The difference in the demand for wood-based intermediate products between the baseline scenario and the “slight wood increase” scenario was less than 1 Mm^3. As the expert-driven scenarios resulted in barely noticeable changes in harvest levels or in GHG emissions and removals, two explorative “what if” scenarios were created for comparison: *“Major wood increase”* and *“Decreased living area”*. The “wood increase” scenario resulted in an increase of around 13 Mm^3 of intermediate products compared to the baseline, while the effect of the “decreased living area” scenarios was -1.7 Mm^3. Note that these values lack data from brick- and stone buildings, so these values can only be used for scenario comparison and not for assessing the absolute volumes or total demand for intermediate wood products in the EU. Also, the scenarios in square meters are estimates, and should be used only for comparison (Table 7).

In terms of the generalization of the scenarios based on only Finnish respondents, the experts mentioned that they do not believe the scenarios would be much different elsewhere in the EU, regarding increase in wood construction. Considering the market structures and similarity in construction practises, we applied the scenarios only to Northern EU and Central EU.

The quantitative projections of the construction market scenarios are summarised in Table 7 and Figures 11 and 12, and characterized in the boxes below.

Table 7. Summary of results for the construction market scenarios.

Scenario	**Region**	**Total floor area**	**Concrete multi-storey buildings**		**Brick and stone**		**Wood structured multi-storey buildings**		**Wood structured (semi-) detached buildings**	**Other**
		million m^2	**Residential (million m^2)**	**Non-residential (million m^2)**	**Multi storey buildings (million m^2)**	**Detached- and semi detached (million m^2)**	**Residential (million m^2)**	**Non-residential (million m^2)**	**Residential (million m^2)**	**million m^2**
Baseline 2050	**Northern EU**	35.6	29.8	0.1	0.0	0.0	4.6	0.0	1.1	0.0
	Central Eu	201.2	16.5	27.4	45.7	13.8	2.6	16.3	7.3	71.5
	Eastern EU	79.2	0.0	22.0	6.3	22.9	0.0	0.0	0.3	27.7
	Southern EU	39.9	23.9	4.2	4.7	0.5	0.5	0.5	0.0	5.7
Wood increase 2050	**Northern EU**	36.4	26.1	0.1	0.0	0.0	8.7	0.0	1.0	0.6
	Central Eu	206.3	14.5	27.4	45.8	13.8	2.9	16.4	6.4	79.1
	Eastern EU	79.2	0.0	22.0	6.3	22.9	0.0	0.0	0.3	27.7
	Southern EU	39.9	23.9	4.2	4.7	0.5	0.5	0.5	0.0	5.7
Major wood increase 2050	**Northern EU**	35.6	17.2	0.0	0.0	0.6	17.2	0.0	0.6	0.0
	Central Eu	201.2	9.5	21.9	45.7	10.6	9.5	21.9	10.6	71.5
	Eastern EU	79.2	0.0	11.0	6.3	11.6	0.0	11.0	11.6	27.7
	Southern EU	40.0	12.2	2.3	4.7	0.3	12.2	2.3	0.3	5.7
Decreased living area 2050	**Northern EU**	32.0	26.8	0.1	0.0	0.0	4.1	0.0	1.0	0.0
	Central Eu	181.0	14.9	24.7	41.1	12.4	2.3	14.7	6.6	64.3
	Eastern EU	71.3	0.0	19.8	5.7	20.6	0.0	0.0	0.3	24.9
	Southern EU	36.0	21.6	3.8	4.2	0.4	0.4	0.4	0.04	5.1

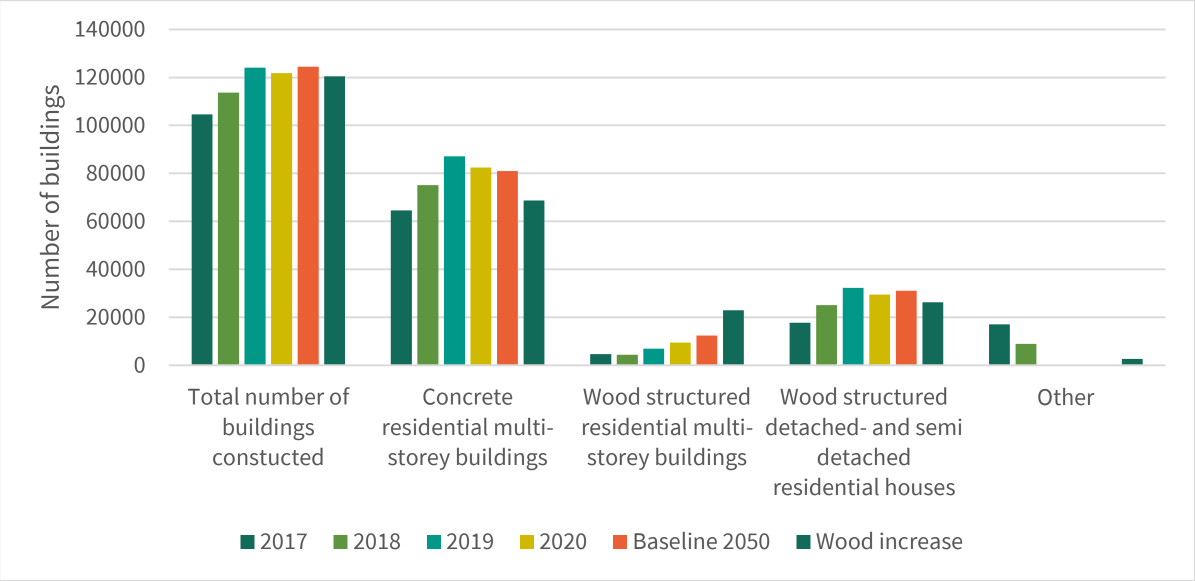


Figure 11. Finnish wood construction scenarios, and statistics from 2017-2020 and the "baseline" and "slight wood increase" scenarios for 2050 (Official Statistics of Finland, 2021).

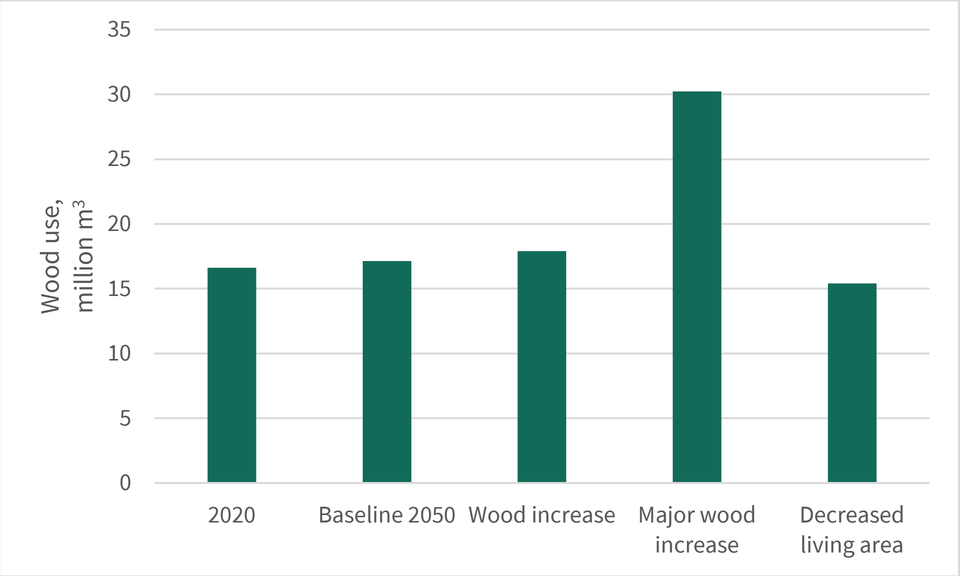


Figure 12. Wood use in new buildings annually (excluding brick- an stone multi-storey buildings and "other" building types).

Baseline scenario

In the baseline scenario, the market share of wood increased from 8% in 2020 to 10% in 2050 in new buildings. The total number of buildings remains at the 2019 level. Construction rates are radically reducing, but urbanization continues. The amount of renovation construction will increase and be able to prolong the lifetime of old buildings. Yet it might not cause remarkable changes to new construction rates, as changes in the energy efficiency regulation might mean demolition of all the buildings that do not meet the requirements. The living space per capita is decreasing as well.

Non-wood construction keeps its position since mineral sectors look for low-carbon solutions. Globally demand for concrete and steel will increase regardless due to population growth.

There is no radical change for wood construction, as decades of lobbying for wood-based multi-storey buildings has not been translated into significant increases in the market shares. The price and cost-competitiveness are the main influence factors, along with the evidence and transparency of climate benefits. The potential is mainly in fast-solution wood construction components such as separating walls.

Mixed material buildings become more common. Wood-based cheaper solutions may get more mainstream in, e.g., mixtures of wood-stone or wood-concrete. Entirely new material solutions will also become available. Classification into wood and non-wood buildings may become increasingly arbitrary.

The amount of detached- and semi-detached houses remains on the level of 2020, as there is too little space available for single-family housing. Instead, tall building construction will increase with higher number of floors.

CLT and other massive components will retain its position compared to light framed wooden buildings.

The slight increase in the wood raw material demand should be covered through shifts in the end uses of intermediate wood-based products.

“Wood increase” scenario

Wood-based multi-storey buildings will increase from 8% in 2020 to 19% in 2050, substituting concrete-based buildings. The total number of buildings is the same as in the Baseline. However, there is a slight increase in floor area due to distribution changes between multi-storey buildings and single family homes, when comparing this scenario to the baseline. The floor number will increase and living density will increase due to urbanization. Immigration compensates for the low birth rate, so overall the population remains similar as in 2020. Renovation construction increases.

As in the baseline, concrete construction will decarbonize, so the climate benefits of wood are not anymore remarkably higher compared to concrete. However, the decarbonization and circularity efforts in the concrete sector also support wood construction, since wood and concrete mixed material solutions are adopted.

Wood partially substitutes concrete, as carbon footprint calculation will become mandatory. Lobbying is successful, but regulation still poses limitations. Restrictions on the use of forests due to climate and biodiversity targets may also pose a barrier to this trend.

