ForestNavigator

D6.4 Report on modelling the EU forests in a multisectoral context

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Abstract

Task 6.4 of the ForestNavigator project focuses on developing a robust and integrated modelling toolbox to assess the climate mitigation potential of the EU forest-based sector. Building on the conceptual framework of Task 6.1, the toolbox enhances existing models by addressing key limitations in representing climate change impacts, forest disturbances, harvested wood product dynamics, and cross-sectoral policy interactions. At its core, the toolbox integrates the GLOBIOM/G4M-X modelling framework, which combines economic land-use modelling with detailed forest management simulations that now include climate-induced risks and adaptive responses.

A major achievement of Task 6.4 was the linkage between GLOBIOM/G4M-X and the PRIMES Energy Systems model. This connection enables PRIMES to incorporate land-based biomass supply curves that reflect forest sector mitigation efforts, enhancing its data on future biomass availability. Additionally, the integration with the MAGNET economic model allows for the representation of rising demand for wood-based materials and products, ensuring that non-energy uses are captured in mitigation scenarios.

These model linkages ensure internal consistency across the AFOLU, energy, and economic sectors, aligning EU climate neutrality pathways with global targets (POLES). The ForestNavigator Modelling Toolbox thus provides a comprehensive and policy-relevant platform for evaluating forest sector contributions to climate mitigation, biodiversity conservation, and sustainable development.

Keywords

Climate mitigation, biomass, forest sector, modelling

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Abbreviations

EC	European Commission
EU	European Union
WP	Work Package
MS	Member State
GECO	Global Energy and Climate Outlook
AFOLU	Agriculture, Forestry and other Land Use
LULUFC	Land Use, Land-Use Change, and Forestry
GHG	Greenhouse gas
Mtoe	Million tons of oil equivalent

1. Introduction

Forests play a key role in climate policy, currently offsetting around 7% of the EU's greenhouse gas emissions, with expectations for increased contributions according to the EU climate neutrality goal. The EU Green Deal emphasizes the dual goals of climate mitigation and biodiversity conservation, with initiatives like the Nature Restoration Law aiming to restore 20% of land and sea areas by 2030. However, forest carbon sinks are weakening due to rising harvest rates, ageing forest structures, and climate impacts that are shifting disturbance regimes (pest and wildfire outbreaks). These changes threaten ecosystem service delivery, especially in vulnerable regions. To address these challenges, integrated forest management and policy assessment models are needed to balance climate goals, biodiversity protection, and economic development. The ForestNavigator project aims to evaluate climate change mitigation pathways of the forest-based sector in the EU. In this context, Task 6.4 of WP6 aims to provide a robust modelling toolbox for integrated impact assessment of the forest sector's climate mitigation potential.

The ForestNavigator Modelling Toolbox as conceptualised in Task 6.1[i] aims to overcome existing limitations in currently used modelling frameworks, such as lack of representation of climate change impacts and disturbances in mitigation potential estimates (Jäger, et al., 2024), the representation of the harvested wood products pool and the substitution effects in policy pathways (Lauri, et al., 2021), as well as the lack of cross-sectoral interactions, potentially overlooking synergies an unintended consequence of policy implementation across sectors (Berry, et al., 2015).

The modelling toolbox developed in Task 6.1 is centred around the GLOBIOM/G4M-X model (https://globiom.org/documentation.html). The GLOBIOM/G4M-X consist of two iteratively linked models, GLOBIOM (IBF- IIASA, 2023) and G4M-X (Gusti, 2020). The Global Biosphere Management Model (GLOBIOM) is a global recursive dynamic equilibrium model of the agriculture, forest and bioenergy sectors, which provides a rich set of environmental and socioeconomic indicators for policy impact assessment of the land use sector. G4M is a global model of forest management and land use change, which estimates the impact of forestry activities (i.e., biomass harvest, afforestation,) on carbon stock and afforestation/deforestation decisions. G4M-X resulted after the development of the G4M model which has a scope to enhance the biophysical representation in G4M, to account for climate change impacts, disturbances, and adaptive actions of forest management decisions. G4M-X hence adapts forest management in each grid cell, in terms of afforestation/deforestation decisions, changes in rotation length, thinning intensity, salvage logging and stocking density, depending on the wood demand, wood price, carbon taxes, changes in forest increments and land prices. GLOBIOM/G4M-X is the primary tool for computing the AFOLU sector's policy pathways toward climate neutrality, including climate change effects disturbances and emerging bio-based economic demands.

The decarbonization pathways of the energy sector in the ForestNavigator modelling Toolbox will be developed using the PRIMES Energy Systems modelling suite. In this task, the land-based biomass mitigation potential of PRIMES is enhanced in order to represent changes in land management schemes of the AFOLU sector, characterised by different climate mitigation efforts of the sector. This is achieved through the linkage between PRIMES (E3M-Lab NTUA, 2018) and GLOBIOM/G4M-X implemented by the utilisation of the GLOBIOM/G4M-X lookup tables by PRIMES Biomass Supply model as input for the model's primary biomass cost-supply curves. The effects of

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[i] https://www.forestnavigator.eu/wp-content/uploads/FN_D6.1-Integrated-Policy-Modelling-Toolbox.pdf

this update reduced the mitigation potential of both forestry biomass and dedicated energy crops in PRIMES Biomass Supply model, compared to their potential previously assumed by the model.

The effect of the forest bio-based economy, implying the increase of wood demand across all the non-energy uses (materials, construction, novel wood-products, etc.) in the ForestNavigator EU modelling Toolbox, will be addressed via the integration between GLOBIOM/G4M-X and the MAGNET (Woltjer, G.B. and M.H. Kuiper, 2014) model. GLOBIOM/G4M-X and MAGNET will include internal PRIMES EU bioenergy demand, ensuring alignment with EU climate targets, while the alignment with the POLES (Despres, et al., 2018) global energy model in terms of global bioenergy demand ensures that EU climate neutrality pathways are in line with global climate goals represented in Integrated Assessment Models at the global scale.

2. Objectives

The main objective of Task 6.4 is the development of the Integrated Modelling Toolbox for impact assessment of forest-based mitigation pathways in the context of EU mitigation targets, focusing on:

- The integration of GLOBIOM/G4M-X, representing the forest sector, with PRIMES, and MAGNET, representing the energy and materials side of the bio-economy, respectively, for cross-sectoral dynamics.
- The alignment of EU forest-based climate mitigation pathways, with global assumptions on forestry biomass deployment, with projections provided by IAMs (i.e., POLES)
- A better representation of forest management response, in terms of rotation length, thinning intensity, afforestation/deforestation decisions depending on socioeconomic conditions and environmental changes
- The inclusion of substitution factors for enhanced representation of wood uses mitigation impacts in GLOBIOM/G4M-X
- Updating the land-based biomass mitigation potential of PRIMES and the wood feedstocks subcategorization and supply curves in MAGNET using the lookup table generated by GLOBIOM/G4M-X.

The following sections present the methodological approach followed to achieve the above linkages between the modelling suites of the Integrated Modelling Toolbox for impact assessment of forest-based mitigation pathways in the EU.

3. Methodology

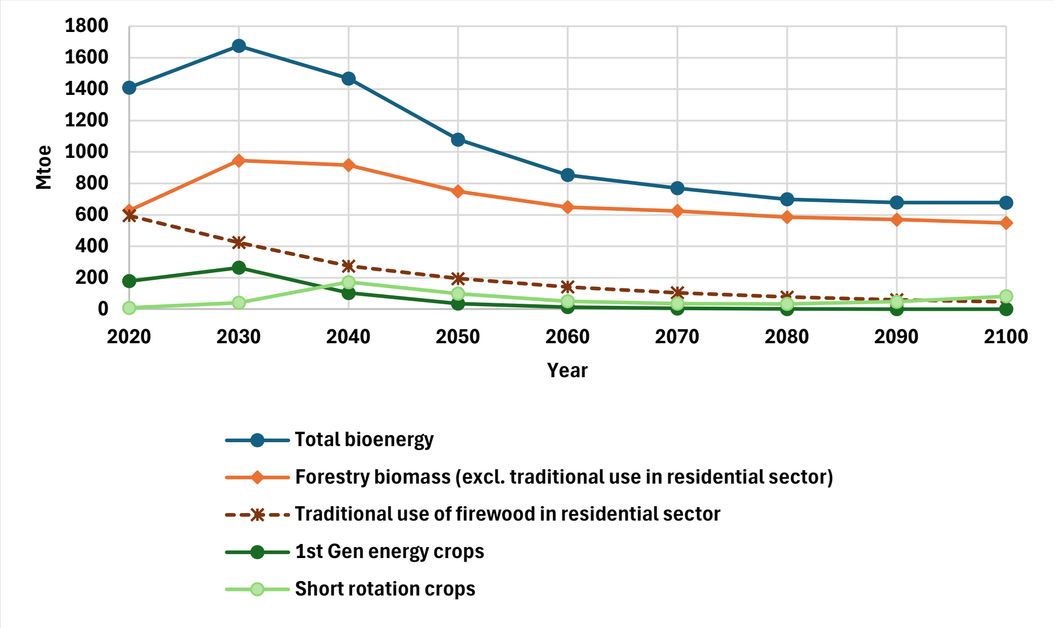
3.1. Alignment of GLOBIOM/G4M-X, PRIMES and MAGNET with IAMs and other global regions

In the modelling of scenarios (WP7), GLOBIOM/G4M-X and MAGNET will align with internal PRIMES EU bioenergy projections (see D5.1 preliminary EU bioenergy demands). The PRIMES scenarios are all aligned to the EU climate neutrality 2050 goal and leverage to a extent on forest biomass in the bioenergy contribution to the policies.

For the global bioenergy demand, we have explored three different scenarios provided by the POLES-JRC model. These scenarios included the POLES Reference, 2 and 1.5-degree scenarios quantified for the purpose of the 2024 Global Energy and Climate Outlook (GECO 2024) (KERAMIDAS, 2025). As a global bioenergy demand Baseline, the GLOBIOM/G4M-X and MAGNET will be aligned with the "**GECO 2024 2C**" POLES scenarios. The GECO 2024 2C (or NDC-LTS) scenario portrays energy-emissions pathways fully achieving existing NDC targets; the scenario also includes long-term pledges for reducing global emissions. This scenario employs country-specific carbon values to achieve economy-wide emission targets and aligns with a 2 °C temperature change by the end of the century. Therefore, this is considered the most relevant scenario as the global "Baseline" when considering international mitigation ambitions aligned to IAMs.

As shown in Figure 1 the global bioenergy demand of the POLES 2C scenario is projected first to increase by 18% between 2020 and 2030 and after to reduce by 34% (i.e., by almost 500 Mtoe) in 2050 (compared to 2020), further reducing by 39% in 2100, compared to 2050. Forestry biomass is the main contributor of biomass supply, representing 80%-95% of total biomass supply, with agricultural biomass representing the rest biomass demand. The total forest biomass demand follows a similar trend as global bioenergy demand, however, with different trends for modern (i.e. for industrial uses) and traditional (i.e. for residential use) forest biomass. Figure 1 shows the traditional use of firewood for heating in the residential sector, in the GECO 2024 2C scenario is driven down after 2020, reducing by 92% in 2100, compared to 2020. This trend is not in agreement with the firewood assumption of the GLOBIOM/G4M-X modelling suite, which is kept as constant over time at the global scale, according to the sectoral outlooks of the FAO. Due to this difference, POLES projections will be the basis for "modern forestry" bioenergy uses for GLOBIOM/G4M-X and MAGNET, while projections of the traditional uses (i.e., firewood used for heating in the residential sector) will be considered to remain in the future at the same level as in year 2020.

Figure 1 Global bioenergy demand projection of the GECO 2024 2C scenario, by biomass source[ii]. Source: POLES-JRC



GLOBIOM-G4M-X aligns in the EU for bioenergy and bioeconomy scenarios to PRIMES and MAGNET, respectively. This alignment will be further enhanced under the deployment of scenarios in WP7 to be aligned also with the baseline scenarios for China and the United States (See Task 7.4).

For China, the improved representation of China's food system and land-use policies derived from GLOBIOM-China (Zhao et al., 2021) was implemented in the GLOBIOM version used in this project. The GLOBIOM-China was calibrated for food demand elasticity, crop yield shift due to technological change, grass yield, and bilateral trade for agricultural products. The Baseline scenario for China aligns with the following policies, programs and official plans: i) the Chinese consumer preference for monogastric products and the important structural changes in the production practices; ii) the self-sufficiency in three major cereal crops of 95% under the baseline scenario in line with the current trade policies; iii) the "zero synthetic fertilizer use growth after 2020"; iii) the forestry policy including the zero deforestation policy, the afforestation target, and the harvest ban on natural forests. For the US, the Baseline scenario aligns with the US land-use and forestry policies will be incorporated at a later stage according to Forest Service U.S. Department of Agriculture (Forest Service, U.S. Department of Agriculture, 2023).

As a result, a consistent version of the GLOBIOM model where EU, China, US baselines and global bioenergy demand (now from MESSAGE and to be updated according to POLES scenario above) will be established. Given this alignment, under Task 7.4, a set of scenarios will be explored with three main dimensions of variation: i) regional (EU, China and the US) forest-based mitigation policies including baseline and more ambitious mitigation target through bioenergy production, wood demand for construction, circular bioeconomy, and biodiversity conservation; ii) Rest of the World (ROW) mitigation ambition (POLES scenarios); and iii) trade barriers. The feasibility and pathways to achieve the regional and global mitigation target, their impacts on land-use change,

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[ii] **1st Gen energy crops:** Dedicated agricultural energy crops (non-lignocellulosic) used specifically for the production of 1st gen biofuels,

Short rotation crops: Dedicated agricultural lignocellulosic energy crops used for bioenergy production food system dynamics (e.g., food consumption, trade and price), biodiversity, and forest sector dynamics (e.g., carbon stock and sink in forest and through harvest wood products, potential carbon leakage due to regional mitigation target) will be assessed.

3.2. Inclusion of substitution impact into the wood demand of GLOBIOM/G4M-X

We further linked the GLOBIOM-G4M-X output to displacement factors, quantifying avoided emissions in other sectors due to wood use, to include the mitigation potential related to wood product use in the bioeconomy.

In ForestNavigator Deliverable 5.3 "Substitution potentials and impact of wood use in Europe", two approaches were taken to determine avoided fossil emissions through wood use, as additional substitution impacts:

- Demand-oriented substitution cases tracing absolute changes in fossil emissions for selected sectors.
- A complete set of displacement factors for the major end uses and weighted at level of intermediate wood products based on average market data.

The calculation of the substitution impacts within the EU wood industry for the various scenarios addressed in ForestNavigator WP 7 and 8 will be based on the "displacement factors" from D5.3 determined for each intermediate (semi-finished) wood product, covering all major sectors where wood is used. These displacement factors were calculated per kg of semi-finished product and per end use, as described in Section 2.2.1 of Deliverable 5.3. The factors have been established for the year 2020, as well as for three prospective policy scenarios projected for 2050:

- Baseline scenario (or business as usual)
- National Policies Impact scenario (NPI) where national policies regarding climate change are implemented
- PkBudg500 scenario where the Paris Agreement is implemented and the net zero emissions level is reached before 2050.

These three scenarios reflect different EU decarbonization pathways, resulting in different amounts of fossil emissions being avoided per unit of wood product being used in the bioeconomy, and are implicitly aligned with the energy sector development after 2020.

Displacement factors (DFs), in order to be processed in the GLOBIOM/G4M-X model, have been aggregated using data from Annex 7 of D5.3, resulting in 26 aggregated products. For each product, DFs for 'Production' and 'End of Life' were provided, the first one to be applied to the production volumes at a specific year, and the second one to be applied to products reaching their end of life.

The inclusion of fossil emissions substitution impacts in relation to wood uses in GLOBIOM-G4M-X is performed at the level of the semifinished products output. Hence, the DF (in kg C per kg C in semi-finished product) is multiplied by the amount of each semi-finished product (i.e. including both material and energy products) after conversion from solid m^3 to kg C.

The DFs were provided for the years 2020 and 2050 under each decarbonization pathway. For the decades between these time steps included in GLOBIOM projections, the factors were linearly interpolated. For the projections for years after 2050, the DFs are assumed to remain at the 2050 level.

The substitution impacts are calculated as “additional” to the Baseline scenario. First, GLOBIOM models a Baseline wood demand scenario, after which it computes the changes in the volumes of semi-finished products and the associated additional substitution relative to the Baseline. This approach ensures that only the additional substitution effects are attributed to forest products.

For further aligning to the EU energy model Baseline (PRIMES), we have selected to use the PkBudg500 dynamic DFs as ‘default’ in the GLOBIOM/G4M-X scenarios analyses to be performed under WP7. The other two sets of DFs are considered for sensitivity analyses.

3.3. Interdependence of bioenergy demand and biomass supply with land management schemes

The linkage between the GLOBIOM/G4M-X and the PRIMES modelling suite is based on the utilization of the GLOBIOM/G4M-X lookup table by the PRIMES Biomass Supply model (a PRIMES module) as input for the calculation of land-based biomass mitigation potentials. The scope of the linkage between the two modelling suites is to make both the bioenergy demand and biomass deployment projections in PRIMES responsive to climate mitigation efforts in the AFOLU (Agriculture, Forestry, and Land Use) sector.

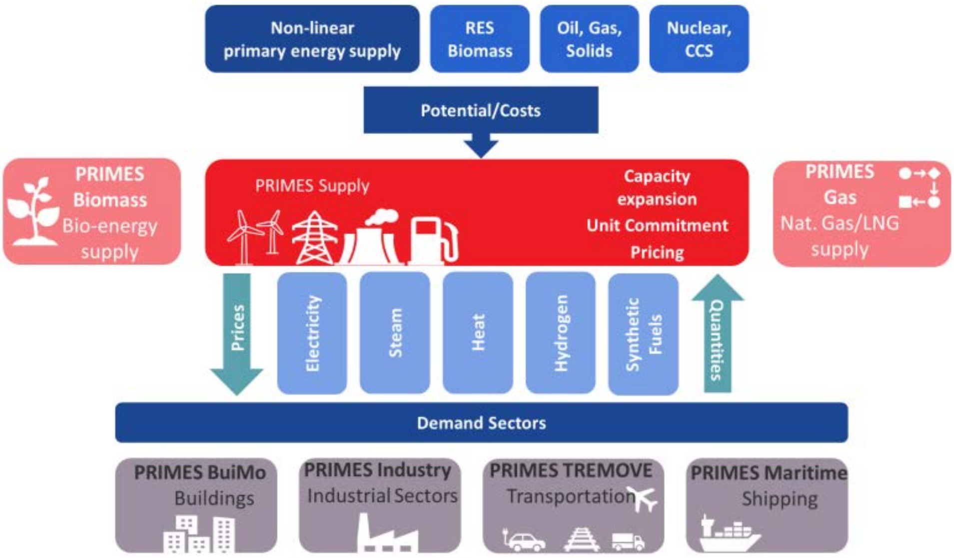
PRIME Energy Systems Model

The Price-Induced Market Equilibrium System (PRIMES) is a structural partial equilibrium model developed by E3M-Lab at the National Technical University of Athens (NTUA). Among others, it is designed to quantify energy capacity and fuel mix across various end-use sectors within the European Union (EU) and its Member States (MS). PRIMES provides detailed projections on energy demand and supply, future investments in energy-related sectors, and energy prices. It achieves equilibrium by balancing supply and demand across multiple energy and emissions markets, with a particular emphasis on price dynamics (E3M-Lab NTUA, 2018).

PRIMES is particularly suitable for medium- to long-term energy system projections, extending up to the year 2070 in five-year intervals. A key feature of the model is its integration of behavioural modelling, grounded in microeconomic theory, with engineering and system-level analysis, enabling high-resolution coverage of all sectors and markets. The model supports impact assessments of energy and environmental policies at both the MS and EU levels. These assessments include the evaluation of price signals such as taxation, subsidies, emissions trading systems, and policies promoting renewable energy, energy efficiency, environmental protection, and technology standards (E3M-Lab NTUA, 2018). PRIMES consists of several modular sub-models, each representing the behaviour of specific agents on either the demand or supply side of the energy system. The demand-side modules include the transport sector (i.e., PRIMES-TREMOVE & PRIMES International Maritime), the residential and services sectors (i.e., PRIMES-BuiMo), and the industrial sector (i.e., PRIMES-Industry). The supply side is represented by the PRIMES power supply module concerning power generation in terms of electricity, steam, hydrogen and synthetic fuels, and by the PRIMES Biomass Supply model, which has also been used in WP5 of

ForestNavigator. Comprehensive descriptions of the PRIMES model and its key applications are available in the literature (Capros, et al., 2018) (Capros, et al., 2019) (E3M-Lab NTUA, 2018). The demand and supply modules of PRIMES are linked with each other through a model integration algorithm, which determines equilibrium prices in multiple markets and equilibrium volume meets balancing and overall constraints (E3M-Lab NTUA, 2018). The structural linkages between the demand and supply modules of PRIMES are presented in Figure 2.

Figure 2 PRIMES module linkages between the demand and supply side of the energy system



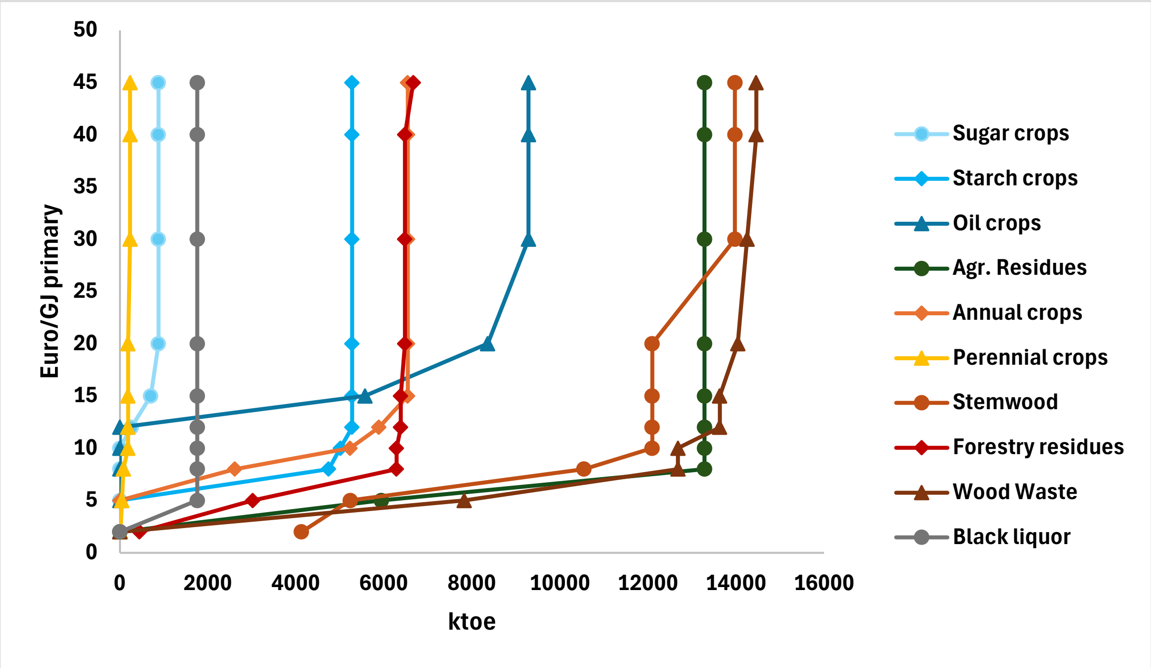
Source: PRIMES energy system model manual

Primes Biomass Supply model

The PRIMES Biomass Supply model is an economic-engineering model that projects the optimal use of biomass and waste resources through utilizing transformation pathways to meet a specific demand of biomass-derived energy products, provided by the modules of PRIMES energy system model. The model solves a cost minimization problem for long-term biomass supply, subject to equilibrium constraints stemming from biomass availability, cost structures, and technical characteristics of conversion technologies (E3M-Lab NTUA, 2018). Biomass availability is represented through cost-supply curves specific to each type of feedstock and MS, which also serve as the interface for the GLOBIOM/G4M-X &PRIMES linkage in this deliverable. Biomass to bioenergy conversion technologies are characterized by a set of techno-economic specifications concerning their cost structure (e.g., investment cost, operational cost) and their technological feasibility (e.g., conversion rate, lifetime). For each MS, the cost-supply curves represent biomass availability with increasing cost to scale. The curves consist of different levels of biomass deployment volumes, with each level associated with a specific acquisition cost. The total sum of these volume levels represents the maximum available potential of biomass (*see example for Germany in 2025 Figure 3 and Figure 4*). For biomass feedstocks associated with land cultivation (i.e., food crops & lignocellulosic energy crops), the cost-supply curves are built based on the different cost components associated with land use (i.e., land rent, energy and chemical inputs, labour and machinery costs, etc.). 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). Table 1 presents the list of all biomass feedstocks incorporated in PRIMES Biomass Supply model.

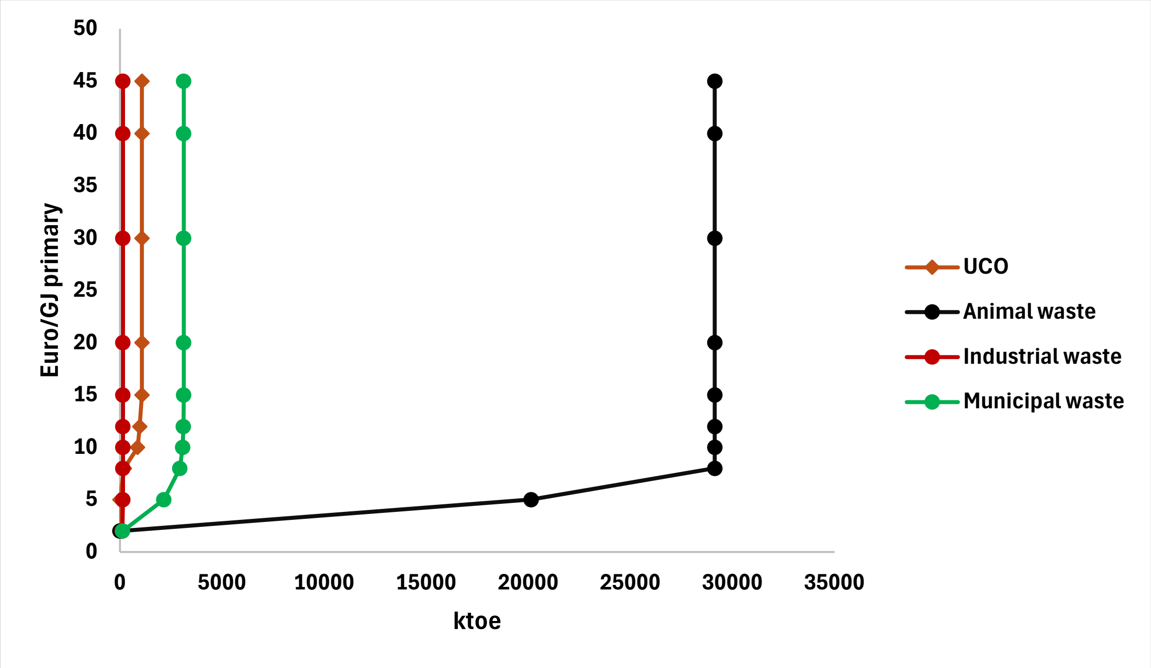
Bioenergy commodities incorporated in PRIMES Biomass Supply model include liquid biofuels mainly consumed in the transport sector, gaseous bioenergy and solid biomass (Table 2). Bioenergy commodities are produced through both conventional biomass transformation pathways (i.e., starch and sugar fermentation, anaerobic digestion, etc.) and advanced transformation pathways (i.e., gasification, Fisher-Tropsch process, etc.).

Figure 3 Cost-supply curves of agriculture and forestry biomass feedstocks for Germany in 2025



Source: PRIMES Biomass Supply model

Figure 4 Cost-supply curves of waste origin biomass feedstocks for Germany in 2025[iii]



Source: PRIMES Biomass Supply model

Table 1 Biomass feedstocks incorporated in the 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 lignocellulosic crops	Annual crops	Herbaceous crops (miscanthus, switchgrass, etc)
	Perennial crops	Wood crops (willow, poplar, etc.)
Forestry biomass	Harvested roundwood	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 (UCO)	Used cooking oil from food processing
	Industrial solid waste	Food, meat, fat, beverages, tobacco etc. manufacturing
	Municipal solid waste	Household waste
	Landfill gas	Gas generated from landfills
	Sewage sludge	Wastewater treatment sludge

Source: PRIMES Biomass Supply model

[iii] Municipal waste consists of Municipal solid waste gather by households, waste activated sludge generated in wastewater treatment facilities, and waste gas generated by landfills. Animal waste consists of mainly manure along with a small volume of animal waste generated by food industry.

Table 2 Bioenergy commodities incorporated in the PRIMES Biomass Supply model

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

Source: PRIMES Biomass Supply model

GLOBIOM/G4M-X modelling suite

The GLOBIOM/G4M-X modelling suite was described in deliverable D6.1. The key features of GLOBIOM/G4M-X modelling suite that are relevant for generating a lookup table to link with the PRIMES model include the following:

(1) GLOBIOM/G4M-X has a detailed representation of bioenergy feedstocks. It considers seven main categories of bioenergy feedstocks, including stem wood, forestry residues, annual and perennial lignocellulosic crops. It can simulate their substitution or complementarity, as well as the competition between biomass for material usage and biomass for energy, through detailed modelling of supply and demand of semi-finished products based on forestry sector processing parameters.

(2) GLOBIOM/G4M-X explicitly simulates land-use change flows and has improved consistency between forest sector and other land-use sectors. It projects not only land cover under each period, but also endogenous land-use changes between periods. Besides, intertemporal decisions on forest land-use changes and forest management schemes, which are simulated in G4M, are considered and fed back to the recursive-dynamic projections of other land-use changes projected by GLOBIOM. This ensures to feature the long-term economic optimization for the forest sector, where forest rotation time is typically much longer than multiple decades, and at the same time leverages the advantages from recursive dynamic land-use change simulation that can characterize complex land-use competition across sectors. Together, such a land-use simulation mechanism ensures better consistency and practicability when estimating the supply potential of bioenergy from different feedstocks, which are based on different land-use types.

(3) GLOBIOM/G4M-X is calibrated to historical data sources e.g., FAOSTAT and Global Forest Resource Assessment reports for important variables, including land areas, forest carbon flows, agricultural and forestry production and consumptions. This improves the credibility of agricultural and forestry projections underlying the bioenergy and emission estimates in the lookup table.

GLOBIOM/G4M-X lookup table

To generate the lookup table, a set of scenario runs with multiple levels of bioenergy prices and carbon prices is implemented in the integrated modelling system. Together, these scenarios form a response surface (see more information in the next part) that allows for "look up" bioenergy supply potentials by different feedstocks, land activities related emissions, as well as land-use dynamics. For each of the scenarios with a specific combination of bioenergy price and carbon price, a two-way iteration between GLOBIOM/G4M-X is implemented to improve the consistency in forest dynamic simulation. Firstly, GLOBIOM conducts an initial run with afforestation until 2020 and fixed thereafter, to provide prior estimates of land cover, wood prices, and land prices etc. for G4M. Secondly, G4M takes GLOBIOM input to simulate intertemporal optimization of forest land-use change decisions and forest management schemes at spatial scales, to provide projections on forest land-use changes, harvest volumes, forest management schemes, and related emissions. Among these G4M results, the G4M afforestation projection is taken up again by GLOBIOM in its feedback run, to include the corresponding afforestation projection to account for the increased land-use competition when future afforestation is considered. Together, the GLOBIOM feedback run and the G4M run provide the final estimate of bioenergy supply potentials, emissions, and other land sector variables for the specific lookup table scenario.

The GLOBIOM/G4M-X lookup table consists of a matrix providing primary bioenergy supply potential from forestry and lignocellulosic crop biomass feedstocks at different levels of bioenergy prices and carbon prices. The matrix is constructed around two dimensions: bioenergy price and carbon price. The biomass price dimension functions as driver for estimating corresponding biomass supply potential in GLOBIOM/G4M-X; multiple GLOBIOM/G4M-X lookup scenarios with different biomass price levels therefore allow to derive multiple combinations of bioenergy price-supply, which together form a bioenergy cost-supply curve. The carbon price dimension resembles different levels of climate change mitigation efforts associated with the AFOLU sector, representing land management schemes towards climate-friendly management. This allows to derive multiple bioenergy cost-supply curves under different land-management schemes. Besides, while the bioenergy cost-supply curves are of primary importance for energy models like PRIMES, the GLOBIOM/G4M-X lookup table also provides additional information on land-use dynamics and related economic and environmental implications. The two-dimensional scenarios with different combinations of bioenergy prices and carbon prices form a response surface for looking up the trajectories of important land-system variables like land cover, wood removals, and land-related emissions.

The applied version of GLOBIOM/G4M-X lookup table provides estimates of available biomass supply used for energy purposes under nine bioenergy price levels in the range of 0-30 Euro/GJ[iv] primary biomass, and under 14 levels of carbon prices starting from 0 Euro/tCO_2 up to 300 Euro/tCO_2. These wide ranges of price levels cover the majority of future land-system evolution possibilities from the perspective of bioenergy provision and AFOLU mitigation and allow the energy model to derive bioenergy supply curves as well as AFOLU emission variables without the need to iterate with the full-fledged GLOBIOM/G4M-X modelling system.