The number of floors in the multi-storey buildings increases by 1-2 floors by 2050, with the average being 4 floors in 2020. This is driven by the need to reduce transport and maximise the community living-space efficiency.

Wood-based massive element construction will increase its importance and CLT and LVL are part of it, although new solutions may come as well. The global market share of CLT increases year-by-year until it reaches 40%-50% of the wood construction market, due to high quality and increased floors. However, the increase of CLT might be less than anticipated before.

The growth in wood-based construction will not affect the harvest rates: The domestic markets offer better price for wood products, so extra demand will shift away from global exports. The increase in wood construction should be remarkably higher for it wo have notable impact on harvests or production volumes.

“Major wood increase” scenario

In the *“Wood increase”* scenario, wood-based- and concrete multistorey buildings (both residential and non-residential) have equal market share and the market share of brick- and stone multi storey buildings remains unchanged. The share of brick-and stone multi-storey buildings is unchanged (due to data limitations). In detached and semi-detached houses, wood-based detached houses hold a 50% market share and brick- and stone detached houses hold a 50% market share.

“Decreased living area” scenario

In the *“Decreased living area”* scenario, the floor area is reduced 10% in each house type regardless of the material. This is to contrast material substitution with reduced consumption as one means for climate change mitigation, i.e., being content with somewhat smaller apartments on average.

3.3. Expert interview results on biofuels and biochemicals

The experts generally agreed that bio-based chemicals and fuels will increase their relevance in the EU rapidly due to attempts to replace fossil-based production. However, experts stated that wood-based raw materials are not likely playing a significant role in the transition, and instead agricultural side streams and fast-growing crops are used. The experts stated that the same applies even for wood-based side streams on the global scale, since the raw material yield of the chemical process is low, and the extract again distributes into several different smaller fraction end-uses. This makes the biochemical extraction from wood unattractive in terms of profitability. However, the experts did believe that single factories in the EU could arise, compiling raw materials from multiple sources and maximising the production efficiency via integrates.

One of the experts (biochemical industry background) believed wood could play some role in ethanol production and further in ethanol -based biochemical production. For further analysis, we excluded ethanol -based biochemicals due to lack of LCA data (D5.3). The data was based on low TRL (technical readiness level) production processes and did not show any substitution potential.

Regarding advanced biofuels, the experts agreed with our background information highlighting that the forecasts show slowly decreasing trend for biodiesel and bioethanol production in the EU, due to electrification of the transport sector. However, the experts also agreed that liquid fuels still will hold their place in the aviation and maritime sector, regarding long-distance transportation. The fuel industry experts believed short distance flights will be using electricity by 2040, reducing the overall jet fuel demand. They believed that regarding long-distance flights, sustainable aviation fuel will start substituting fossil kerosene in a larger scale. This could utilize wood as a raw material too.

Staples et al. (2018) estimated that bio-based aviation fuel could reach 955 billion litres/a by 2050, if 178.7 exajoules per year (EJ/a) of feedstock is available. It means the potential feedstocks should be first used for jet production before it is allocated to bioenergy and other applications. The experts (biofuel industry) believed this scenario could be attainable, if there was a political measure restricting wood combustion for energy and encouraging use for higher value applications, in this case hydrocarbons. Hydrocarbons can be further processed into chemicals and fuels such as biodiesel or jet fuel. The experts evaluated, that the total volume of hydrocarbons could reach globally 955 billion litres (theoretical maximum based on report of Irena, 2021), of which 70%-80% would likely be allocated to jet fuel production, if fossil fuels would not be in use anymore by 2040. Of the total production globally (955 billion litres), 50%-60% could be based on forest- and agricultural resources, which would result in around 215 billion liters of wood-based jet fuel annually. However, in the forest sector this would mean a complete renewal of the energy sector and in addition crop fields should be established to ensure raw material availability. This is highly unrealistic scenario. Nevertheless, policies should ensure all the wood resources globally that currently are allocated to energy, would be used for hydrocarbon production. Forest industries utilize their side streams for mill energy, meaning this energy should be covered with alternative sources. However, the experts believe possibilities exist, since there are already potential technologies which could implement this. The resource availability was not considered the only restriction for forest resource use. We don't have infinite potential to increase harvest potential. The experts stated that the forest growth rates fluctuate and decisions made now will affect the growth in the future. Climate change (e.g. drought) and possible use regulation can restrict the potential further, they assumed.

The experts estimated that Power-to-liquid- or Hydrothermal Liquefaction (HTL) could be most potential biofuel production technologies in 2040. Power-to-Liquid was mentioned as zero-carbon technology in the Clean Skies report of World Economic Forum (2022). Gasification is one of the existing technologies that is used already for, e.g., biodiesel production, but experts stated that the technology is inefficient and expensive compared to future technologies.

3.4. Energy scenarios PRIMES and end uses in 2050

3.4.1. Bioenergy demand

The total bioenergy demand projection for the EU27 is similar between the BioEnerHigh, BioEnerLow and the LimForestry scenarios in 2030, i.e. 6.4 EJ and 6.1 EJ, respectively. In the years that follow, bioenergy demand projections in BioEnerHigh increases to 9 EJ in 2050, which represents a growth of approximately 1.7% annually in the period 2030 to 2050. In the low bioenergy demand scenarios, the demand for bioenergy is relatively stable at 6.2-6.4 EJ throughout the period 2020-2050. As it is observed in Figure 13 the growth rate differentiates from 2030 to 2040 (i.e. 2.9% annual growth) and from 2040 to 2050 (0.6% annual growth) in the BioEnerHigh scenario.

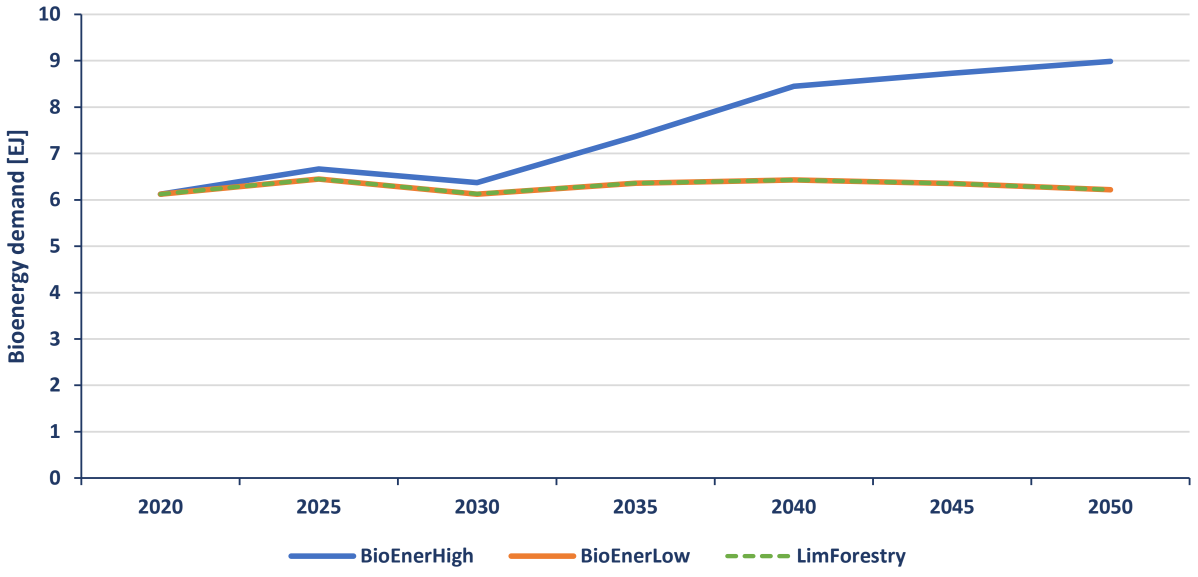


Figure 13. Bioenergy demand projections for the EU27 in 2020-2050 (Source: PRIMES)

3.4.2. Bioenergy demand by sector

In 2030, in all scenarios the majority of net bioenergy demand comes from the power and district heat sector; its share is roughly one-third (or 33-37%) of total bioenergy demand, followed by industry and the households sectors (i.e. each sector represents 20-22% of total bioenergy demand), and the remainder comes from the transport sector, including international maritime (i.e. 15-17% of total bioenergy demand). Finally, the tertiary sector consumes about 7% of total bioenergy demand.

In 2050, the increase in bioenergy demand in BioEnerHigh compared to 2030 is mainly due to the increase in the power and district heat sector (i.e. additional 2.2 EJ or 95% in 2050 compared to 2030), followed by the transport sector (i.e. additional 1EJ or 102%, in 2050 compared to 2030). The demand of the households and industry sectors is reduced by 0.3 EJ or -24% when compared to 2030 levels. The demand of the tertiary sector increased by 0.1 EJ in 2050.

In BioEnerLow and LimForestry scenarios the demand from power and heat is reduced when compared to BioEnerHigh by 2.59 EJ or 57%. As such, the contribution of power and district heat over total bioenergy demand is similar to that of transport (i.e. 1.96 EJ or 32% and 1.80 EJ or 29%, respectively), the share of industry and household sectors is 15-17% (i.e. 0.98 and 1.05 EJ respectively) and that of the tertiary sector is 7% (or 0.44 EJ). Notably, the demand for bioenergy in transport increases across both high and low bioenergy demand scenarios, due to the penetration of biofuels in, aviation and maritime in 2050, and the limited alternatives that these sectors have to decarbonise.

The projection of bioenergy demand by end-use sector for 2030 and 2050 is presented in Figure 14.