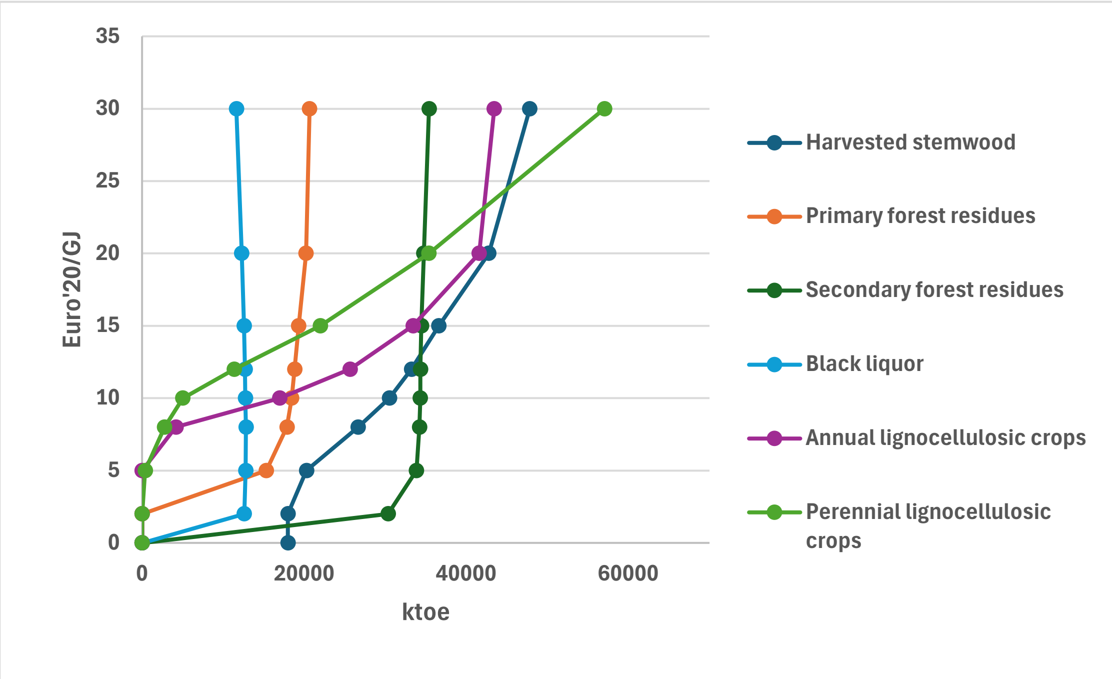
In GLOBIOM/G4M-X simulation of these lookup table scenarios, the maximum potential of available biomass feedstock is restricted by sustainability criteria (e.g., protected forest areas), and biomass demand for other uses (e.g., construction sector). Specifically, in GLOBIOM/G4M-X, the availability of stem wood for bioenergy from direct forest harvest is restricted by additional non-linear cost components to ensure that the forest sink will not be significantly affected by lower bioenergy prices, and to better resemble policies targeting protected forest areas (i.e., old-growth forest). Additionally, a cap was placed on the potential availability of secondary forestry residues, with almost all their potential (i.e., almost 40 Mtoe) utilised at 5 Euro/EJ. This decision was made because restricting the direct harvesting of wood for bioenergy in the GLOBIOM modelling

[iv] All monetary values presented in the PRIMES Biomass Supply model are expressed in constant 2020 euros, adjusted to remove the effects of inflation.

framework could incentivize increased forestry activity aimed at generating more residues for bioenergy production at high bioenergy prices.

Figure 5 presents the biomass cost-supply curves for different feedstocks as provided by the GLOBIOM/G4M-X lookup table. It is observed that forestry biomass feedstocks are the first to be deployed, with black liquor and forestry residues deploying almost all their potential at primary biomass prices of 2 Euro/GJ and at 5 Euro/GJ, respectively. Stemwood becomes economically viable as a bioenergy feedstock when the market price for primary biomass exceeds 5 Euro/GJ, with a strong upward trend continuing up to 20 Euro/GJ, reaching 42 Mtoe of stemwood supply (i.e., 89% of overall available stemwood potential for bioenergy use). Biomass from lignocellulosic crops is sourced either from annually harvested species like miscanthus and switchgrass, or from perennial lignocellulosic crops such as short rotation coppice. These feedstocks generally have higher production costs compared to by-products, waste, and other forest-derived biomass, which is why their supply curves begin at higher price points. However, as prices increase, their supply potential grows rapidly, ultimately surpassing that of forest biomass.

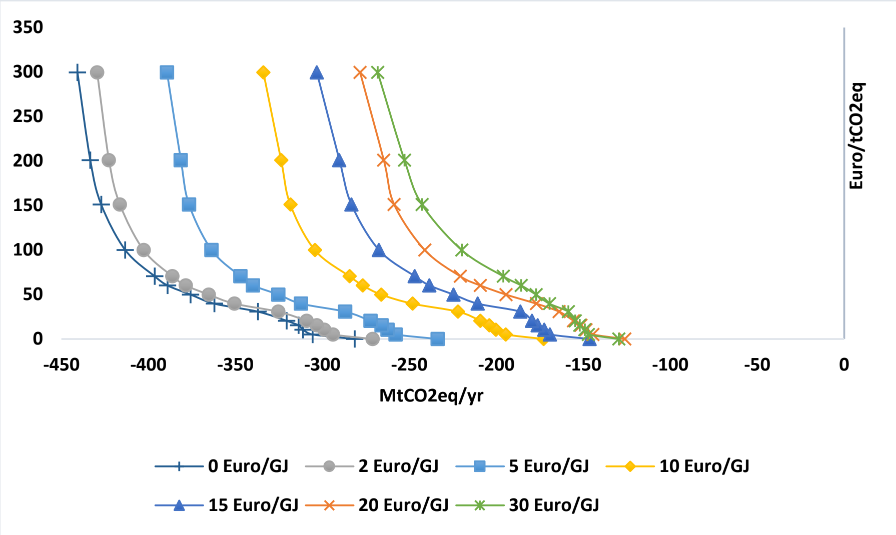
Figure 5 Biomass cost supply curves for EU27 in the year 2030 based on zero GHG value price scenario



Source: GLOBIOM/G4M-X lookup table

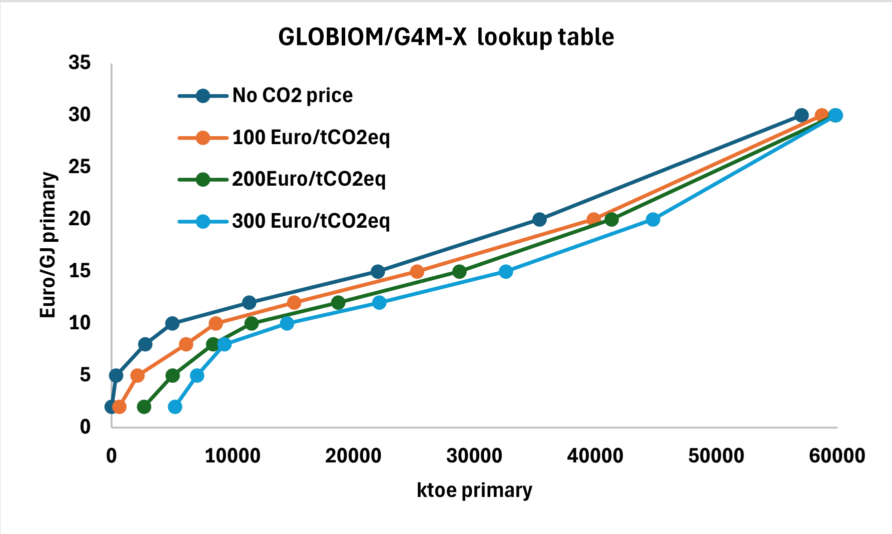
Besides the market price of primary bioenergy, the available biomass potential is also subject to the carbon price assumed for the LULUCF sink. A higher carbon price (or GHG price) represents increased ambition of climate mitigation policies implemented in the AFOLU sector. The climate mitigation effort of the sector is represented through different land management schemes affecting forests, croplands, grasslands, and wetlands, etc, and are quantified based on their effect in the LULUCF sink. As shown in Figure 6, the LULUCF sink declines with increasing bioenergy prices, but with diminishing marginal effects. Specifically for a zero carbon price, the LULUCF sink reduces by almost 152MtCO2eq/year when the primary biomass market price increases from 2 Euro/GJ primary to 30 Euro/GJ. The respective reduction of the LULUCF sink when the carbon price is 300 Euro/tCO2eq is approximately 160MtCO2. The effect of carbon prices on biomass deployment is presented in this version of the lookup table. Carbon price affects mainly dedicated energy lignocellulosic crops. Figure 7 presents the variation of annual lignocellulosic crops available potential based on different carbon prices assumed for CO2 removed from the LULUCF sink. At lower primary biomass prices, the supply of annual lignocellulosic crops increases slightly as the carbon price rises. The carbon price effectively acts as a modest subsidy, enabling these crops to remain economically viable even at low to mid-range biomass market prices. Up to a biomass market price of 20 Euro/GJ, higher carbon prices continue to boost the supply of lignocellulosic crops because they contribute positively to the soil carbon sink. However, at higher biomass prices, land costs increase substantially, and the additional "subsidy" from the carbon price has only marginal effect on the supply potential of lignocellulosic crops. As a result, when primary bioenergy prices exceed 20 Euro/GJ, the availability of lignocellulosic crops becomes nearly the same regardless of the carbon price assumed.

Figure 6 EU LULUCF sink, by carbon price and bioenergy price, in 2030[v]



Source: GLOBIOM/G4M-X lookup table

Figure 7 Biomass supply of annual lignocellulosic crops for EU27, under different carbon value for the LULUCF sink



Source: GLOBIOM/G4M-X lookup table

[v] UNFCCC CRF categories included: Forest land remaining forest land, land converted to forest land, cropland, grassland, wetlands, settlements, other land, harvested wood products.

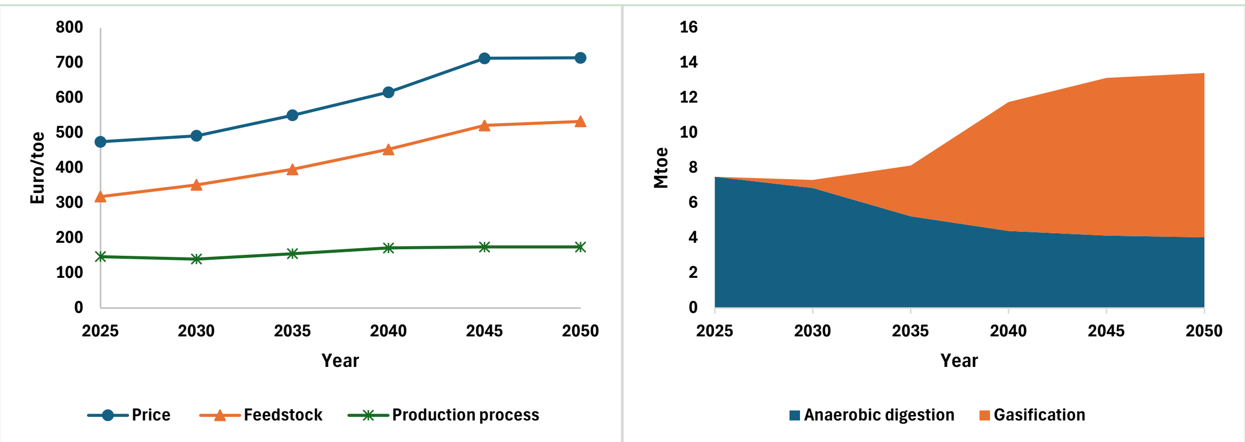
PRIMES bioenergy demand and biomass deployment responsiveness to changes in land management

The demand and supply modules of the PRIMES modelling suite operate in a closed-loop system, continuously balancing energy demand with energy prices. The bioenergy demand projected by the demand-side modules is fed into the PRIMES Biomass Supply model, which determines the optimal deployment of biomass transformation pathways to meet the projected demand, and estimates endogenously the corresponding prices of bioenergy commodities. Bioenergy prices are communicated back to the demand modules as price signals, which may lead to adjustments in bioenergy demand across sectors. If demand is altered in response to these signals, the updated demand is reintroduced into the PRIMES Biomass Supply model, triggering a second iteration of the supply-demand balancing process.

In the cost structure of bioenergy commodities, feedstock costs—particularly the cost of primary biomass—represent a major component influencing final bioenergy prices, as illustrated in Figure 8. Notably, feedstock prices are projected to be the primary driver behind the gradual increase in biogas prices in Germany after 2030. This observed price escalation is attributed to a shift in biogas production technology: from anaerobic digestion to gasification. While anaerobic digestion primarily utilizes waste-origin biomass (e.g., animal manure, sewage sludge), gasification relies on lignocellulosic biomass (e.g., forestry and agricultural residues and energy crops), which is significantly more expensive. As a result, the transition to gasification introduces higher feedstock costs, thereby increasing the overall price of biogas.

Given the substantial impact of feedstock costs on the final price of bioenergy commodities, variations in the acquisition cost of primary biomass—driven by different land management practices and their associated GHG price—will directly influence the price outcomes generated endogenously by the PRIMES Biomass Supply model. These price changes, in turn, affect the estimated demand for each bioenergy commodity within the PRIMES demand modules.

Figure 8 Biogas price and cost components projections (left) along with biogas production projections by pathway (right), for Germany.



Source: PRIMES Biomass Supply model

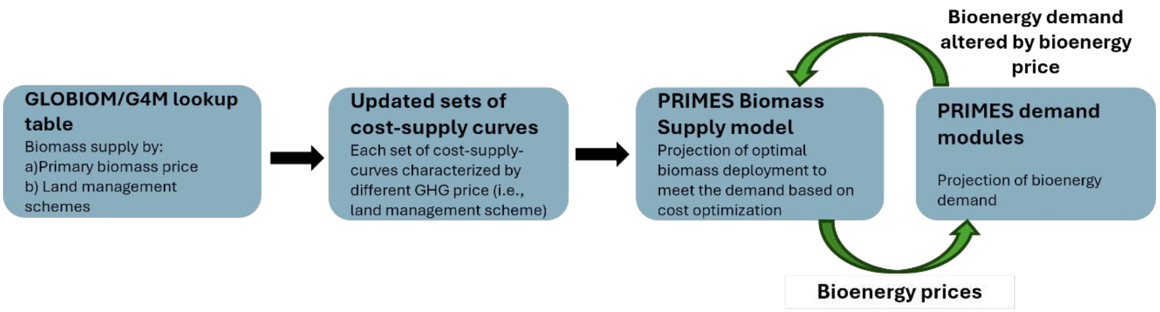
The available biomass supply, as provided by the GLOBIOM/G4M-X lookup table, depends on both bioenergy prices and the land management schemes assumed for the forest sector. Integrating the lookup table into the PRIMES Biomass Supply model—as input for the biomass cost-supply curves—enables both biomass deployment and bioenergy demand (via the iterative mechanism described earlier) to respond dynamically to changes in forest management strategies, which are themselves shaped by climate mitigation efforts in the sector.

An already established link exists between PRIMES and GLOBIOM, as the potential of lignocellulosic crops and forestry biomass is derived directly from GLOBIOM data. The use of the GLOBIOM/G4M-X lookup table further strengthens this integration, enhancing the representation of these feedstocks within the PRIMES model. The following section presents the methodological approach used to generate the updated cost-supply curves, ensuring consistency with the revised biomass availability data and the structure of the PRIMES Biomass Supply model.

Integration of GLOBIOM/G4M-X lookup table into PRIMES Biomass Supply model Methodology

The utilisation of the lookup table as input for the representation of biomass availability in the PRIMES Biomass Supply model is achieved through the generation of sets of cost-supply curves, with each curve characterised by a specific carbon price, as shown in Figure 9.

Figure 9 Schematic representation of the lookup table integration in the PRIMES Biomass Supply model



The incorporation of biomass cost-supply curves, as provided by the GLOBIOM/G4M-X lookup table, into the PRIMES Biomass Supply model requires an initial processing step to ensure compatibility with the model's structure. This section outlines the methodology used to translate the lookup table into the cost-supply curves.

- **Zero-cost biomass exclusion:**
  In the lookup table, certain biomass feedstocks are available without any acquisition cost. These quantities were added to the biomass potential corresponding to the lowest acquisition cost level in the PRIMES Biomass Supply model (i.e., 2 €/GJ).

- **Correction of decreasing availability:**
  For some feedstocks and Member States (MS), the lookup table shows decreasing biomass availability with increasing primary biomass prices, which contradicts the logic of cost-supply curves in PRIMES. To resolve this, the data were processed to ensure that biomass availability at each price point is at least 3% higher than at the previous price point.

- **Feedstock mapping and redistribution**
  Finally, the feedstock categories included in the lookup table are mapped to the feedstocks incorporated in the PRIMES Biomass Supply model (Table 3), and their potential originally provided across eight price points, was redistributed to the ten supply levels of the cost-supply curves.

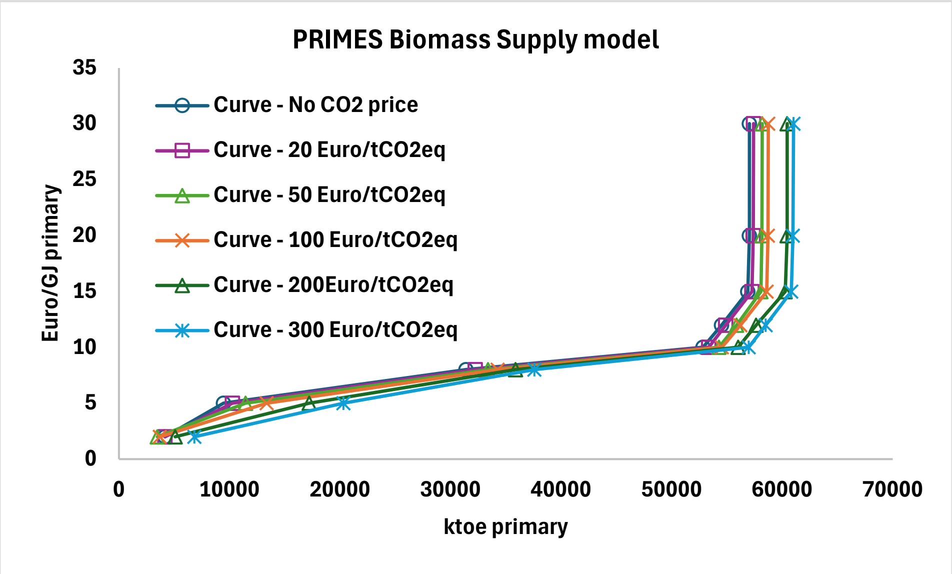
Table 3 Mapping of GLOBIOM/G4M biomass feedstocks to biomass feedstock categories incorporated in PRIMES Biomass Supply model

GLOBIOM	PRIMES Biomass Supply model
Logging residues	Primary forestry residues
Fuelwood	Harvestable stemwood
Energy roundwood	
Sawmill residues	Secondary forestry residues
Post consumer wood	
Plantation biomass	Perennial lignocellulosic crops
Annual lignocellulosic crops	Annual lignocellulosic crops

Implementation

This section presents the effect of the update of the biomass cost-supply curves using as input the GLOBIOM/G4M-X lookup table, compared to the cost-supply curves previously used in PRIMES Biomass Supply model. The process described above led to the generation of 14 cost-supply curves each one characterised by a different carbon price assumption (Figure 10). Through this linkage with GLOBIOM/G4M-X, the mitigation potential of land-based biomass in PRIMES Biomass Supply is now responsive to changes in land management policies and mitigation efforts of the AFOLU sector.

Figure 10 Available potential of annual lignocellulosic crops by primary biomass price, and by cost-supply curves, at the EU level in 2030



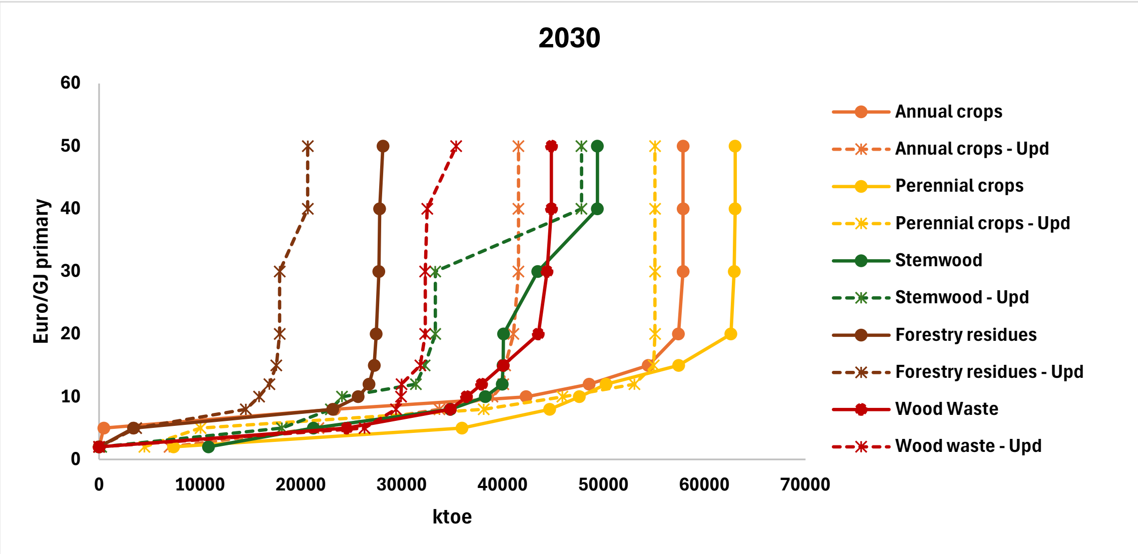
Source PRIMES Biomass Supply & GLOBIOM/G4M-X

The following analysis will focus on the impact of the linkage on the cost-supply curves of the PRIMES Biomass Supply model. The updated cost-supply curves are compared with the previous curves assumed in the PRIMES Biomass Supply model. While the update of the cost-supply curves using as input the GLOBIOM/G4M-X lookup table was conducted for all MS, the following analysis will focus on the aggregated EU27 level.

Figure 11 presents the cost-supply curves of forestry biomass and lignocellulosic crops resulting from the update using the GLOBIOM/G4M-X lookup table when assuming a zero carbon price, compared to the respective cost-supply curves previously used by the PRIMES Biomass Supply model, aggregated at the EU level, in 2030. It is observed that the total biomass potential provided by the lookup table (*i.e.,-upd)* is significantly lower for both the lignocellulosic crops and forestry feedstocks, when compared with the total potential previously assumed by the model for these feedstocks. Specifically, the total availability of primary forest residues experiences the highest relative reduction in 2030 (i.e., 26% or 7.5 Mtoe reduction), compared to the previous version used by the model. The available potential wood waste (*i.e., secondary forest residues and post-consumer wood*) after the update reduces by 21% (or by 9.4 Mtoe) in 2030, while the available potential of direct stemwood harvest decreases by almost 2 Mtoe.

The update of the cost-supply curves using the GLOBIOM/G4M-X lookup table results in reducing the available potential of lignocellulosic energy crops in 2030 (compared to the previous cost-supply curves version), with the impact being more significant for annual lignocellulosic crops. The maximum available potential of annual lignocellulosic crops is reduced by 28% (or by 16 Mtoe), while perennial lignocellulosic crops experience a relative reduction of 13% (or 8 Mtoe), compared to the previous version of the cost-supply curves.

Figure 11 Cost-supply curves of forest biomass and lignocellulosic crops in PRIMES Biomass Supply model, before and after the linkage with GLOBIOM/G4M-X, for EU, in 2030



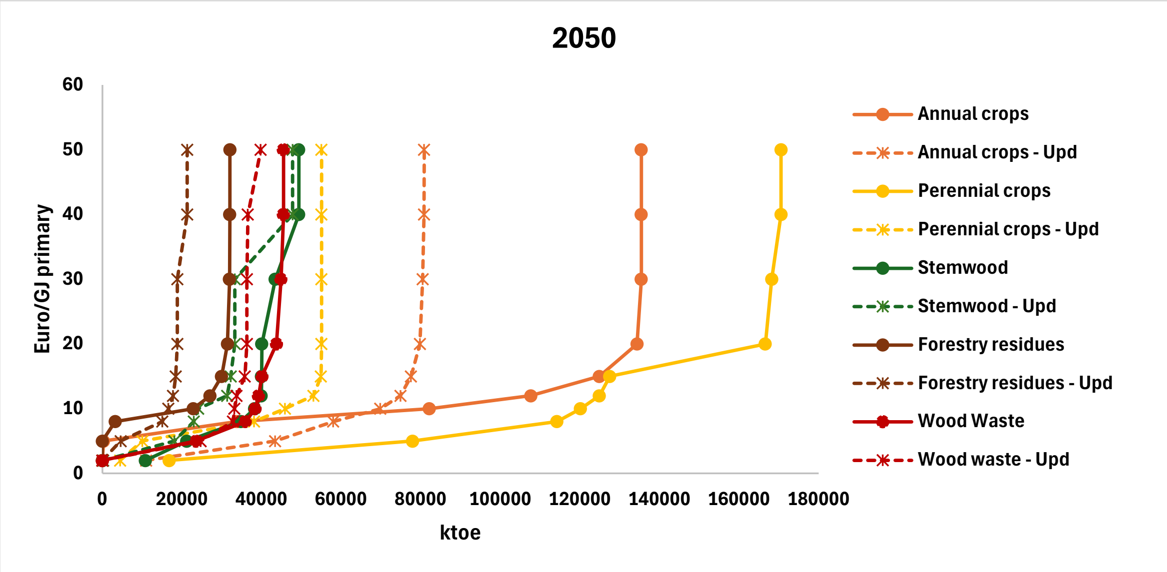
Source: PRIMES Biomass Supply model & GLOBIOM/G4M-X

As shown in Figure 12, in 2050, forestry biomass availability in the PRIMES Biomass Supply model is impacted similarly to 2030 from the update of the cost-supply curves using the GLOBIOM/G4M-X lookup table. The maximum availability of direct harvest for energy use is reduced by 5% (i.e., by 2 Mtoe) in the updated version (compared to the previous). Primary forest residues experience a reduction of 33% (or 11 Mtoe) in their total potential, while the total availability of wood waste reduces by 13% (or 5.7 Mtoe) in 2050, compared to the previous version of the cost-supply curves used by PRIMES Biomass Supply model.

The impact of the cost-supply curves update on the availability of lignocellulosic crops is more intense in 2050, with the total potential of annual crops reducing by 40% (i.e., by almost 55 Mtoe) and the potential of perennial crops reducing by 68% (i.e., by 115 Mtoe), compared to the previous maximum availability previously assumed in the model. Despite this decrease, the overall combined availability of lignocellulosic crops in the updated version of the cost-supply curves is significantly higher than the biomass potential of forestry biomass (i.e., 35 Mtoe higher potential).

The impact observed on the biomass potential of PRIMES Biomass Supply model after the linkage with the GLOBIOM-G4M-X modelling suite is the result of stricter mitigation policies imposed in the AFOLU sector in this version of the lookup table, compared to the data previously provided by the GLOBIOM model and incorporated in PRIMES.

Figure 12 Cost-supply curves of forest biomass and lignocellulosic crops in PRIMES Biomass Supply model, before and after the linkage with GLOBIOM/G4M-X, for EU, in 2050



Source PRIMES Biomass Supply model & GLOBIOM/G4M-X

3.4. Lookup table development MAGNET-IIASA

The integration between GLOBIOM/G4M-X and MAGNET is mediated by look-up tables produced by the MAGNET model. The main goal of the integration between MAGNET and GLOBIOM/G4M-X is the assessment of socio-economic benefits of the development of the bioeconomy in the project's scenarios and pathways, including the contribution of the forest sector to GDP, employment, and green growth. The rationale of the lookup tables is similar to the ones used between PRIMES and GLOBIOM, with alignment of macroeconomic drivers and output parameters at the MS level for the EU.

The lookup table is built upon the development implemented in the MAGNET model, which allows for aligning the forest feedstocks, primary, semifinished and final products. The improved model was run on an extensive set of scenarios covering a gradient in the use of forest biomass for material use in different sectors (construction, furniture, textiles, paper, among other) with varying levels of increase relative to 2025, different GHG price levels (GHG), and increasing levels of bioenergy use relative to 2025 (BIO) – details in Table 4.

Table 4. MAGNET lookup table scenario dimensions.

Scenario dimension	Description	Range
BASE	Baseline endogenous model outcome for standard SSP2 model setting. Here, the fuelwood sector (private consumption of forestry sector) is fixed to base year levels.	

FOR	Increase in use of wood products in construction, paper & pulp and textiles in 2050 relative to 2025.	0%, 50%, 100% 150%, 200%, 250%
BIO	Increase of the share of pellets/forestry residues use for bioelectricity in 2050 relative to 2025.	0%, 100%, 200%, 300%
GHG	Greenhouse gas tax on all sectors, including implementation of MAC curves in primary agricultural sector. Linear increase from 2025 to 2050. Implemented either in EU.	0, 50, 100, 200 \$/ton CO_2.

Figure 13 show the obtained ranges of the share of the forest sector to the total value added in the EU and Figure 14 the employment for a subset of the lookup table scenarios with increasing use of forest biomass use in construction and textiles (FOR scenario dimension, where FOR 0 to FOR 200 represent a 0% to 200 % increase in wood use in construction and textile sectors compared to the baseline).

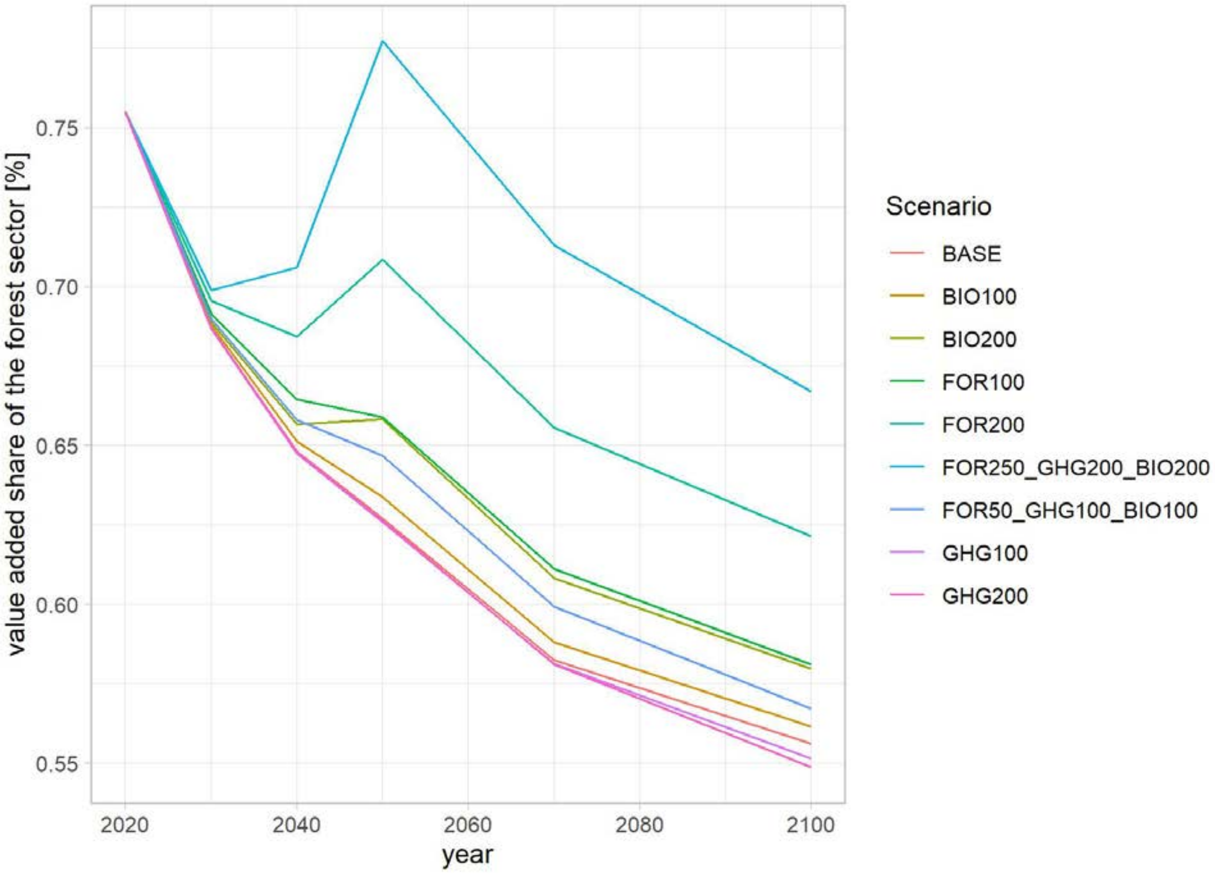


Figure 13. Value added share of the forest sector in the EU, for selected scenarios in the lookup table. FOR indicates relative increase in wood use in the forest sector, BIO stands for relative increases in the bioenergy use, GHG represent carbon price levels and combinations of FOR, GHG and BIO indicates a simultaneous consideration of these levers.

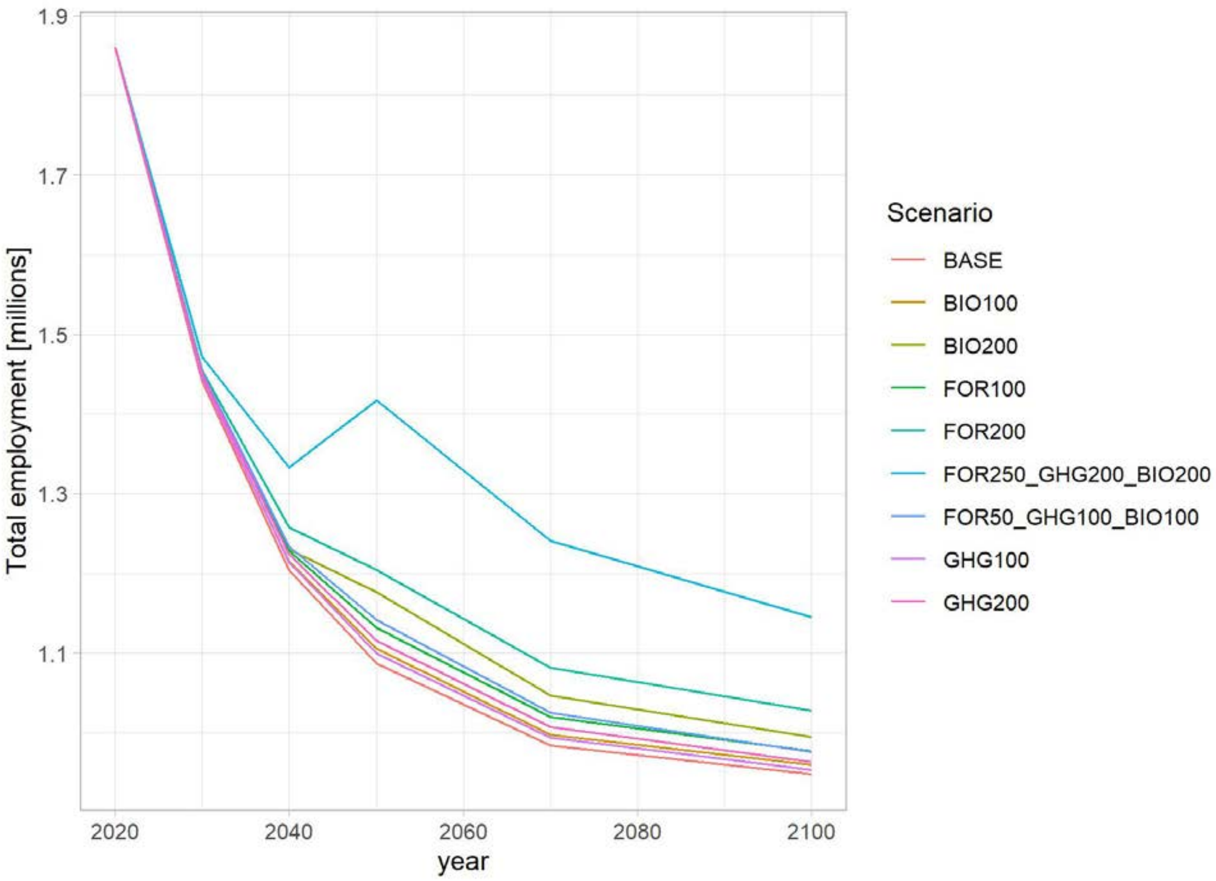


Figure 14. Employment in the forest sector in the EU, for selected scenarios in the lookup table. FOR indicates relative increase in wood use in the forest sector, BIO stands for relative increases in the bioenergy use, GHG represent carbon price levels and combinations of FOR, GHG and BIO indicates a simultaneous consideration of these levers.