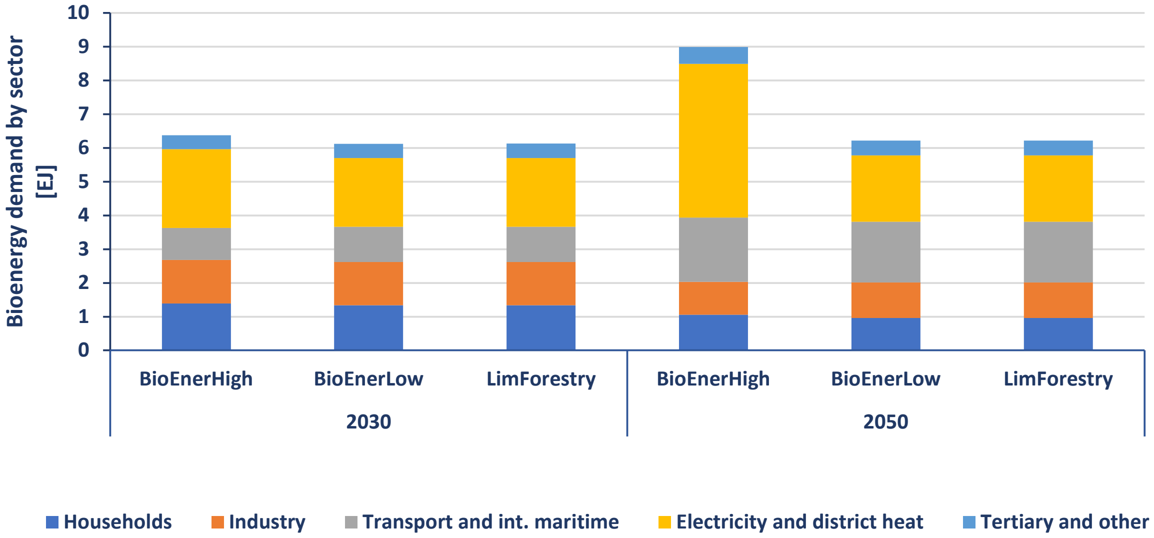


Figure 14. Bioenergy demand projections by end-user for EU27 in 2030 and 2050 (Source: PRIMES).

The supply of electricity from renewable energy sources (RES), including biomass is significant, as compared to 2020 the overall demand grows by 34% in 2030 and 174% in 2050, following the growth of the sector and the electrification of the energy system as a means to decarbonize.

Projections indicate that the total energy demand of the power sector will range between 20-21 EJ by 2030 across both PRIMES scenarios, increasing to 33 EJ by 2050. As shown in Figure 15, biomass and waste sources collectively account for 11.5% (i.e. 2.4 EJ) of fuel mix in the BioEnerHigh scenario, and 10.6% (i.e. 2.1 EJ) in the BioEnerLow scenario. In 2050, the share of biomass in the transformation input fuel mix is projected to rise to 13.9% (i.e. 4.6 EJ) in the BioEnerHigh scenario, while it is projected to be lower by 5.2% (i.e. to 2.1 EJ) in the BioEnerLow scenario. The cap imposed on biomass supply in the BioEnerLow scenario, results in a higher natural gas share compared to BioEnerHigh in 2050.

In the BioEnerHigh, scenario the higher share of solid fossils in the fuel mix in 2030 leads to higher emission intensity when compared to BioEnerLow scenario. In the BioEnerHigh scenario the share of bioenergy is higher substituting fossil fuels targeting emission reduction and delivering negative emissions with BECCS.

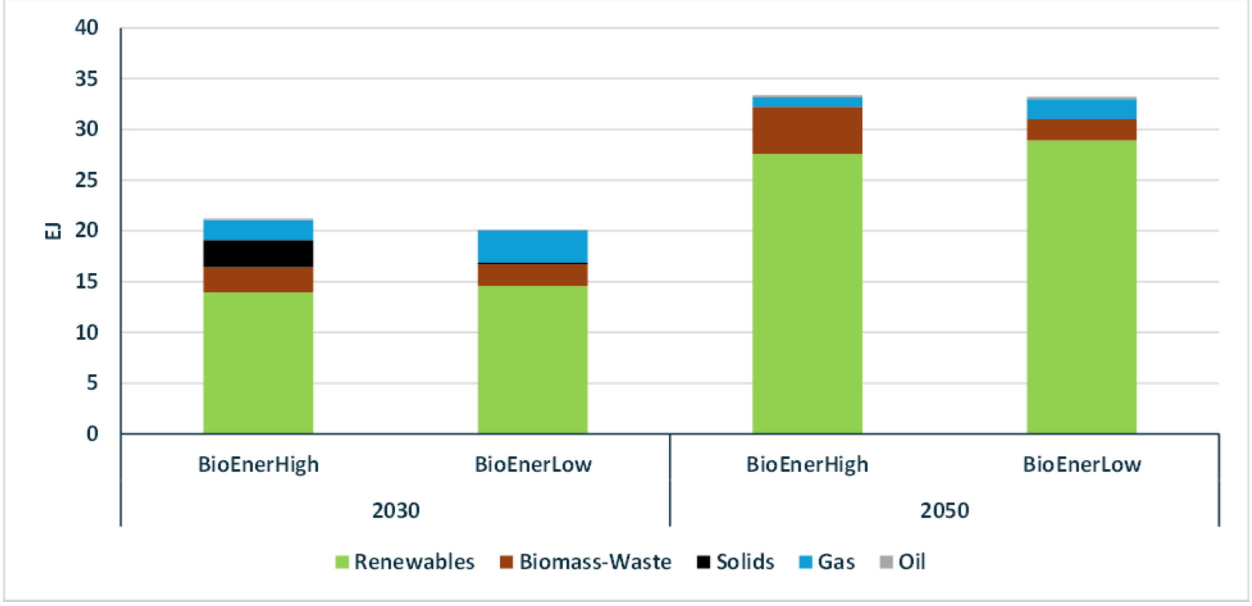


Figure 15 . Fuel mix for gross power generation for the EU27 in 2030 and 2050 (Source: PRIMES).

3.4.3. Bioenergy demand by bioenergy commodity type

Bioenergy commodities are comprised of liquid biofuels (used primarily in transport sector), solid bioenergy (i.e. mainly used in power and district heat sector, industry and the households sectors) and gaseous bioenergy (consumed mainly in power and district heat sector). In 2030, the main bioenergy commodity consumed is solid bioenergy, representing 70% of total bioenergy demand (i.e. 4.6 EJ in BioEnerHigh, 4.3 EJ in BioEnerLow and LimForestry), followed by liquid biofuels (i.e. 16-18% of total bioenergy demand, or 1 -1.1 EJ in all scenarios) and gaseous bioenergy (12-13% of total bioenergy demand or 0.8 EJ in all scenarios). All scenarios follow similar projections, with small differences.

In 2050, the increase in BioEnerHigh (2.6 EJ) is due to liquid biofuels (0.8 EJ increase compared to 2030 level) and gaseous biofuels (1.8 EJ increase compared to 2030 level). Solid biofuels, while being again the dominant bioenergy commodity representing 51% of the total demand, remain on the same level (4.6 EJ). Gaseous bioenergy is responsible for 29% (i.e. 2.6 EJ), and biofuels for 20% (i.e. 1.8 EJ) of total bioenergy demand. The increase demand of gaseous biofuels as shown in Figure 16 is higher for the BioEnerHigh due to the increased bioenergy demand of power and district heat sector.

While the total demand in BioEnerLow and LimForestry scenarios is similar between 2030 and 2050, there is a decrease in the demand of solid bioenergy and an increase of biofuels and gaseous bioenergy commodities. The demand for biofuels reaches 1.7 EJ (27% of total demand in 2050) and is slightly higher than the demand in gaseous bioenergy that is 1.5 EJ (24% of total demand in 2050). Solid biofuels are again the primary bioenergy commodity consumed (49% or 3.1 EJ in 2050). The increase in the demand of biofuels is linked with the increased penetration of bioenergy in the transport sector in 2050 (mainly maritime and aviation).

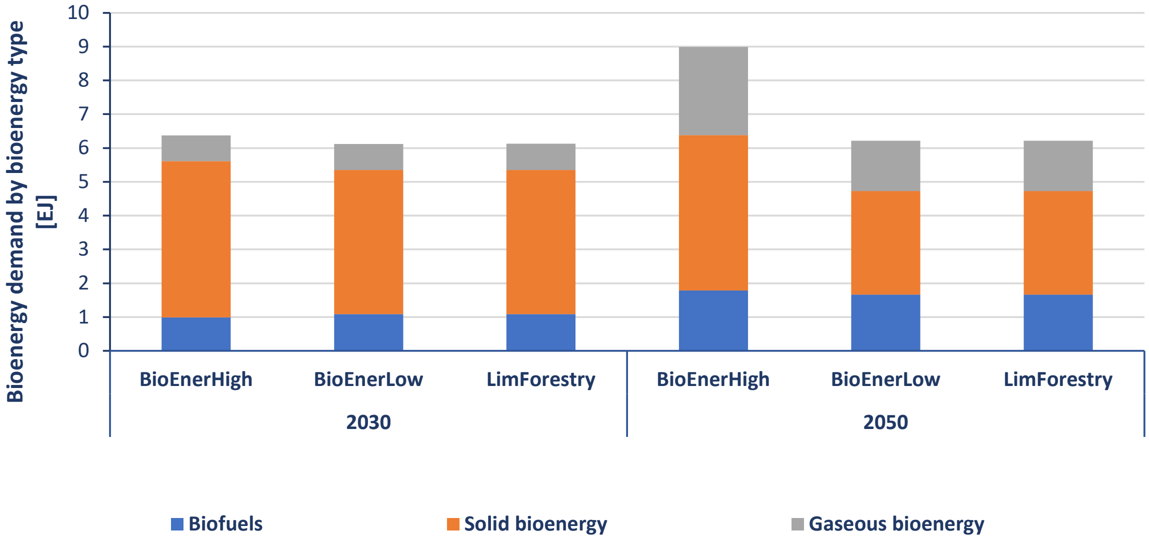


Figure 16. Bioenergy demand projections by bioenergy type for EU27 in 2030 and 2050 (Source: PRIMES).

3.4.4. Bioenergy demand by primary feedstock

In 2030, primary biomass and waste supply to meet the demand reaches 7.5 EJ in BioEnerHigh and 7.3 EJ in BioEnerLow and LimForestry, excluding imports. Biomass from forestry (harvested wood along with primary and secondary forestry residues) is the main feedstock used to produce bioenergy across all scenarios with shares from 41% to 45% of total biomass, followed by biomass of waste origin such as municipal solid waste, biowastes and industrial waste, with shares reaching 30% to 35% of total biomass supply, depending on the scenario. Agricultural residues and food-crops represent about 10-11% and 11-16% of primary supply of biomass, respectively in all scenarios. By 2030, lignocellulosic biomass crops (energy-crops) are not developed to such an extent to contribute to bioenergy demand, supplying only 0.5% of feedstock demand. Net imports of biomass and bioenergy products contribute by 0.3 EJ, primarily consisting of end-use solid biomass.

In 2050, in BioEnerHigh primary biomass supply reaches 12.7 EJ. Forestry biomass (4.4 EJ) and energy-crops (4.2 EJ) are the main source of supply, followed by biomass of waste origin (2.6 EJ) and agricultural residues (1.4 EJ). Compared to 2030, this is a growth of 69% for agricultural residues supply and 35% for forestry biomass. Supply of energy-crops shows the highest growth with their contribution reaching 33% of total biomass supply in 2050 (0.5% in 2030). It should be mentioned that the cultivation of dedicated lignocellulosic energy crops is very important for the decarbonization concept as it ensures supply of a feedstock, compatible with various bioenergy production pathways. In BioEnerLow, forestry biomass represents 43% of total biomass supply (4.0 EJ), followed by biomass of waste origin (2.4 EJ) and energy-crops (2.0 EJ). Agricultural residues contribute by 9% (0.8 EJ) and food-crops represent less than 1% of total biomass supply (0.05 EJ), owing to the phase-out of food-crops from the energy system driven to some extent by policy (i.e. the cap on food-based biofuels) and the uptake of advanced biomass conversion technologies that utilise lignocellulosic biomass (i.e. energy-crops). In LimForestry, owing to limits on forestry biomass feedstock, its primary supply is 3.1 EJ (or 31% of total biomass supply). Compared to BioEnerLow, the supply of energy crops increases to 2.23 EJ (or 12%), agricultural residues supply increases to 1.1 EJ (or 41%) with a respective share of 13% of total biomass supply. Primary feedstocks of waste origin remain at the same level as in BioEnerLow (i.e. 2.4 EJ). Food-crops represent less than 1% of biomass supply (0.05 EJ). Net imports of biomass and bioenergy products contributes by 0.2 EJ primarily consisting of end-use solid biomass. Between BioEnerLow and LimForestry, the supply gap owing to the limits on forestry biomass feedstock is covered through utilisation of energy-crops and the increase in the use of agricultural residues. These can be achieved by intensification of land-use and increase in residue recovery rates.

Figure 17 shows the projection of biomass supply for all types of primary feedstocks of all PRIMES scenarios for EU27 in 2030 and 2050.

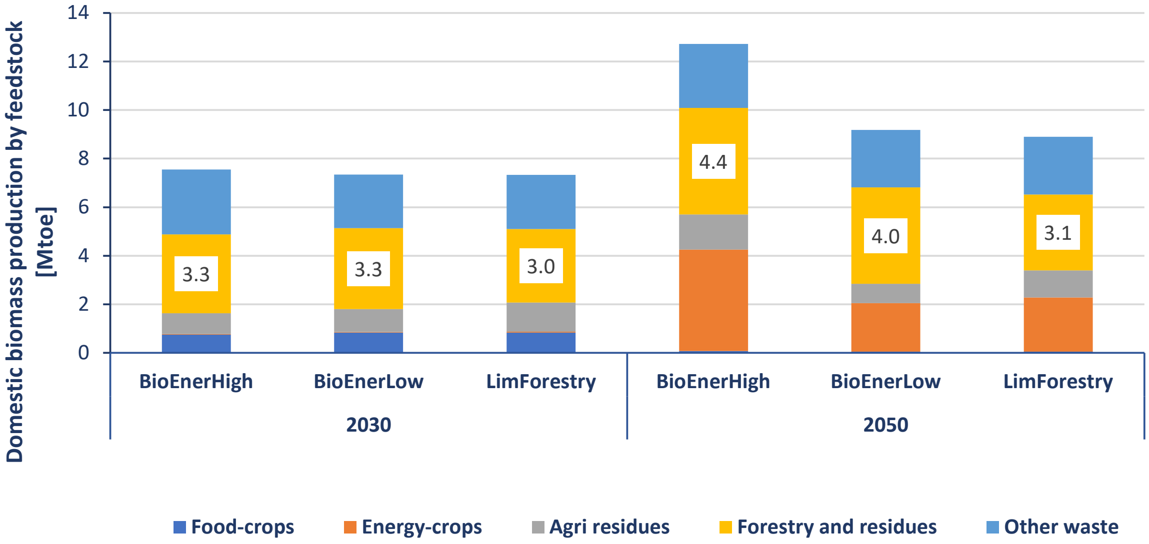


Figure 17. Primary biomass supply projections by feedstock type for EU27 in 2030 and 2050 (Source: PRIMES Biomass Supply model).

As shown in Figure 17 forestry biomass plays a crucial role in supplying the feedstock necessary to meet the bioenergy demand for the EU27 in 2030-2050. Figure 18 shows that in 2030, the consumption of harvested stemwood, primary and secondary forestry residues is similar (each forestry feedstock segment contributes about 0.9 to 1.2 EJ), across scenarios. In 2050, the overall amount of biomass of forestry origin is 29% lower in LimForestry when compared with BioEnerHigh and 21% lower than in BioEnerLow. Imposing limits on forestry feedstock owing to sustainability considerations primarily affects primary forestry residues.

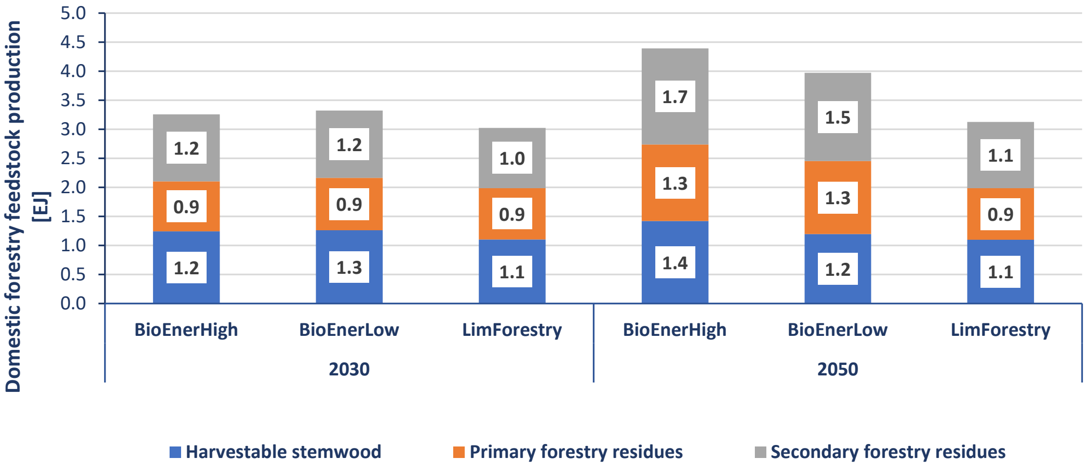


Figure 18. Forestry biomass feedstocks supply projections for EU27 in 2030 and 2050 (Source: PRIMES Biomass Supply model).

The modelling includes an additional exploratory scenario as a variant of the BioEnerLow scenario (i.e. MinForestry), that further reduces the consumption of forestry biomass compared to LimForestry. The two scenarios meet the same demand for bioenergy, but what sets them apart is the reduction in consumption of mainly primary forestry residues. The MinForestry scenario projects lower consumption of primary forest residues by 23% and of secondary forestry residues by 5% in 2050 when compared to LimForestry scenario, whilst consumption of harvestable stemwood and secondary forestry residues is similar. The levels of forestry biomass feedstocks of the MinForestry and the LimForestry scenario are presented in Figure 19.

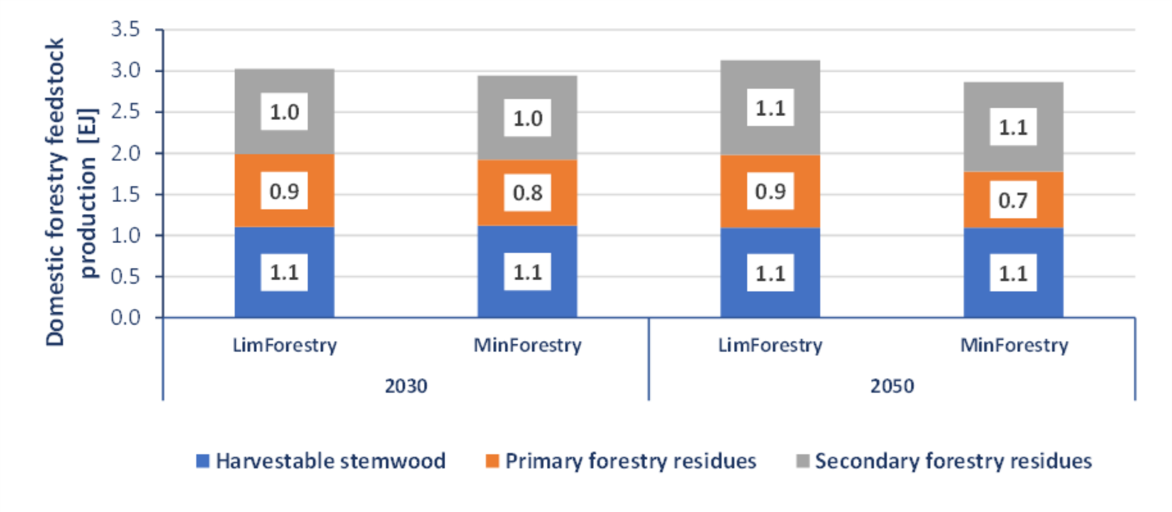


Figure 19. *Forestry biomass feedstocks supply projections for EU27 in 2030 and 2050* [exploratory scenario] (Source: PRIMES Biomass Supply model).*

The overall results of the analysis are presented in Table 8.