To integrate the socioeconomic implications of the scenarios for the forests sector developed in GLOBIOM, we have fitted an emulator to the MAGNET lookup table results for each parameter of interest for the EU. Here, we initially focused on total employment in the forest sector and the contribution of the forest sector to the total value added in absolute and relative terms.

This required defining the quantities of interest present in the lookup tables that can also be derived from GLOBIOM/G4M-X scenario outputs. We have selected to this end the production quantities for the final uses, namely biomass used in the construction, furniture, textile, pulp and paper, as well as biomass use for bioenergy in MAGNET (considering pellets and logging residues). In addition to production quantities, we have also considered the GHG price and time dimension in the lookup tables to capture the dynamics of GDP and population growth.

Since the lookup table provides point estimates for each scenario, to fully couple with GLOBIOM and assess intermediary combinations of the produced quantities of the final product categories described above, we have fitted a Gaussian process to the point estimates from the lookup tables and generated a model for each corresponding parameter of interest. We then deploy the fitted emulator based on the GLOBIOM projection quantities to quantify changes in the socioeconomic parameters under different pathways.

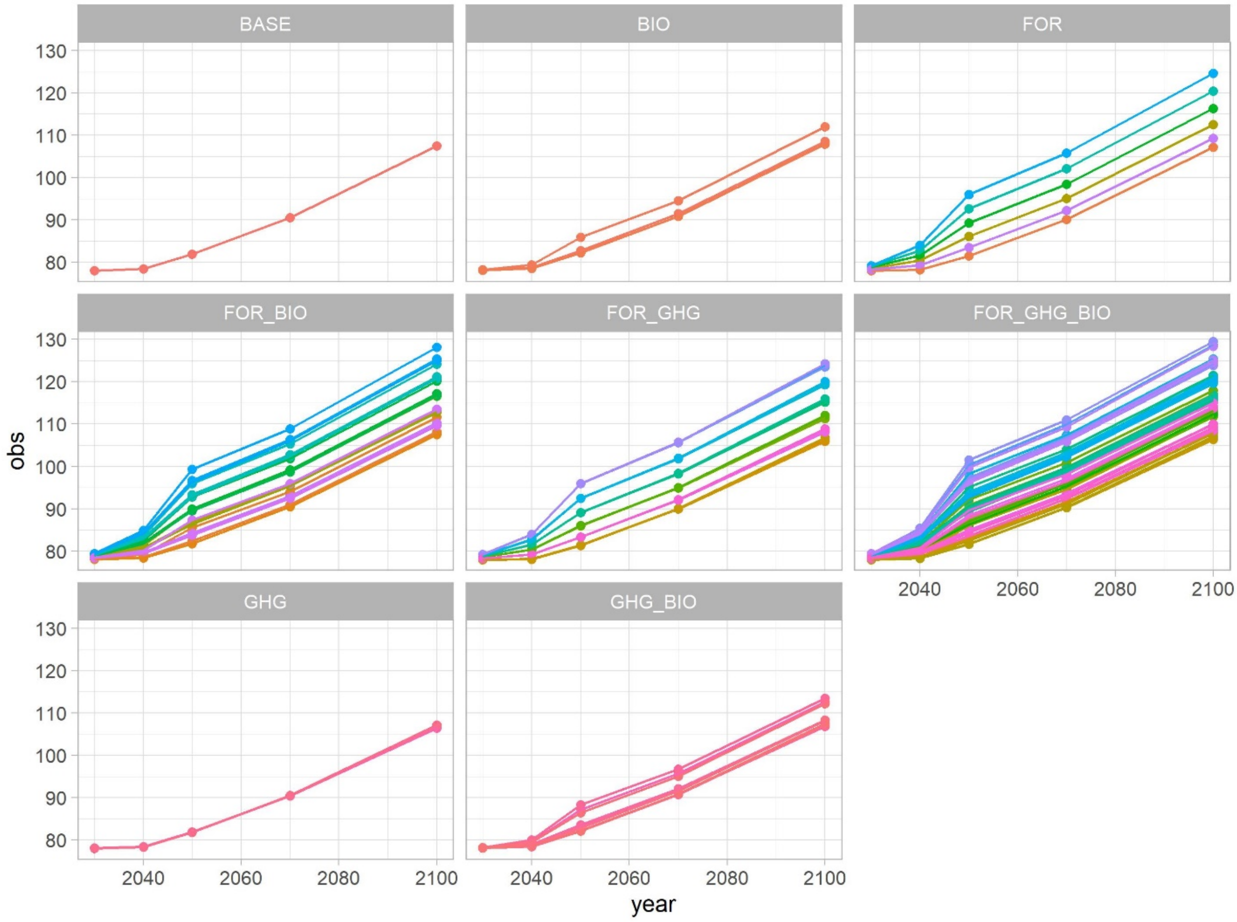


Figure 14. Emulated and observed values in the lookup table for the value added for the forest sector.

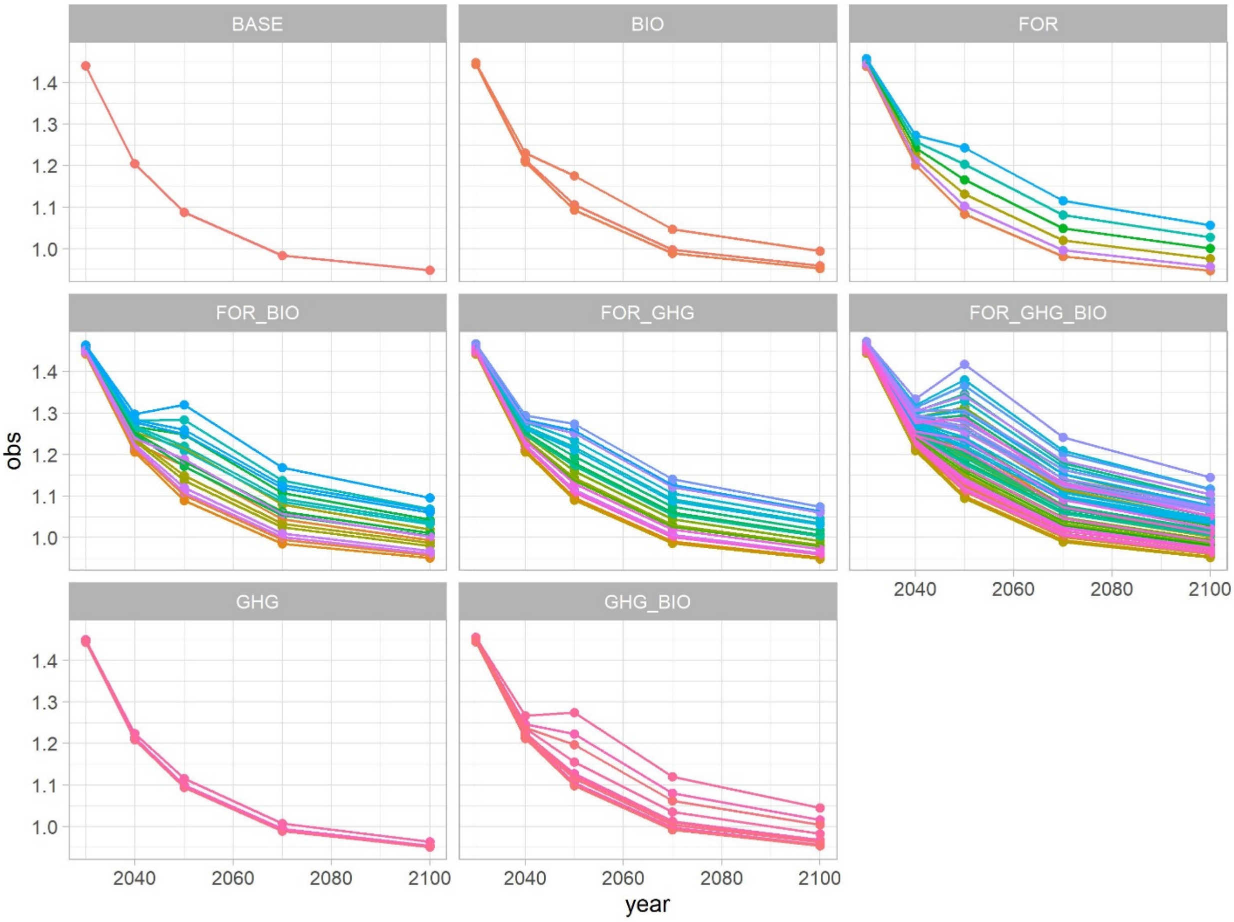


Figure 15. Emulated and observed values in the lookup table for total employment in the forest sector.

Figures 14 and 15 display the results of the emulator as solid lines and the lookup table scenario values as points for the total valued added of the forest sector and employment, for a range of scenarios considering different levels of increase in use of forest biomass, GHG price and bioenergy use. The emulator was able to closely interpolate both socioeconomic variables under a variety of conditions across scenarios. Additionally, to check the consistency of the outputs, we have cross-validated the model by refitting it, omitting the class of FOR150 scenarios and predicting subsequently on the same scenarios (Figure 16). The emulator was able to accurately capture the developments in this class of scenarios as well.

Figure 17 exemplifies the coupled outputs of the lookup table with GLOBIOM scenarios for the total employment share of valued added and the valued added of the forest sector until the end of the century. The value added grows between 20 and 40% by the end of the simulation period, with the highest values for scenarios with high use of wood in the construction sector. These scenarios also displayed the highest level of employment in the forest sector, albeit employment levels decline along the simulation period, as productivity grows due to technological progress. The value added share of the forest sector is also highest for scenarios with high construction scenarios, whereas scenarios with low wood use result in declining contribution of the forest sector to the total value

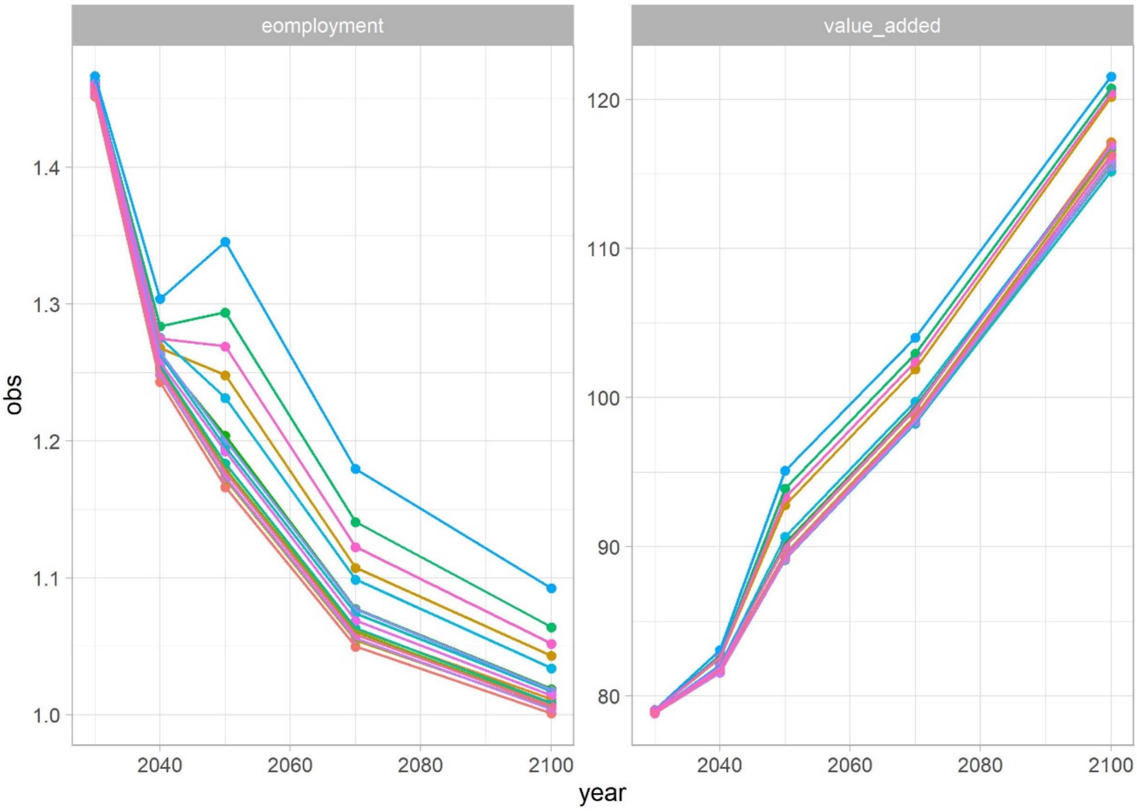


Figure 16. Observed and predicted values for the FOR150 scenario, when FOR150 was excluded from the emulator fitting.

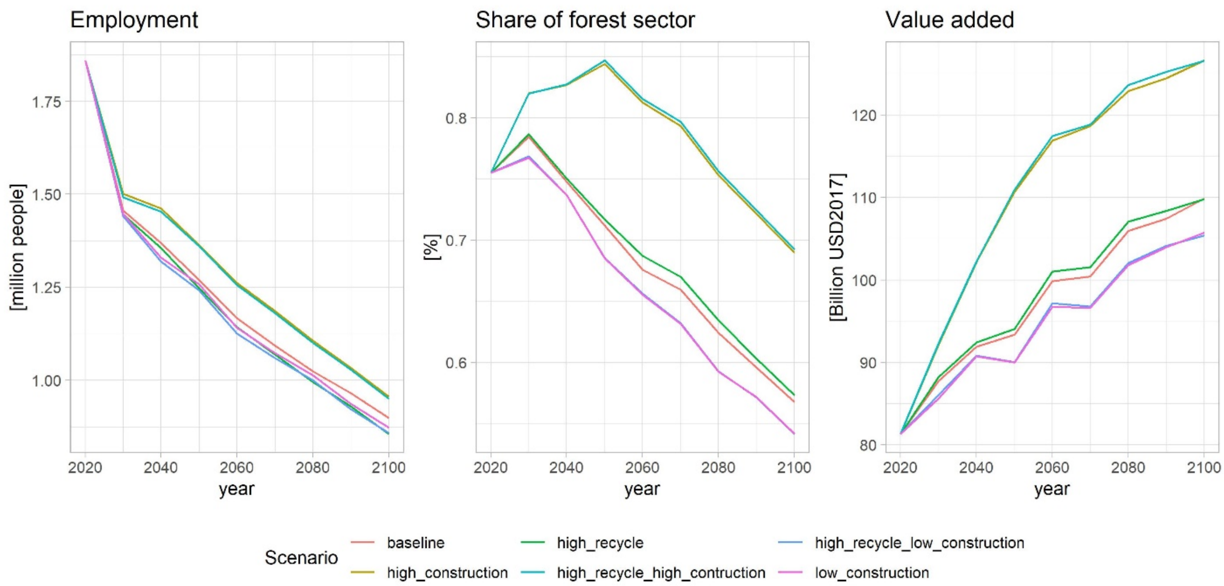


Figure 17. Example of results of the coupled lookup table to GLOBIOM scenario outputs.

4. Scenarios

This section describes the scenarios used to demonstrate the effect of the above linkages between the modelling suites. The scenarios are quantified as proof of concept for the interlinkages between PRIMES and MAGNET, and GLOBIOM/G4M-X. The PRIMES scenarios will demonstrate the effect of the lookup tables in the PRIMES Biomass mitigation potential, while the MAGNET scenarios will be used to analyse the effect of the GLOBIOM/MAGNET lookup table in the deployment of biomass for non-bioenergy uses.