Table 8. Overall numerical results of PRIMES and PRIMES Biomass Supply model for BioEnerHigh, BioEnerLow, and LimForestry scenarios.

Year	**2030**			**2050**		
Unit: EJ	**BioEnerHigh**	**BioEnerLow**	**LimForestry**	**BioEnerHigh**	**BioEnerLow**	**LimForestry**
Bioenergy demand	**6.4**	**6.1**	**6.1**	**9.0**	**6.2**	**6.2**
Households	1.4	1.3	1.3	1.1	1.0	1.0
Industry	1.3	1.3	1.3	1.0	1.1	1.1
Transport and int. maritime	0.9	1.0	1.0	1.9	1.8	1.8
Electricity and district heat	2.3	2.0	2.0	4.6	2.0	2.0
Tertiary and other	0.4	0.4	0.4	0.5	0.4	0.4
End-use bioenergy commodities demand	**6.4**	**6.1**	**6.1**	**9.0**	**6.2**	**6.2**
Biofuels (Liquid bioenergy)	1.0	1.1	1.1	1.8	1.7	1.7
Solid bioenergy	4.6	4.3	4.3	4.6	3.1	3.1
Gaseous bioenergy	0.8	0.8	0.8	2.6	1.5	1.5
Primary Domestic biomass supply	**7.5**	**7.3**	**7.3**	**12.7**	**9.2**	**8.9**
Food-crops	0.8	0.8	0.8	0.1	0.0	0.1
Energy-crops	0.0	0.0	0.0	4.2	2.0	2.2
Agri residues	0.9	1.0	1.2	1.4	0.8	1.1
Other waste	2.7	2.2	2.2	2.6	2.4	2.4
Forestry biomass	**3.3**	**3.3**	**3.0**	**4.4**	**4.0**	**3.1**
Harvestable stemwood	1.2	1.3	1.1	1.4	1.2	1.1
Primary forestry residues	0.9	0.9	0.9	1.3	1.3	0.9
Secondary forestry residues	1.2	1.2	1.0	1.7	1.5	1.1
Net Imports (primary and end-use bioenergy)	**0.3**	**0.3**	**0.3**	**0.2**	**0.2**	**0.2**

3.5. GLOBIOM scenarios and implications for intermediate wood product supply and demand

3.5.1. EU roundwood harvest

The harvest of roundwood in the GLOBIOM scenarios is primary driven by the levels of bioenergy demands, with an evident segregation of scenarios with LowBIOEN vs. HighBIOEN. In the baseline (BaseBIOEN_BaseCIRCU_BaseCONST), there will be an increase of roundwood harvest from 502 to 567 Mm^3 $year^{-1}$ (13% increase) between 2020 and 2040, when the peak of roundwood harvest will be reached (Fig. 20), according to the peaking of bioenergy demand. The difference in harvest between the BaseBIOEN scenario compared to HighBIOEN (BaseCIRCU_BaseCONST) reaches 14 Mm^3 in 2030 and 82 Mm^3 in 2050, under this latter scenario harvest increase between 2020-2040 is 32%. The scenario with the lowest roundwood harvest is the one where low bioenergy demand is associated with low construction materials demand and high circularity (LowBIOEN_HighCIRCU_LowCONST), under this scenario, harvest decreases by 6% between 2020-2030 and 10% by 2040. The maximum harvest increases between 2020 and 2040 are observed under the HighBIOEN_BaseCIRCU_HIghCONST_HighTEXT (34% increase), where high demands level for construction wood and wood-based textiles are assumed without improvement in wood recycling/reuse.

The high bioenergy demand scenarios increase forest industry by-products demand and forest industry profitability, which leads to higher forest industry roundwood use. In GLOBIOM, industrial roundwood is not allowed to be used directly for energy, hence, high bioenergy demand does not increase directly roundwood use for energy, but only indirectly.

The HighCONST scenarios increases roundwood harvest by 37 Mm^3 in 2050 compared to the BaseCONST under the BaseBIOEN. However, this effect could in principle be fully compensated by HighCIRCU that allows to maintain harvest level for HighCONST at the same level as BaseCONST. Therefore, if high construction demand is combined to high circular economy, roundwood harvest can theoretically remain stable at parity of bioenergy demand. The high circular economy scenario decreases also roundwood prices, which increases forest industry profitability and net exports. This effect tends to increase also EU roundwood harvest (pulplogs relative to sawlogs), but this effect is smaller than material saving effects.

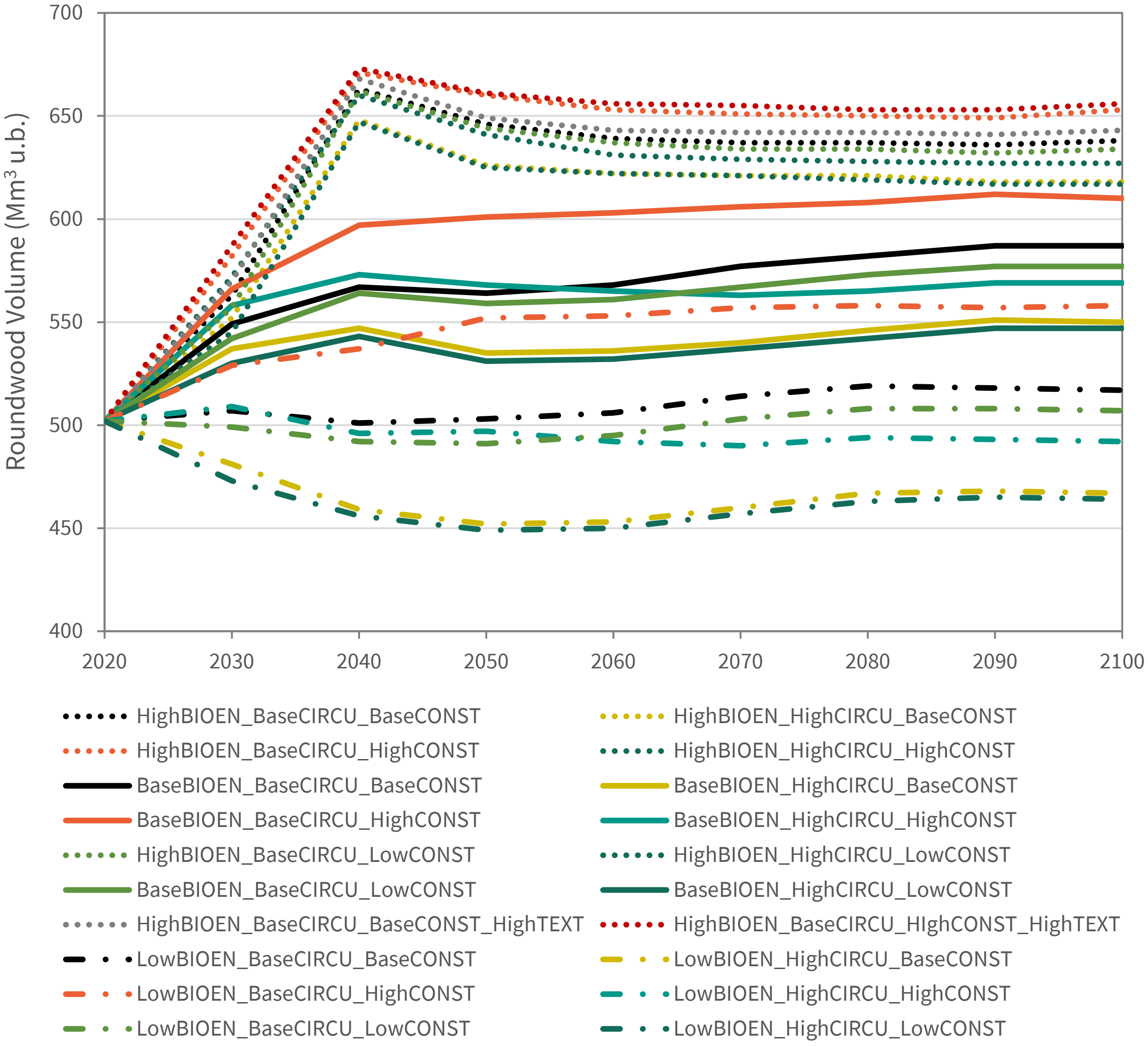


Figure 20. EU roundwood harvest volume projections according to the GLOBIOM scenarios.

3.5.2. EU woody biomass harvest

In the baseline (BaseBIOEN_BaseCIRCU_BaseCONST), woody biomass harvest increases from 610 (year 2020) to 693 Mm^3 year^{-1} (13%) by 2040 and afterwards it stabilizes at a similar level. Under the scenario with the highest harvest (HighBIOEN_BaseCIRCU_HIghCONST_HighTEXT), it reaches 840 Mm^3 by 2040 (38% increase) and under the scenario with the lowest harvest (LowBIOEN_HighCIRCU_LowCONST), it reaches 532 Mm^3 by 2040, that corresponds to a 13% decrease from current levels.

Hence, when including the logging residues together with the roundwood, the segregation between the LowBIOEN and the HighBIOEN scenarios is more evident, given that logging residues are used only for satisfying energy demand. However, the ordering of scenarios remains generally the same as for the roundwood harvest (Fig. 21).