4.1. MAGNET

Instead of aligning directly with particular PRIMES scenarios, the MAGNET approach focuses on the generation of a wide range of scenarios for the lookup table, where the GLOBIOM team can extract the relevant results from (see section 3.4). Moreover, the MAGNET model setup is far less detailed in the other bioenergy sectors compared to PRIMES, so the focus of the bioenergy implementation is on the forestry residues and pellets sector used for bioelectricity. The MAGNET scenario lookup table follows a stylized approach, where, in the current implementation, three scenario dimensions have been added, which are elaborated based on those presented in deliverable 5.4. All the scenario dimensions have been implemented as simple stepwise paths starting from 2025 to 2050. Thus, for example, FOR0 means fixing the wood products demand for construction in the EU at the current level (i.e., 0% change), and FOR100 means an increase of +100% from 2025 to 2050. The baseline scenario includes fixing the fuel wood demand to the base year level, in order to align with PRIMES in that regard. For the BIO scenarios, a dimension was added where the path is implemented globally, instead of just for the EU27 member states. (More information on the MAGNET model and its range of indicators in Deliverable D5.4 "Macro-economic assessment of wood demand scenarios".

Table 5 MAGNET scenario dimensions in the lookup table.

Scenario dimension	Description	Range
BASE	Baseline endogenous model outcome for standard SSP2 model setting. Here, the fuelwood sector (private consumption of forestry sector) is fixed to base year levels.	
FOR	Increase in use of wood products in construction (EU) and paper & pulp in textiles sector (globally) in 2050 relative to 2025.	-25%, 0, 50%, 100%, 200%
GHG	Greenhouse gas tax, globally on all sectors, including implementation of MAC curves in primary agricultural sector. Linear increase from 2025 to 2050.	0, 50, 100, 200 \$/ton CO_2.
BIO / BIOW	Increase of the share of pellets/forestry residues use for bioelectricity in 2050 relative to 2025. Implemented either in EU or globally (W).	-25%, 0, 50%, 100%.

Figure 18 below highlights core changes in the forest material quantities as resulting from the core stylized scenario elements of +50% bioenergy (corresponding to PRIMES' HighBioDem), +100% forestry products in construction and textiles, and a GHG price of 100\$/ton CO_2 by 2050. The scenarios in the current setup resemble those implemented for D5.4, yet with a larger range of implementation of various levels, where this full scenario combination is then designated FOR100_GHG100_BIO50. For WP7, this lookup table will be expanded with more dimensions regarding trade and protected area settings. Please note that in the baseline scenario, without any GHG tax or other incentives, the biobased electricity sector is projected to decline, hence the reduction of the wood pellets sector as seen in the figure below.

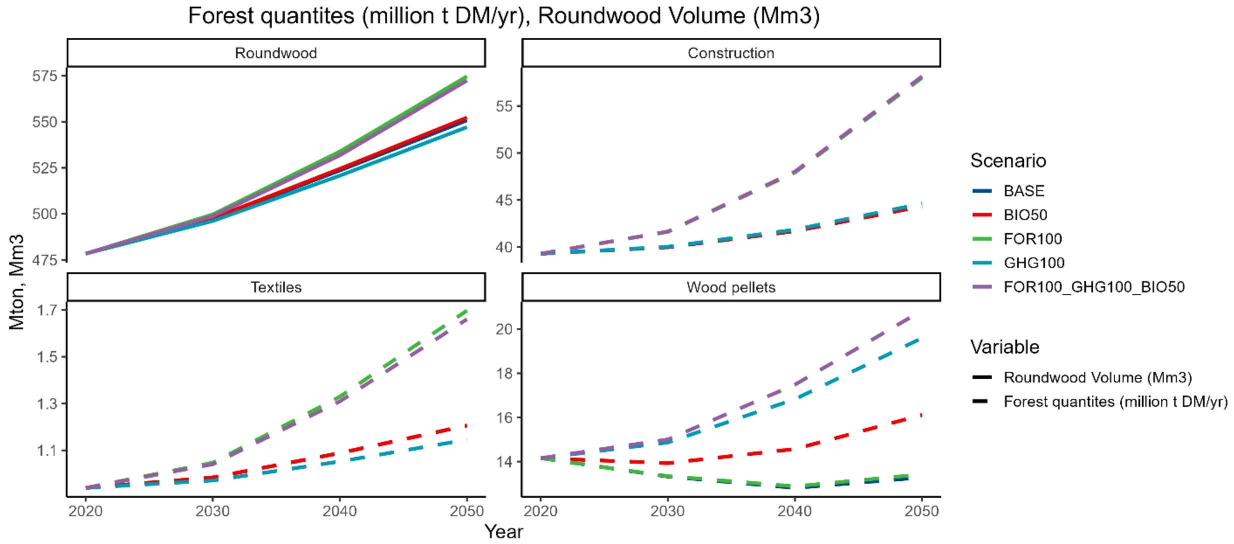


Figure 18 Total Forest material quantity projections for the EU, by sample scenario

4.2. PRIMES

The overall impact of the integration of the GLOBIOM/G4M-X lookup table into the projected biomass deployment in PRIMES Biomass Supply model is assessed through the quantification of two PRIMES Biomass Supply model scenarios: one characterised by high bioenergy demand (BioDemHigh) and a lower bioenergy demand scenario (BioDemLow). The scenarios used in this task are quantified based on the BioEnerHigh and the BioEnerLow PRIMES scenarios developed in WP5[vi]. Using the updated version of the biomass cost-supply curves resulted after the update using the GLOBIOM/G4M lookup table. Both scenarios are developed under the same policy framework, assuming the implementation of policies that contribute to the attainment of the EU Green Deal targets (EU, 2019) stipulated in the EU Climate Law (EU, 2021). 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 (EU, 2023a) EU ETS extension (EU, 2023b)**,** EU ETD (EU, 2021) transport-related initiatives. The description of the scenarios used for the scope of this task is presented in Table 6.

Table 6 PRIMES Biomass Supply scenarios and their respective baseline scenarios.

Scenario	Baseline	Storyline
HighBioDem	BioEnerHigh- developed in Task 5.1 of WP5	High bioenergy penetration in the final fuel mix, especially in power sector
LowBioDem	BioEnerHigh- developed in Task 5.1 of WP5	BioEnerHigh- developed in Task 5.1 of WP5

[vi] https://www.forestnavigator.eu/wp-content/uploads/FN_D-5.1_final.pdf

5. Scenario results

5.1. MAGNET

The sections below give a brief overview of scenario results of the MAGNET lookup table, showcasing some typical results and interactions between sectors and regions. For all these scenarios, a full range of indicators are reported such as value added, trade and employment which are processed by GLOBIOM for reporting of socio-economic indicators.

5.1.1. EU focus results

First focusing on the EU level results, it is clear that instituting a GHG price that increases up to 100$/ton CO_2 has a great impact on both renewables (wind, hydro & solar) and the biobased electricity production (Figure 19). However, as the bioelectricity production is still limited compared to fossil-based electricity, the impact of the BIO50 scenario on fossil electricity is fairly limited. On the other hand, second-generation biofuels, which increase substantially in BASE and FOR100, are dampened in the other scenarios through a competition of resources with other biobased sectors.

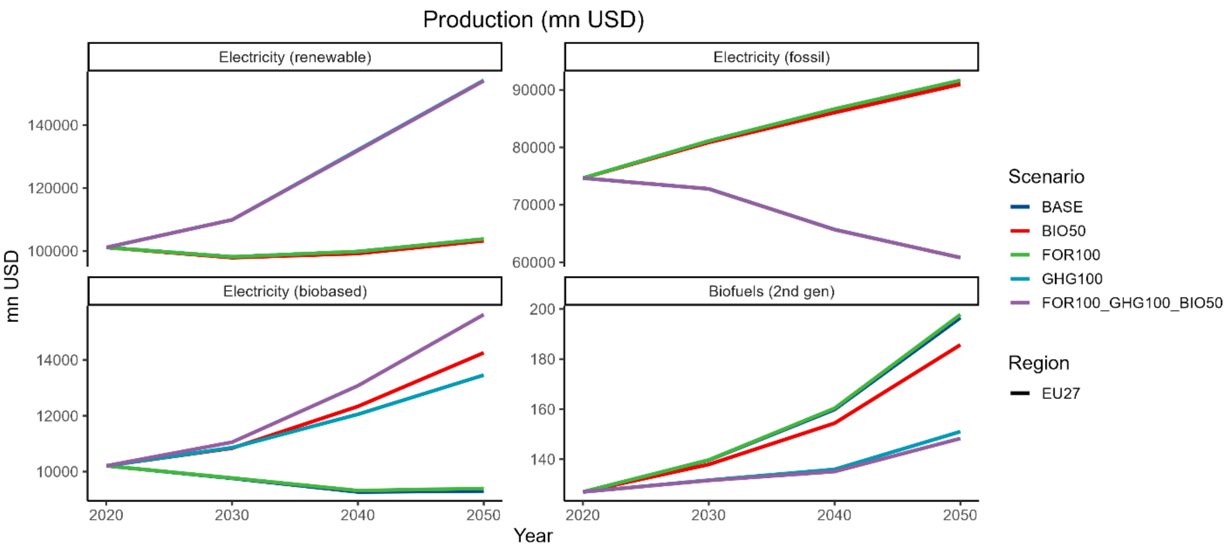


Figure 19 MAGNET projections on electricity production for the EU, by scenario and fuel.

As can be expected, the residues & pellets sector increases in line with the biobased electricity (Figure 20). Other sectors are, however, only marginally affected by the increase in biobased electricity, where the scenario dimensions of higher wood demand have an obvious direct large impact on the wood products demand through the construction sector. Biochemicals production is positively affected by the GHG price scenario. Yet overall, the interactions between different sectors are fairly limited in the MAGNET scenario outcomes.

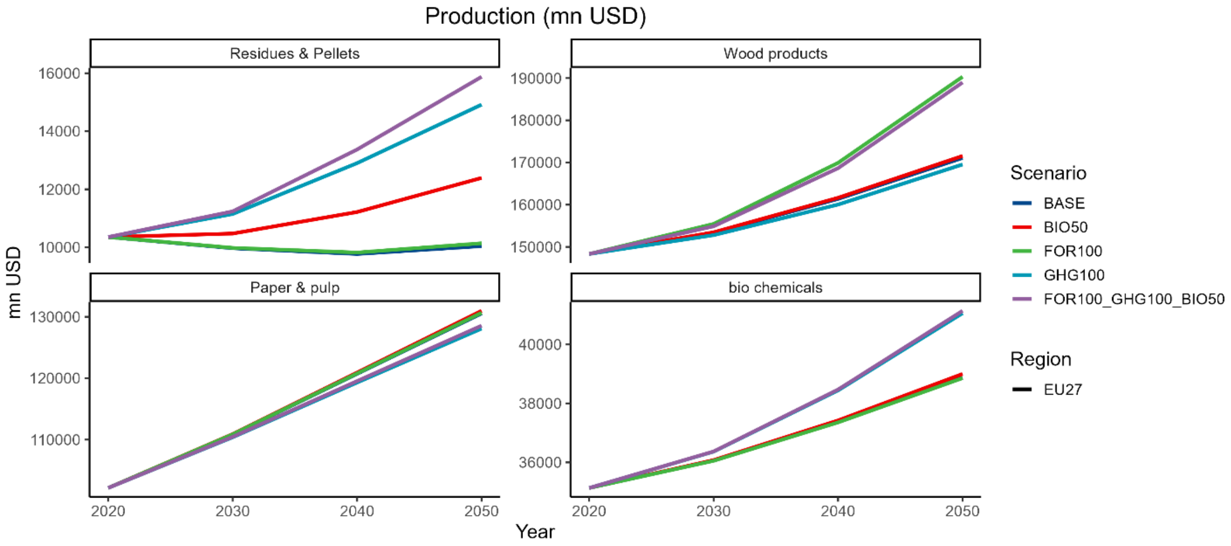


Figure 20 MAGNET scenario results on the production of various related forestry & biobased sectors

When comparing the forestry sector to the total agricultural sector (crops & pastureland, Figure 21), a clear trade-off towards less agricultural land and production as a reaction to the increase in the forestry demand exists. Also, especially for the GHG price, there is a strong effect of reducing pastureland due to the connection with high emissions of methane from ruminants and N_2O emissions from manure.

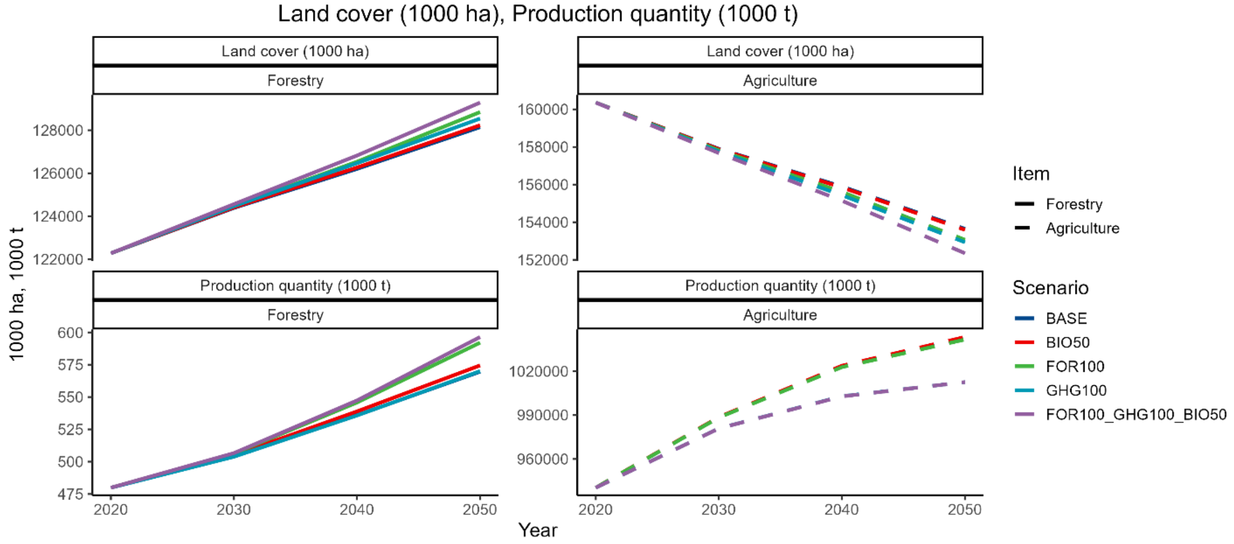


Figure 21 MAGNET scenario results on land cover and production quantity of forestry versus agriculture

5.1.2. Developments in Europe vs the rest of the world

In the BIO50W scenario, bioelectricity from forestry residues & pellets is boosted by 50% globally, as opposed to just in the EU for BIO50. In both cases, as can be seen in Figure 22, most interaction with other renewable electricity and fossil fuels is in the scenarios with the global GHG price.

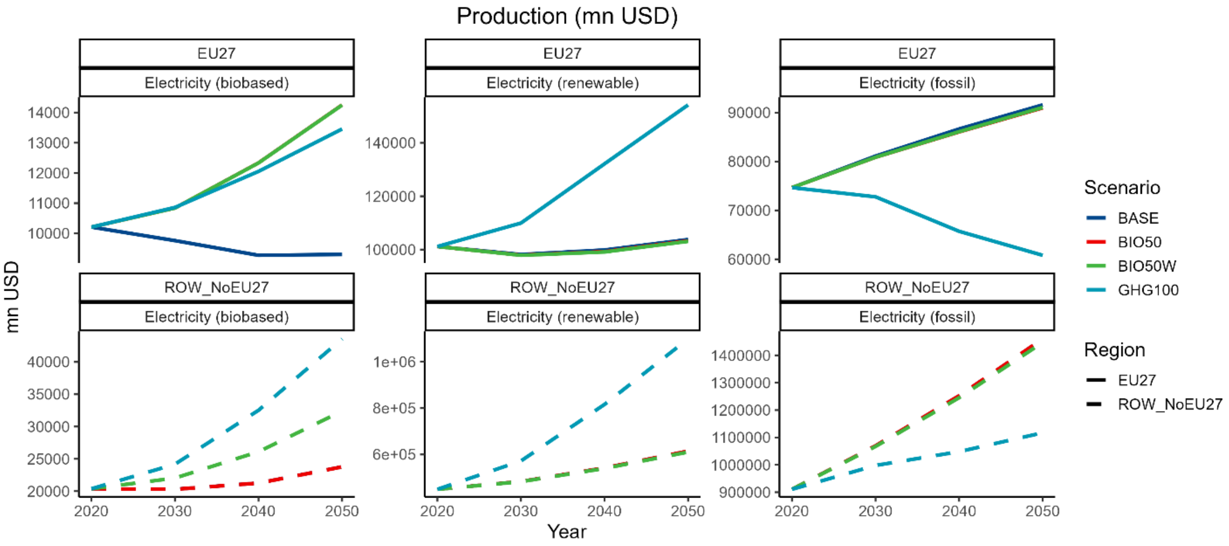


Figure 22 MAGNET scenarios of electricity production in EU vs the rest of the world (ROW_NoEU27)

What is clear in both the BIO and GHG scenarios the increase in the biobased electricity sector leads to an increase in pellets imports in the EU (Figure 23). In the GHG scenario, the global pellets sector increases substantially, leading to overall large changes in trade. In the BIO50, with the focus on EU, it also already clear that the EU increase relies partly on increased imports. In the expanded lookup table for WP7, the MAGNET results will also include a trade dimension where the increased imports in the high demand scenarios is discouraged.