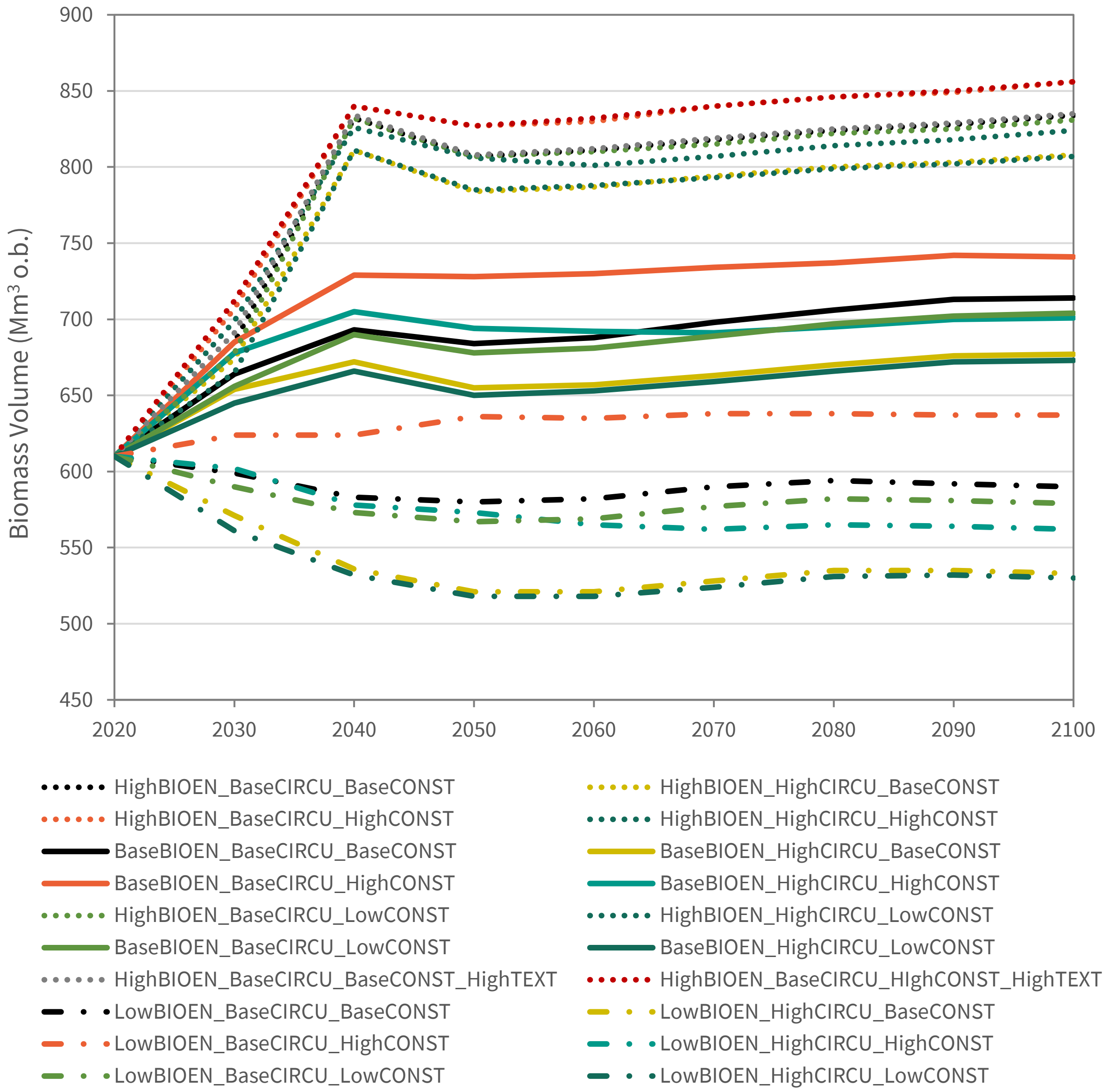


Figure 21. EU woody biomass harvest volume (roundwood over bark and logging residues) projections according to the GLOBIOM scenarios.

The harvest trend is dominated by sawlogs, that represent 42% of the total biomass harvest in 2020, followed by pulpwood that represent 29%. Under the BaseCONST sawlogs increase to 45% by 2050. In the HighCONST there is an increasing demand for sawlogs that make their share to reach 48% of total biomass harvest by 2050. HighCIRCU has an opposite effect, by maintaining the share of sawlogs at 42% of biomass harvest in 2050, that is compensated by an increase of pulpwood harvest that reaches 32% of total harvest. These effects are due to a decrease in sawmills by-products under HighCIRCU, being compensated by more pulpwood harvest (Table 9). Fuelwood follows a stable development over time, and it is not influenced significantly by the scenarios. Logging residues harvest amount increase by 10-25% during 2020-2050 under the BaseBIOEN and almost double their amount under the HighBIOEN. In case of LowBIOEN, their harvest remains at the current level.

Table 9. EU harvest amounts (Mm^3 over bark year^{-1}) for primary forest products according to selected GLOBIOM scenarios.

SCENARIO	PRODUCT	2020	2030	2040	2050	2100
BaseBIOEN_BaseCIRCU_BaseCONST (GLOBIOM Baseline)	Sawlogs	254	298	308	309	333
	Pulpwood	177	190	201	198	200
	Fuelwood	139	135	135	135	135
	Log. residues	39	41	49	43	47
BaseBIOEN_BaseCIRCU_HighCONST	Sawlogs	254	319	343	351	365
	Pulpwood	177	190	200	198	194
	Fuelwood	139	135	134	134	134
	Log. residues	39	42	51	45	49
BaseBIOEN_HighCIRCU_HighCONST	Sawlogs	254	292	295	290	279
	Pulpwood	177	207	222	222	232
	Fuelwood	139	135	134	135	135
	Log. residues	39	45	54	49	55
HighBIOEN_BaseCIRCU_HighCONST _HighTEXT	Sawlogs	254	323	358	358	366
	Pulpwood	177	210	278	262	245
	Fuelwood	139	134	128	132	134
	Log. residues	39	45	75	76	111
LowBIOEN_HighCIRCU_LowCONST	Sawlogs	254	248	241	243	264
	Pulpwood	177	170	178	192	206
	Fuelwood	139	102	69	35	34
	Log. residues	39	40	40	41	40

3.5.3. EU forest products net exports

Forest products net export can be interpreted as indicator of EU forest industry future competitiveness (Lauri et al. 2021). We observe that EU is generally expected to remain a net-exporter of forest products in most of the scenarios, and to be able to increase its trade competitiveness in the short term. However, in the scenarios where there is HighCONST demand and at the same time LowCIRCU, the EU could become a net importer of wood products by 2050 (Fig. 22). This effect could potentially be exacerbated when adding also a highTEXT demand on the top of the HighCONST.

The HighCIRCU has potential to impact on EU net export, by lowering roundwood prices in the EU and favouring its export competitiveness. HighCONST has an opposite effect by increasing internal EU demands and roundwood prices, and by reducing by that forest industry competitiveness and EU net exports. The HighTEXT increases the internal demand even more and it adds to the effects of HighCONST. The effect of alternative BIOEN scenarios are less evident for the net exports, if compared to the harvest levels. However, low bioenergy demand is reducing (like under LowBIOEN) EU wood industry competitiveness by reducing the energy demand for by-products.

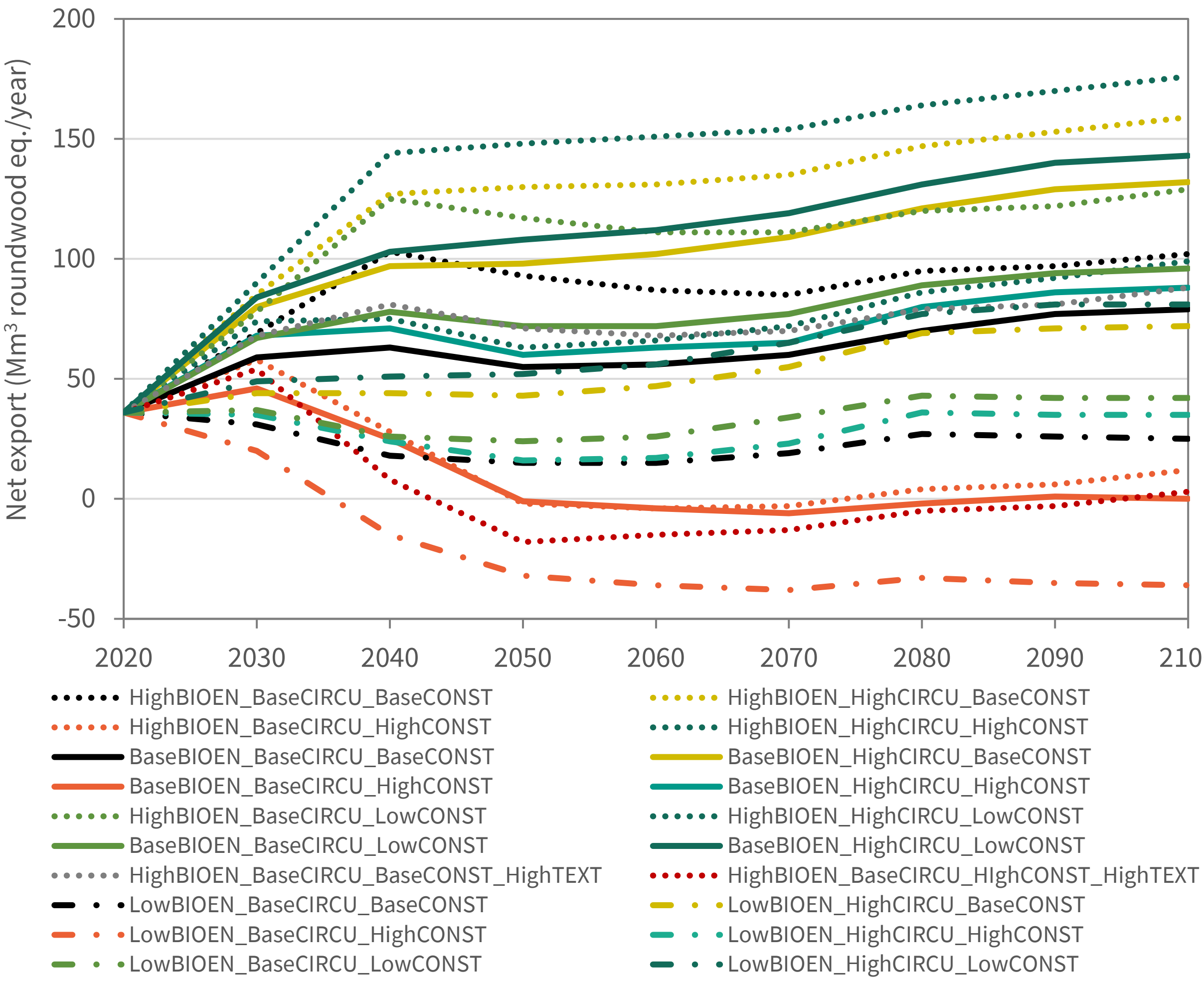


Figure 22. EU forest products net export (in roundwood equivalents) projections according to the GLOBIOM scenarios.