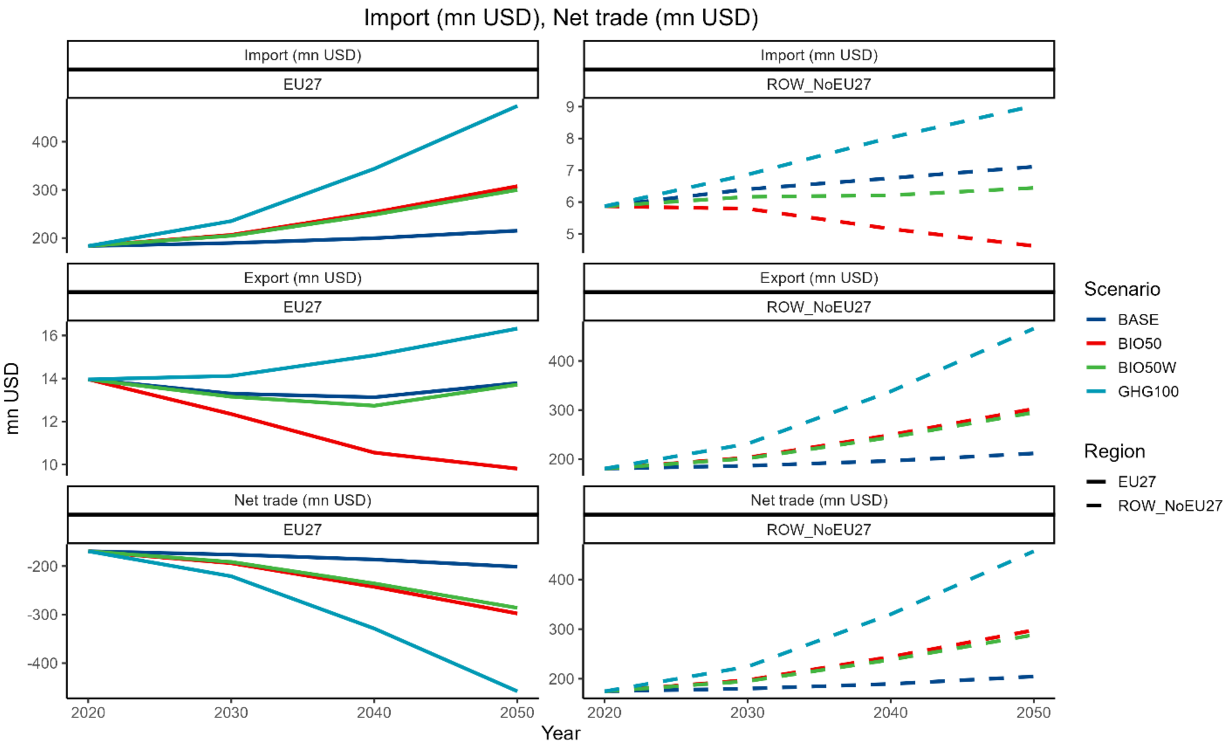


Figure 23 MAGNET scenarios of “residues & pellets” sector trade in EU vs the rest of the world (ROW_NoEU27)

Several sectors are dependent on the forestry sector and affected by the various scenario levers. For example, the biobased chemicals sector reacts strongly to the GHG scenario (Figure 24). There is only very little interaction between the BIO scenario due to the fact that currently the biobased sectors in MAGNET cannot employ residues, so there is no direct competition. The mineral products sector, which includes cement, decreases in size (shown below as the domestic use, in mln USD) due to substitution with wood in the FOR scenario, but also substantially due to GHG emissions.

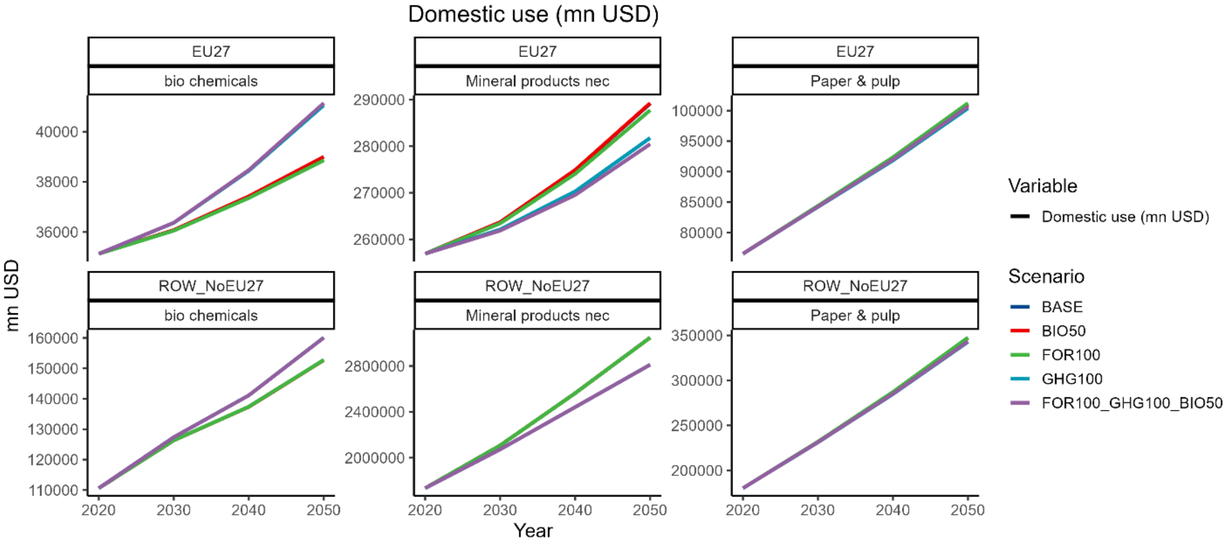


Figure 24 MAGNET scenario results on domestic demand of bio-chemicals and mineral products.

Finally, Figure 25 shows the material quantities as post-calculated by MAGNET (described in D5.4), which, as the FOR scenario is only implemented for the EU, shows only limited effects in the material quantities used globally. The main exception is the rise in wood pellets globally due to the global GHG scenario.

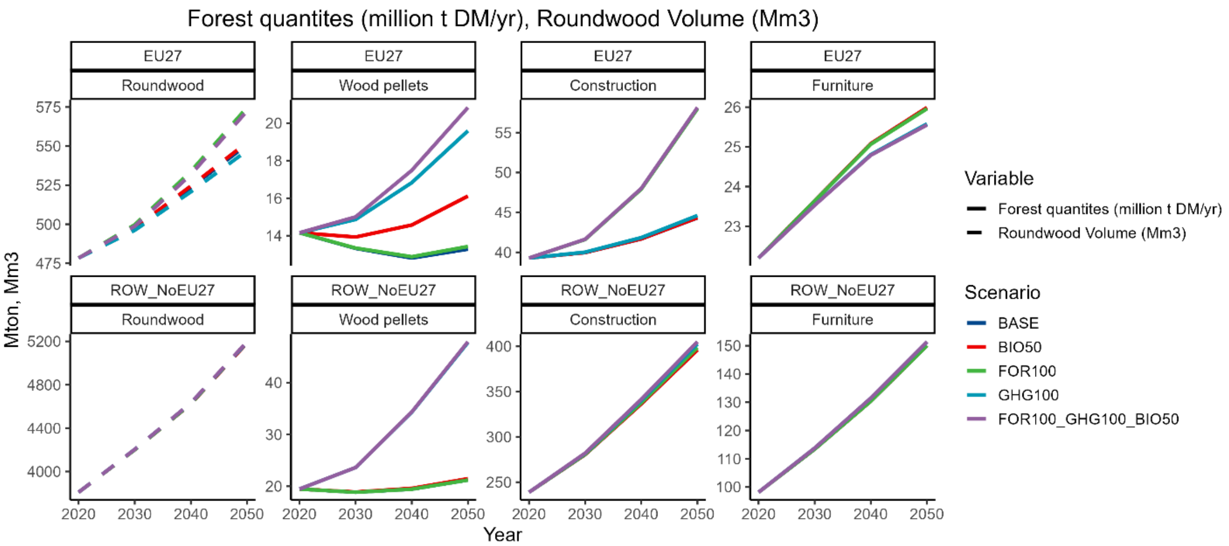


Figure 25 MAGNET scenario results on various forestry material quantities.

5.2. PRIMES

This section presents the results of the HighBioDem and the LowBioDem scenarios, compared with the results of their baseline scenarios as developed in WP5 (i.e., BioEnerHigh and BioEnerLow, respectively).

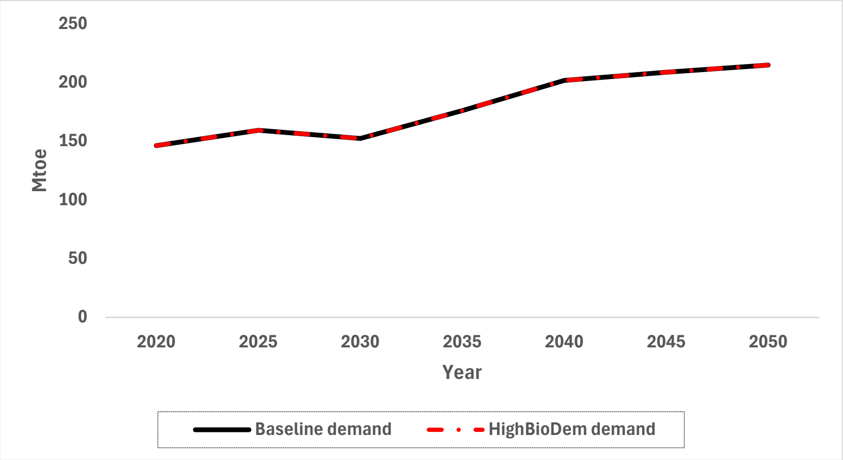
5.2.1. High bioenergy demand scenario (HighBioDem)

The HighBioDem, scenario is quantified based on the BioEnerHigh scenario developed on WP5 for the scope of Task 5.1, which in this analysis is used as a baseline scenario. The differentiation of the HighBioDem scenario from its baseline is the integration of the cost-supply curves provided by GLOBIOM/G4M-X lookup table (*for forestry biomass and lignocellulosic crops*), in the PRIMES Biomass Supply model. The following comparison will assess the impact of the lookup table integration into the biomass development of the PRIMES Biomass Supply model in a scenario characterised by high projected bioenergy demand.

The HighBioDem scenario and the baseline are characterised by the same projection of bioenergy demand, as shown in Figure 26. The bioenergy demand of the EU is increasing by 1.7% annually during the 2030-2050 period, reaching the value of almost 215 Mtoe in 2050. Figure 27 indicates that the bioenergy demand increases between 2030 and 2050, which is attributed to the power supply sector (including district heating supply) and the transport sector (including bunkers). The bioenergy demand of the power supply sector increases by 53 Mtoe in 2050 (compared to 2030), reaching 109 Mtoe, while the bioenergy demand of the transport sector is projected to increase by 23 Mtoe in 2050, compared to 2030. Bioenergy demand of the tertiary sector is projected to increase by 2 Mtoe in 2050 (compared to 2030), while the bioenergy demand of the residential and the industrial sector is decreasing by 7.4 and 8.1 Mtoe, respectively in the same period.

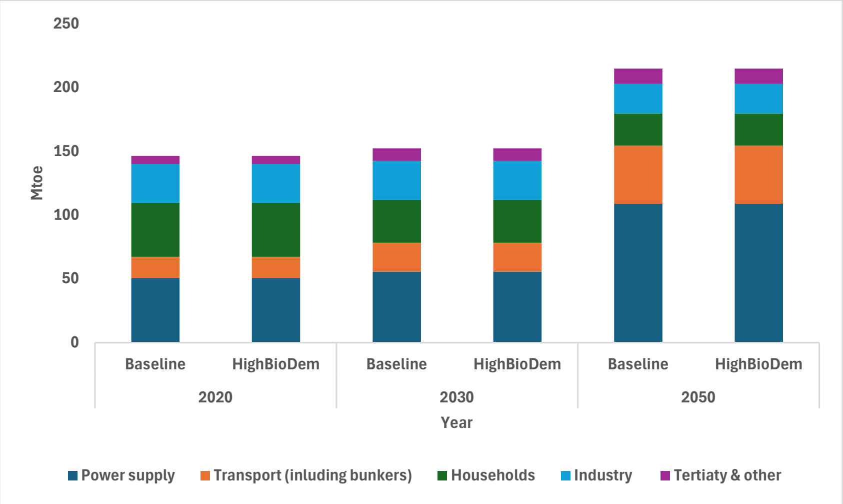
The breakdown of the bioenergy demand projections into bioenergy commodities along with the net imports of bioenergy in the EU, in the HighBioDem scenario and the baseline is presented in Figure 28. Solid bioenergy commodities represent the majority of bioenergy consumption, with their consumption remaining relatively stable at 110-114 Mtoe during the 2020-2050 period. Solid bioenergy is divided into small-scale solids mainly consumed in the residential sector, and large-scale solids along with solid waste biomass, which is directly consumed in thermal process of the power supply and industrial sector. Liquid biofuels consist of biofuels used mainly in road transport (i.e., biogasoline and biodiesel), jet-fuels (i.e., bio-kerosene) and bioenergy consumed by the maritime sector (i.e., Bio-HFO). The consumption of liquid biofuels increases by 6 Mtoe in 2030 (compared to 2020), further increasing by 19 Mtoe in 2050, following the bioenergy demand trajectory of the transport sector (*including bunkers*). Gaseous bioenergy commodities are projected to experience the highest increase in terms of absolute energy, with their consumption increasing by 44 Mtoe in 2050, compared to 2030. The ascending trajectory of gaseous bioenergy demand is linked with the bioenergy demand trajectory of the power supply sector, which is responsible for most raw biogases consumption, and the bioenergy demand trajectory of the transport sector, and especially the maritime segment, which is responsible for the majority of biomethane consumption.

Figure 26 Bioenergy demand projections for the EU, by scenario



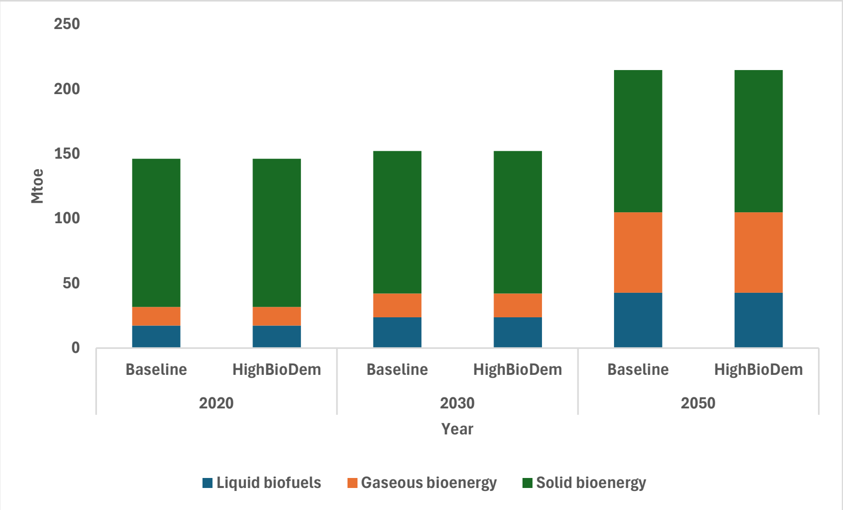
Source: PRIMES

Figure 27 Bioenergy demand projections for the EU, by sector and scenario



Source: PRIMES

Figure 28 Bioenergy demand projections for the EU, by bioenergy commodity type and scenario

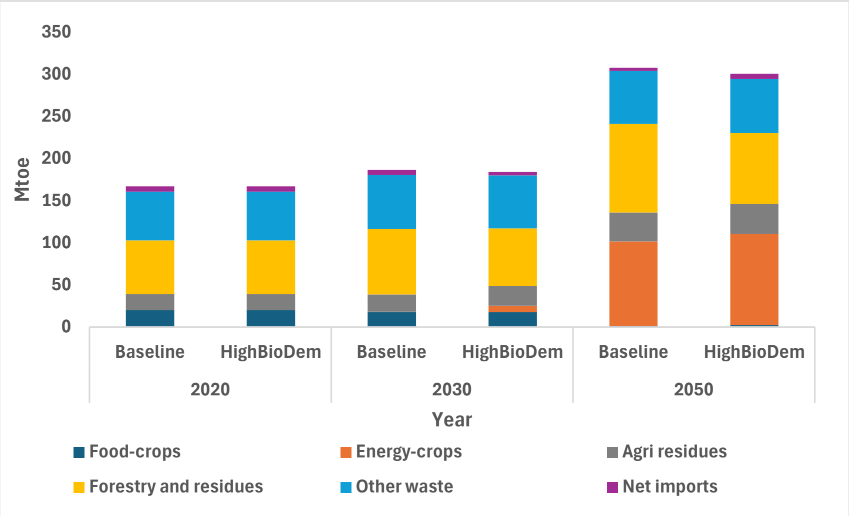


Source: PRIMES

The impact of the GLOBIOM/G4M-X lookup table integration in PRIMES Biomass Supply model is observed in the composition of the primary biomass supply mix of the HighBioDem scenario, compared to the primary biomass supply mix of the baseline scenario as presented in Figure 29. The overall domestically produced biomass supply of the HighBioDem scenario in 2030, is projected to at the same level as the baseline scenario (i.e., 180 Mtoe). The domestic supply of forestry biomass in the HighBioDem scenario is projected to reduce by 12% (i.e., by 10 Mtoe) in 2030, compared to the baseline scenario. The projected loss of forestry biomass supply in the HighBioDem scenario (compared to the baseline), is mainly covered by the higher deployment of lignocellulosic energy crops, and of agricultural residues, increasing by 7.4 Mtoe and 3.3 Mtoe respectively. The production of food/feed crops, along with the utilisation of waste origin biomass for bioenergy production, remain at the same level between the HighBioDem and the baseline scenario in 2030.