3.5.4. EU wood-based products production

The production of sawnwood in 2050 spans between 127 and 181 Mm^3 year^{-1}, that is an increase between 13% and 62% compared to 2020 (Table 10). The largest increase compared to the Baseline (in 2050) is observed when considering HighCONST together with HighCIRCU (+54 Mm^3 year^{-1}). That is, increased sawnwood reuse leads to a rebound effect by lowering the prices and increasing the demand. BIOEN scenarios has a relatively smaller impact on sawnwood production than CONST scenarios. Under the scenarios, wood panels follow a similar trend as sawnwood production.

Table 10. EU production amount (Mm^3 year^{-1}) for semi-finished products (sawnwood and wood panels) according to selected GLOBIOM scenarios.

SCENARIO	PRODUCT	2020	2030	2040	2050	2100
BaseBIOEN_BaseCIRCU_BaseCONST	SawnWood	112	125	128	127	133
(Baseline)	WoodPanel	62	75	78	82	92
BaseBIOEN_BaseCIRCU_HighCONST	SawnWood	112	135	145	147	149
	WoodPanel	62	89	108	129	139
BaseBIOEN_HighCIRCU_HighCONST	SawnWood	112	147	167	181	194

	WoodPanel	62	87	106	125	132
HighBIOEN_BaseCIRCU_HighCONST _HighTEXT	SawnWood	112	136	154	154	154
	WoodPanel	62	89	96	119	132
LowBIOEN_HighCIRCU_LowCONST	SawnWood	112	125	133	136	147
	WoodPanel	62	69	73	76	86

The production of chemical pulp in 2050 spans between 32 and 45 Mton year^{-1}, that is an increase of 3%-55% compared to 2020 (Table 11). The maximum of chemical pulp production is observed under the HighBIOEN_BaseRECYCLE_HighCONST_HighTEXT. Whereas, in the LowBIOEN scenarios pulpwood production stays at a lower level, due to the reduced demand for by-products for energy use. Recycled pulp does not differ significantly between the scenarios and the increase over time is aligned to the one of chemical pulp production.

Table 11. EU production amount (M ton year^{-1}) for semi-finished products (pulp-based) according to selected GLOBIOM scenarios.

SCENARIO	PRODUCT	2020	2030	2040	2050	2100
BaseBIOEN_BaseCIRCU_BaseCONST	ChemPulp	29	35	38	38	40
	MechPulp	9	9	8	8	8
	Recycledpulp	40	45	49	52	58
BaseBIOEN_BaseCIRCU_HighCONST	ChemPulp	29	35	37	37	37
	MechPulp	9	9	8	8	8
	Recycledpulp	40	45	49	52	59
BaseBIOEN_HighCIRCU_HighCONST	ChemPulp	29	36	39	39	41
	MechPulp	9	9	8	8	7
	Recycledpulp	40	45	49	52	58
HighBIOEN_BaseCIRCU_HighCONST _HighTEXT	ChemPulp	29	39	47	45	47
	MechPulp	9	9	7	7	6
	Recycledpulp	40	45	49	52	58
LowBIOEN_LowCIRCU_LowCONST	ChemPulp	29	28	30	32	35
	MechPulp	9	11	11	10	10
	Recycledpulp	40	46	50	53	59

For forest industry by-products, an interplay is evident between the sawnwood industry residues (sawdust), recycled wood and the black liquor from pulpwood (Table 12). Under scenarios of HighCONST there is an increase of sawdust that is generated by processing more sawnwood, this effect is lowered under the HighCIRCU where more wood is being reused. At the same time, under the HighCIRCU, a relative reduction of sawdust from virgin sawnwood is compensated by an increase of production in the pulpwood industry that contributes by increasing the amount of black liquor. Black liquor is also strongly influenced by the level of bioenergy demand, with

LowBIOEN substantially reducing production of black liquor over time compared to the HighBIOEN.

Table 12. EU production amount (Mm^3 year^{-1}) of forest industry by-products according to selected GLOBIOM scenarios.

SCENARIO	PRODUCT	2020	2030	2040	2050	2100
BaseBIOEN_BaseCIRCU_BaseCONST	WoodChips	121	138	143	143	152
	Sawdust	37	42	43	44	46
	Bark	53	60	62	62	64
	BlackLiquor	68	82	88	87	92
	Recycledwood	58	75	89	94	101
BaseBIOEN_BaseCIRCU_HighCONST	WoodChips	121	148	160	163	168
	Sawdust	37	45	48	50	51
	Bark	53	62	67	67	67
	BlackLiquor	68	82	86	85	86
	Recycledwood	58	83	110	134	149
BaseBIOEN_HighCIRCU_HighCONST	WoodChips	121	136	138	136	130
	Sawdust	37	41	42	41	40
	Bark	53	61	63	62	61
	BlackLiquor	68	85	90	90	95
	Recycledwood	58	98	155	197	228
HighBIOEN_BaseCIRCU_HighCONST _HighTEXT	WoodChips	121	150	171	171	174
	Sawdust	37	45	52	52	53
	Bark	53	65	80	78	76
	BlackLiquor	68	94	117	113	116
	Recycledwood	58	85	121	142	150
LowBIOEN_HighCIRCU_LowCONST	WoodChips	121	116	112	113	119
	Sawdust	37	35	34	34	37
	Bark	53	51	51	52	55
	BlackLiquor	68	65	69	75	81
	Recycledwood	58	91	115	125	135

3.6. Limitations and uncertainties

The analysis of forest products markets is bound by the shortage or lack of market data. This has been considered in the design of the scenario analysis approach combining qualitative and quantitative approaches.

The aim was not to produce a systematic outlook of the entire sector or make predictions of most likely future trajectories, but to explore plausible future developments based on current understanding and available data. This will be further reflected in later deliverables as additional “what if” and sensitivity analyses.

While forest management scenarios often extend up to 2100 or beyond, such projections would be fraught with uncertainty for forest products markets. Thus, the material and energy use scenarios were formed to 2050: Despite great uncertainty on this time frame as well, one can argue that it is only one full investment cycle away, so that the products being produced in large scale in 2050 should already be at least in the pilot phase in the 2020s.

Some of the GLOBIOM scenarios were created by means of ad-hoc assumptions on future markets and technological developments (i.e. LowBIOEN, HighCONST, HighCIRCU), these should be regarded as exploratory “what-if” scenarios for observing potential future impacts on EU harvest levels, beside the more conventional scenarios grounded on the observed market developments. Therefore, further refinement of these scenarios will be required in upcoming tasks.

The naming of GLOBIOM scenarios is not consistently aligned with the ones adopted in 3.1-3.3. GLOBIOM Baseline scenarios are the ones following conventional modelling assumptions for the development for material and energy sectors demands. Hence, deviations from the conventional assumptions were considered as alternative scenarios (relatively Low/High demand growth). Instead, in 3.1-3.2, Baselines are determined case by case. Further effort is needed for improving the alignment of the scenarios created by alternative approaches.

4. Conclusion

4.1. Material and energy scenarios

D5.1 presents plausible demand trajectories for selected key end uses of intermediate wood-based products: regenerated cellulosic fibres (RCFs), wood-based construction, and bioenergy and biofuels. The analysis encompasses three types of scenarios for each of the three markets studied: i) baseline developments following business-as-usual, ii) scenarios depicting a realistic increase in the market share of wood, and iii) “what if” scenarios for examining the sector level responses to structural changes of unprecedented scale. Table 13 summarizes the material and energy use scenarios and the scale of their impacts on the demand of wood-based intermediate products in the EU in 2050.

The total global textile market varied in the scenarios from 176Mt to 350Mt, and the market share of RCFs was assumed to increase from around 6% to 8%-14%, depending on recycling possibilities of polyester and cotton. RFCs were mainly assumed to respond to the increasing demand, and partially substitute cotton whose production cannot increase sustainably from the current level. Most of the substitution was assumed to occur between different RCF types rather than between RCFs and non-wood fibres. In particular, Lyocell and novel RCFs are seen to substitute the established Viscose and Modal production.

The overall construction volume is expected to remain close to the current level in the EU. Minor increase was assumed regarding wood-based multi-storey buildings, but greatest potential for increased wood use is expected from hybrid construction and mixed materials. Due to the minor changes in volumes, changes in the construction sector are expected to have minor effect on harvest levels. Instead, the increase in domestic wood use in construction could be covered from reduced exports of intermediate wood-based products. In the expert scenarios, the difference in intermediate wood product demand was less than 1 Mm^3 when comparing the ‘Wood Increase’ scenario to the baseline in 2050. However, to see the effect of extreme ”what if” scenarios, the GLOBIOM scenarios simulate the effect of gaining a 50% increase in the market share of wood from concrete in selected residential building types in the EU.

The wood-based bioenergy supply increases in all scenarios in the EU to 2050. In the “Bioenergy high” scenario the increase in bioenergy supply compared to 2020 is around 60%, while the increase is around 15% and 7%, respectively, in the “Limited forestry feedstocks” and “Minimum forestry feedstock” scenario, in which LULUCF and biodiversity policies impose limits on the forest harvest. Imposing limits on forestry feedstock owing to sustainability considerations primarily affects the availability of forestry residues for bioenergy rather than fuelwood harvest.

The experts agreed that bio-based chemicals and -fuels will increase their market share in the EU and globally in the future. However, most of the production was believed to be based on agricultural side streams and fast-growing crops instead of wood. Only hydrocarbon production through innovative technologies such as hydrothermal liquefaction (HTL) or Power-To-Liquid could realistically utilize large shares of forest-based raw materials in the production. However, it would require reduced direct energy use of wood especially in the form of secondary residues within wood product mills, leading to increased demand for alternative energy sources within the forest-based sector.

Table 13. Summary of scenarios and their implications on the market share of wood and change in volume demanded in selected markets.

Construction (EU)	**2020-2024**	**Baseline 2050**	**Wood increase 2050**	**Major wood increase 2050**	**Decreased living area 2050**
Total market	352 Mm^2	356 Mm^2	362 Mm^2	356 Mm^2	320 Mm^2
Wood-based market share %	10%	9.3%	10.1%	27%	9.3%
Demand for wood-based intermediate products (Mm^3)	16.6 Mm^3	17.1 Mm^3	17.9 Mm^3	30.2 Mm^3	15.4 Mm^3
Textiles (global)	**2020-2024**	**Baseline 2050**	**Increasing consumption**	**Slowing consumption**	
Total market	113 Mt	253 Mt	350 Mt	176Mt	
Wood-based market share %	6.4%	7.7%	13%	14%	
Demand for wood-based intermediate products (Mt)	7.2 Mt	19.47 Mt	45.5 Mt	24.64 Mt	
Bioenergy (EU)	**2020**	**Baseline: Bioenergy high 2050**	**Bioenergy low 2050**	**Limited forestry feedstocks 2050**	**Minimize forestry feedstock 2050**
Total market	30 EJ	59.3 EJ	59.3 EJ	31.7 EJ	31.7 EJ
Wood-based market share %	9%	7.4%	6.7%	9.8%	9.1%
Total wood-based bioenergy (EJ)	2.7 EJ	4.4 EJ	4.0 EJ	3.1 EJ	2.9 EJ
Harvested wood for energy GLOBIOM scenarios (incl. by products) (Mm^3)	396 Mm^3	589 Mm^3	561 Mm^3[ii]	455 Mm^3	426 Mm^3[ii]

4.2. GLOBIOM scenarios combining material and energy uses

A further set of exploratory scenarios approximately following the material and energy scenarios were assessed with GLOBIOM. The GLOBIOM scenarios are feasible in terms of meeting the different market demands without exceeding forest growth (Table 9). Overall, demand for woody biomass is projected to culminate in 2040 in scenarios with relatively high forest bioenergy demand, to continue to grow but at a slower pace also after 2040 for scenarios with relatively stable forest bioenergy demand or to slightly decrease in scenarios with relatively low bioenergy demand. Accordingly, during the period 2020-2050, EU woody biomass harvest could increase by up to 38% or decreased down to 13% across the scenarios, depending on the specific combinations. The maximum harvest of woody biomass is achieved in case of high demand for construction material and textiles coupled with high bioenergy demand and relatively low circularity. The minimum increase is observed under a scenario of relatively low forest bioenergy demand, constant

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[ii] Interpolated between the scenarios simulated in GLOBIOM.

construction material demand, low growth in demand for textiles and low development of the circularity.

Forest bioenergy demand is the primary driver for the observed harvest differences between the scenarios, creating a segregation of scenarios with low/high bioenergy demand. Scenarios with extremely high wood construction demand will contribute to increase harvest levels, additionally to bioenergy demands, but with a relatively minor impact. However, scenarios with extremely high construction material demands could cause a decline in EU forest products net export, due to the high internal demand for wood. This effect can in principle be fully compensated if increasing the reuse of solid wood products, given favourable market assumptions. Indeed, the high circular economy scenarios allow to maintain harvest at the same level than scenarios with relatively low demands for construction and improve the forest industry competitiveness. Scenarios assuming a decrease in forest bioenergy demand could reduce EU harvest but also reduce the competitiveness of EU forest industries.

4.3. Future work

The demand projections will be used directly in the remining tasks under WP5 to quantify the effect of the scenarios on HWP emissions and removals (D5.2), substitution effects (D5.3), and socio-economic effects (D5.4). The analyses and projections from WP5 will be further utilized in WP6-7 for more encompassing analysis of synergies and trade-offs between forest ecosystem services.

Alternative ways of integrating material and energy scenarios remain an important avenue for further research. With the available models it is not possible to consistently close the gap between supply driven and demand driven modelling. For example, a textiles sector model ought to be integrated to a forest sector model to assess the impact of changes in the textiles sector to the supply and demand for wood-based intermediate products. While general equilibrium models could in principle achieve this, they also tend to operate on a semi-finished product level. More streamlined approaches for the integration of material and energy uses of wood will be performed in the context of the remaining deliverables.

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6. Annexes

Annex 1 *– Interview frame for the textile scenarios.*

1. How do you see the market development regarding the following textile types? Please give your estimates (best guess), what is the total production of textile fibers in 2050, and provide the shares of different textile types. There is no correct answer and you can use the official business as usual estimates as a help (retrieved from Textile Exchange Reports)

Please provide a short justification for your estimate regarding individual fiber types

- Polyester:
- Cotton:
- RCFs:

2. Please provide the shares of different RCFs (of the total RCF production) in 2050

Acetate holds relatively high production volume, but it is mainly used for hygiene products and does not substitute common textile products. Do you believe there is some other RCF form in 2050 that has a more significant market share (which substitutes non-wood textile products)?

Please provide a short justification for your estimate regarding individual RCF types

Viscose:

Lyocell:

Modal:

Acetate, other:

Innovative RCFs:

3. What fiber types are most likely different RCFs substituting?

Viscose:

Lyocell:

Modal:

Acetate, other:

Innovative RCFs:

4. What are the main raw material sources for different RCF types and can you estimate a percentage, how much of the production is based on dissolving pulp? is some of the production based on some other pulp type/ otherwood-based raw material?

Viscose:

Lyocell:

Modal:

Acetate, other:

Innovative RCFs:

5. Can you estimate, how much of the dissolving pulp produced in EU will end up in textile production?

6. Which countries you believe to be the biggest producers in EU?

***If the interviewee indicated rising demand for RCFs*:**

7. **How much (in percentages%) of the increasing demand of RCFs would be covered by extra harvests?** If not 100%, how is the increasing demand of dissolving pulp covered? Is it covered by the end use shifts, for example, more dissolving pulp is produced instead of chemical pulp? Or more sawmilling side streams are directed to pulp production instead of energy?

If the interviewee indicated decreased demand:

How much (%) of the decreased demand is transforming into decreased harvests? If not 100%, will some other production form take over?

8. After assessing your response, what positive do you see in this development? What negative do you see in this development?

9. What are the main drivers of this development and what are the main barriers of this development?

Annex 2 *– Interview frame for the construction scenarios.*

10. How do you see the market development regarding the following construction types? Please give your estimates (best guess), what is the total production of new buoldings in 2050, and provide the shares of different housing types. There is no correct answer and you can use the official statistics estimates as a help

Please provide a short justification for your estimate regarding individual housing types:
- Total number of buildings constructed:
- Concrete residential multi-storey buildings:
- Concrete non-residential multi-storey buildings:
- Brick and Stone multi storey buildings:
- Brick and Stone detached- and semi detached residential houses (single family)
- Wood structured residential multi-storey buildings:
- Wood structured non-residential multi-storey buildings:
- Wood structured detached- and semi detached residential houses:
- Other:
- Other relevant wood-based building type in 2050?:

11. Regarding wooden buildings, how much of them would be CLT/LVL (massive) framed?

12. ***If the demand for wood-based products increase in the estimates*:** How this additional demand for raw materials would be covered? Considering e.g. extra harvests, change in product portfolios or change in the export rates

13. Does the foor number increase in multi-storey buildings?

Annex 3 *– Interview frame for the biofuel/-chemical scenarios.*

The structure of the interview was less formal, since the aim was to define market-potential wood-based chemical and -fuel types based on the expert responses

14. How do you see the market development regarding the biochemical and -fuel types? Please give your estimates (best guess), what is the total production in 2050, and provide the biobased shares. There is no correct answer and you can use the background statistics of some selected chemical and fuel -types as a basis for your answer. Please give your estimate, which are the most potential bio-based chemical and/or -fuel types in 2050 with their production estimates.

    Please provide a short justification for your estimate

15. What are the main raw material sources for different biobased chemicals and -fuels? What share could be wood-based?

16. Can you estimate, how much of the bioethanol produced in the EU will end up in Ethylene?
17. Which countries you believe to be the biggest producers in the EU?

If the interviewee indicated rising demand for some (wood-based) chemicals or fuels:
18. How much (in percentages%) of the increasing demand of (wood-based) biochemicals and fuels would be covered by extra harvests? If not 100%, how is the increasing demand covered? Is it covered by the end use shifts, for example, more sawmilling side streams are directed to refinery instead of energy?

If the interviewee indicated decreased demand:

How much (%) of the decreased demand is transforming into decreased harvests? If not 100%, will some other production form take over?

19. What are the main drivers of this development and what are the main barriers of this development?

Annex 4 – GLOBIOM country shares of solid semifinished products (sawnwood and wood panels) consumption for final products according to Mantau et al. (2010).

Country	Primary and secondary construction	Furniture	Wood Packaging
AUT	0.65	0.27	0.08
BEL	0.5	0.3	0.2
BGR	0.25	0.5	0.25
CYP	0.9	0.1	0
CZE	0.58	0.2	0.22
DEU	0.52	0.28	0.2
DNK	0.68	0.22	0.1
ESP	0.5	0.3	0.2
EST	0.67	0.15	0.18
FIN	0.72	0.13	0.15
FRA	0.35	0.25	0.4
GBR	0.58	0.27	0.15
GRC	0.52	0.36	0.12
HRV	0.6	0.25	0.15
HUN	0.48	0.22	0.3
IRL	0.88	0	0.12
ITA	0.48	0.32	0.2
LTU	0.42	0.3	0.28
LUX	0	1	0
LVA	0.47	0.23	0.3
MLT	0.52	0.3	0.18
NLD	0.58	0.22	0.2
POL	0.42	0.35	0.23
PRT	0.58	0.37	0.05
ROU	0.4	0.48	0.12
SVK	0.4	0.4	0.2
SVN	0.55	0.27	0.18
SWE	0.68	0.14	0.18