In 2050, domestically developed biomass in the HighBioDem scenario is projected to reduce by 3% (i.e., by 9.6 Mtoe) compared to the baseline scenario, while the net imports of total bioenergy in the EU increasing by 61% (i.e., 2.3 Mtoe). The reduction of domestically produced biomass is attributed to forestry biomass supply, decreasing by 20% (i.e., by 21 Mtoe) in the HighBioDem scenario (compared to the baseline), in 2050. The Domestic production of lignocellulosic energy crops is projected to increase by 8% (i.e., almost 8 Mtoe) in the HighBioDem scenario (compared to the baseline). The rest feedstock types are increasing by approximately 1-1.5 Mtoe in the HighBioDem scenario, compared to the baseline, in 2050.

Figure 29 Biomass supply projections of the EU, by feedstock type and scenario.

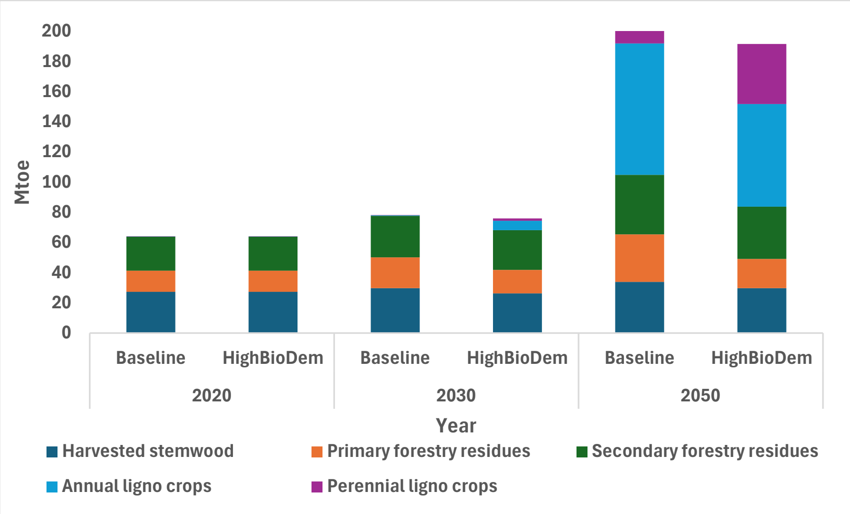


Source: PRIMES Biomass Supply model

Figure 30 which presents the projections of domestically deployed biomass in the EU in a more detailed feedstock breakdown, shows that the projected reduction of forestry biomass in the HighBioDem scenario in 2030 (compared to the baseline), is mainly attributed to the supply of primary forestry residues, which is reducing by 25% (i.e., 5 Mtoe), followed by the supply of harvested stemwood reducing by 11% (i.e., by 3.4 Mtoe). The supply of secondary forestry residues in the HighBioDem scenario, is projected to reduce by 4% (i.e., by 1.2 Mtoe) in 2030, compared to the baseline. On the contrary, the projected increase in the development of lignocellulosic energy crops in the HighBioDem scenario (compared to the baseline), is mainly attributed to annual lignocellulosic crops, representing 79% of HighBioDem total energy crops supply in 2030.

This trajectory continues in 2050, with primary forest residues driving the decrease of forestry biomass in the HighBioDem scenario, compared to the baseline, reducing their supply by 38% (i.e., by 12.1 Mtoe), followed by harvested stemwood supply decreasing by 12% (i.e., by 4.1 Mtoe), secondary forest residues reducing their supply by 12% (i.e., by 4.9 Mtoe), compared to the baseline scenario. While the overall development of lignocellulosic energy crops in the HighBioDem and the baseline scenario is projected to increase slightly (i.e., 4% or by 8 Mtoe)in the HighBioDem, Figure 30 presents a shift of production from annual towards perennial lignocellulosic crops in the HighBioDem scenario. In the baseline scenario, annual lignocellulosic crops are projected to amount for 81% of total energy crops, while their share in the HighBioDem scenario is reduced to 63% of total energy crop production.

Figure 30 Biomass supply projections of the EU, by feedstock and scenario

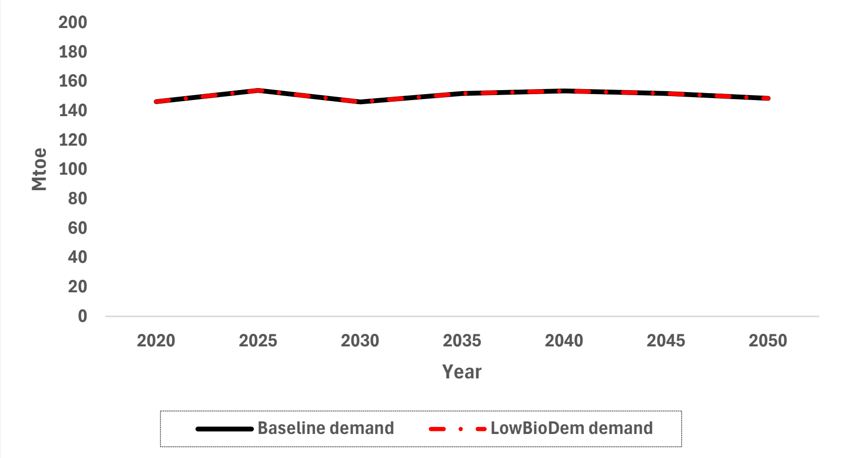


Source: PRIMES Biomass Supply model

5.2.2. Low bioenergy demand scenario (LowBioDem)

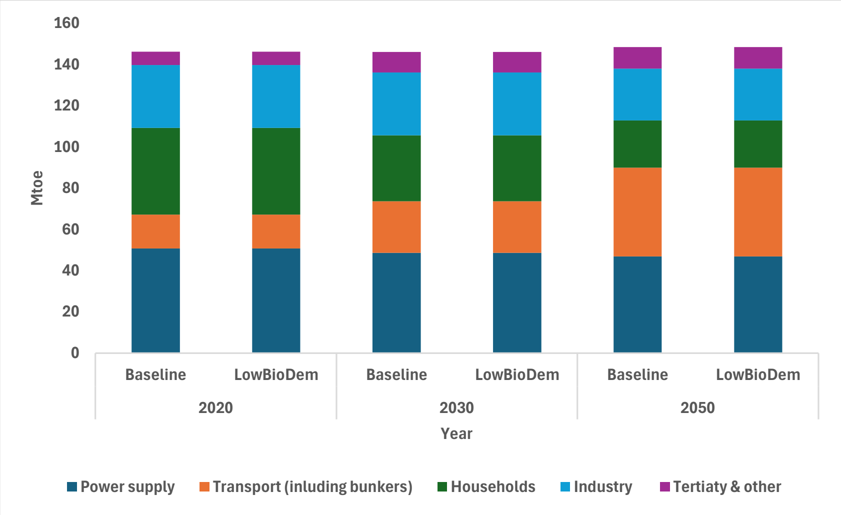
The LowBioDem scenario is quantified based on the BioEnerLow scenario developed in Task 5.1 of WP5, which in this analysis serves as a baseline scenario. The LowBioDem scenario is quantified using the cost-supply curves provided in the GLOBIOM/G4M-X lookup table. The LowBioDem scenario is characterised by the same bioenergy demand projections as its baseline (Figure 31), with bioenergy demand remaining relatively stable during the 2030-2050 period at 146-149 Mtoe. While the transport sector (including bunkers) is increasing its bioenergy demand by 72% (i.e., 18 Mtoe) in 2050 (compared to 2030), this increase is mostly anticipated by a 28% decrease in the bioenergy demand of the residential sector and an 18% decrease in the bioenergy demand of the industrial sector, in the same period. The bioenergy demand of the power supply sector (including district heating generation) is projected to decrease by 4% in 2050 (compared to 2030), while the tertiary sectoral bioenergy demand increases by 5% (Figure 32).

Figure 31 Bioenergy demand projections for the EU, by scenario



Source: PRIMES

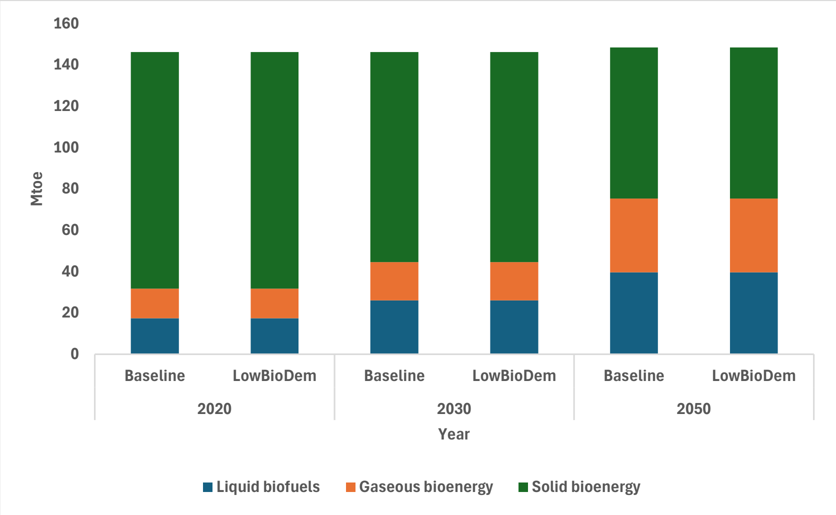
Figure 32 Bioenergy demand projections for the EU, by sector and scenario



Source: PRIMES

As shown in Figure 33 liquid biofuels are projected to increase their contribution in the bioenergy mix by 9 Mtoe in 2030 (compared to 2020), further increasing by 14 Mtoe in 2050 (compared to 2030), following the trend of the transport sector. Gaseous bioenergy demand is increasing by 4 Mtoe in 2030, compared to 2020, further increasing by 17 Mtoe in 2050 (compared to 2030), mainly driven by the maritime segment of the transport sector. The demand for solid bioenergy is characterised by a downward trend in the same period, which is attributed to the decreasing bioenergy demand of the residential sector.

Figure 33 Bioenergy demand projections for the EU, by bioenergy commodity type and scenario

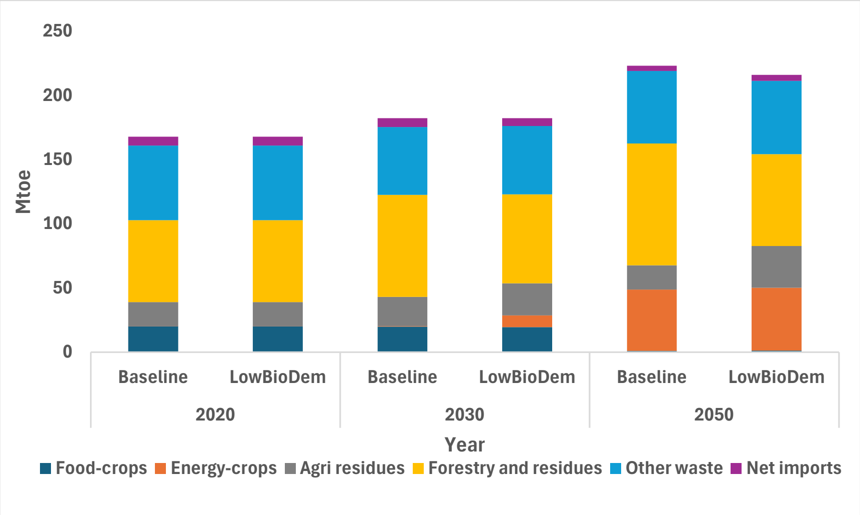


Source: PRIMES

Domestic biomass deployment in the LowBioDem scenario is projected at the same level as the baseline in 2030 (i.e., approximately 176 Mtoe), while the overall bioenergy imports are decreasing by 13% (i.e., by 0.9 Mtoe). However, a shift is observed in the biomass feedstocks developed between the two scenarios. The integration of the GLOBIOM/G4M-X lookup table into PRIMES Biomass Supply model is driving down the supply of forestry biomass by 13% (or 10 Mtoe) compared to the baseline, while favouring the production of energy crops, representing 5% of total domestic biomass production in the LowBioDem scenario. Agricultural residue supply is increasing by 10% (i.e., by 2 Mtoe) in the LowBioDem scenario (compared to the baseline), as the earlier development of energy crops cannot alone cover the reduction of forestry biomass supply in the LowBioDem scenario. The production of food & feed crops in the LowBioDem scenario is projected to decrease by 2% in 2030 (compared to the baseline).

In 2050, the domestic biomass supply in the LowBioDem scenario is projected to reduce by 4% (i.e., by 8 Mtoe), compared to the baseline scenario. This reduction is attributed to forestry biomass reducing its supply by 25% (i.e., by 23 Mtoe) in LowBioDem, compared to the baseline scenario. Domestic supply of agricultural residues in the LowBioDem scenario is projected to increase by 71% (i.e., 13 Mtoe) (compared to the baseline), covering almost half the deficit created by forestry biomass. Energy crops, along with food crops production, are projected at similar levels between the two scenarios. The net imports of bioenergy in the LowBioDem scenario are increasing by 0.6 Mtoe, compared to the baseline.

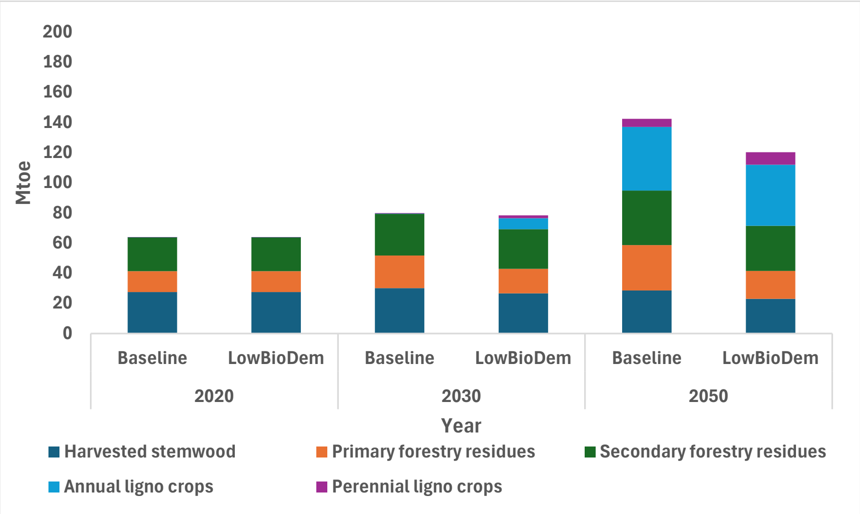
Figure 34 Biomass supply projections of the EU, by feedstock and scenario



Source: PRIMES Biomass Supply model

Figure 35 provides a more detailed breakdown of domestic biomass production of the LowBioDem scenario and its baseline. Specifically, it is observed that the most affected feedstock from the integration of the GLOBIOM/G4M-X lookup table into the PRIMES Biomass Supply model is primary forest residues, reducing their supply by 25% in 2030, and by 39% in 2050, compared to the baseline. This reduction is attributed to the decrease in the available potential of primary forest residues, due to the integration of the lookup table (i.e., 26% in 2030 and 33% in 2050). Harvested stemwood supply is projected to reduce by 11% (i.e., by 3.5 Mtoe) in 2030 and by 19% (i.e., by 5.4 Mtoe) In 2050, compared to the baseline. Secondary residues are the least affected forestry biomass feedstock, reducing their potential by 5% (i.e., by 1.3 Mtoe), and by 18% (i.e., by 6.4 Mtoe) in 2030 and 2050, respectively, compared to the baseline scenario. The projected increase of energy crops development in the LowBioDem scenario in 2030 (compared to the baseline) is mainly attributed to annual lignocellulosic crops, representing 78% of energy crops production in 2030. In 2050, the development of energy crops in the LowBioDem scenario is projected to be similar to the baseline, with no significant differentiation in the contribution of each crop type.

Figure 35 Biomass supply projections of the EU, by feedstock and scenario



Source: PRIMES Biomass Supply model

6. Outlook

The next phase of the ForestNavigator project, involving the policy modelling toolbox developed in this Task, is its application to explore climate mitigation pathways for the EU forest sector in WP7 under alternative scenarios:

- woody biomass demands for energy and material uses
- biodiversity goals and other environmental targets
- adaptation level on climate mitigation targets.

Thereafter, the modelling toolbox will be utilised in WP8 to assess policy-relevant climate mitigation pathways for the EU forest sector.

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