ForestNavigator

D7.4 Report on EU forest sector pathways in the global context

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Abstract

The ForestNavigator project evaluates forest sector mitigation pathways in Europe. In Task 7.4, ForestNavigator partners focus on forest sector mitigation pathways in the global context. Here, we examine how forest-based climate policies in the EU27, China, and the United States interact with global wood markets, carbon dynamics, and land use through trade. Using GLOBIOM-China as a core model, we assess a baseline scenario and three mitigation scenarios with emphasis on bioenergy expansion (HighBIO), increased wood use in construction (HighCONST), and a combination of both (HighBC). To assess harvest and carbon sink leakage, the scenarios are varied with both free-trade and fixed trade settings.

Results show that ambitious forest-based mitigation policies driven by wood demands in the combined policy regions (EU27, China, USA), intensify domestic harvesting, and incentivises increased wood material imports from RoW, inducing increased harvests in the Rest of the World (RoW), decreasing the global forest carbon sink. Despite this, the total carbon storage increases in all three policy regions by 2100, where BECCS deployment in China is an important driver. A comparison of GLOBIOM results against FAOSTAT trade statistics (with additional analysis to correct for re-exports) and MAGNET simulations reveals structural differences between models, in both assumptions and flexibility in optimization for the scenarios, that affect the magnitude of leakage estimates and trade developments.

Our findings highlight the importance of internationally coordinated forest governance to prevent carbon leakage and ensure that regional mitigation ambitions contribute to global climate goals.

Keywords

forest sector mitigation pathways, biomass, carbon leakage, trade

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Abbreviations

BAU	Business as Usual
BECCS	Bioenergy with Carbon Capture and Storage
DF	Displacement Factor
EC	European Commission
EU	European Union
FAO	Food and Agriculture organization of the United Nations
GDP	Gross Domestic Product
GHG	Greenhouse gases
HWP	Harvested Wood Product
IIASA	International Institute for Applied Systems Analysis
LULUCF	Land Use, Land Use-Change and Forestry
Mha	Million hectares
Mm^3	Million cubic metres
Mt	Million tonnes
RCP	Representative Concentration Pathway
RoW	Rest of the World
SSP	Shared Socioeconomic Pathway
UNFCCC	United Nations Framework Convention on Climate Change
WP	Work Package

1. Introduction

The forest sector plays a pivotal role in EU climate neutrality. Together with the broader land use, land-use change, and forestry (LULUCF) sector and industrial carbon removals such as bioenergy with carbon capture and storage (BECCS), forests are expected to compensate for residual emissions from all other sectors by 2050 (EC, 2025). This ambition is reflected in the EU LULUCF Regulation (EC, 2023), which sets national mitigation targets for the land-use sector by 2030, and more recently in the Carbon Removal Certification Framework (CRCF) Regulation (EC, 2024), which supports carbon removals in forest land and wood products. At the same time, the forest sector is also expected to play a key role in the EU bioeconomy and contribute to European economic competitiveness (EC, 2025).

These ambitious EU climate goals must, however, be assessed within a global context in which other high greenhouse gas (GHG) emitters, like China and the USA, are pursuing their own mitigation and bioeconomy strategies. The dynamics of global trade and substitution of sourcing are particularly important in this regard, as they highlight the potential risks of assessing forest sector ambitions in isolation within the EU, China, or the USA.

Within this global context, China's forestry policy has undergone a fundamental transition over the past three decades, shifting from timber production towards ecological conservation and carbon sequestration. Following the Natural Forest Conservation Program launched in the late 1990s, China enacted a comprehensive ban on commercial logging in natural forests by 2017, thereby restricting domestic wood supply largely to planted forests (Zhao et al., 2021). Simultaneously, under the 14th Five-Year Plan (2021–2025), China aims to increase forest coverage to over 24% and expand total forest area to approximately 250 Mha by 2035. Forest carbon sinks are expected to play an important role in achieving the country's carbon neutrality by 2060 under the Paris Agreement. However, the logging ban has also increased China's reliance on wood imports from global markets to meet domestic wood demand (Zhang & Chen, 2021). This development raises important questions about the displacement of harvesting pressure to other regions.

In parallel, several federal policies and environmental market mechanisms in the USA have been introduced to support forest-based climate mitigation, including reforestation and increased emphasis on the use of harvested wood products such as mass timber (Favero et al., 2025). The convergence of forest-based mitigation strategies in the EU27, China, and the USA – each pursuing expanded wood use for bioenergy and/or construction – makes the global wood market a crucial mediating mechanism.

One way to investigate potential concerns associated with these forest-based mitigation strategies is through the concept of carbon leakage. In this context, leakage may occur through shifts in harvesting activity and changes in forest carbon sinks resulting from changes in production locations and management systems (Pan et al., 2020). Carbon leakage can occur when policies in one region displace harvesting activities to other parts of the world, thereby potentially offsetting the domestic mitigation gains (Daigneault et al., 2025). Recent work by Schulte et al. (2025) provides a comprehensive global assessment for Sweden and concludes that only coordinated international policy action can avoid leakage and maximise climate mitigation benefits. Similarly, the EU-focused analysis under ForestNavigator Deliverable 7.1 showed that trade adaptation in a high bioeconomy demand scenario could lead to harvest leakage of up to 74 Mm^3/yr, offsetting roughly 60% of the EU's forest carbon benefits. The present analysis extends this EU-focused leakage assessment to include China and the

USA as regions with strong forest-based mitigation and bioeconomy ambitions, as well as analyses the implications of these policies for leakage effects in the rest of the world.

Work Package 7 explores pathways for increasing the mitigation contribution of EU27 forests while accounting for synergies and trade-offs with biodiversity and the bioeconomy. The modelling of scenarios looking beyond the EU27 under task 7.4 is conceptually based on the demand perspective scenarios from task 7.1. Accordingly, the scenarios compare baseline developments in future wood product demand (including biomaterials and bioenergy) with higher demand scenarios in the EU27, China and the USA as drivers of future mitigation pathways in a global context. Leakage effects are then investigated by comparing high-demand scenarios with alternative cases in which trade adjustments are restrained.

2. Aim

This report aims to place wood demand-oriented forest mitigation pathways, as presented in ForestNavigator's deliverable 7.1, in a global context. China and the USA are introduced as co-equal policy regions where forest mitigation pathways are implemented by alternative wood demand developments.

Three demand-side pathways are explored, covering high bioenergy demand, expanded wood use in construction, and a combined scenario. The scenarios, which are forward-looking up to 2100, explore potential carbon leakage effects to the rest of the world by contrasting the high wood product demand scenarios (where increased imports are allowed) with trade-restricted versions of those scenarios.

The core analysis, employing the GLOBIOM-China model, quantifies roundwood harvest volumes, energy plantation development, net trade shifts, wood harvest leakage, and forest carbon sink leakage across the EU27, China, and the USA, contrasted with the rest of the world. Additional analysis using a complementary set of scenarios implemented in the MAGNET CGE model serves as a sensitivity analysis of harvest leakage effects with fewer restrictions on increasing harvest volumes. Observed international wood trade data corrected for re-export serves as a consistency check on the modelled trade flows.

3. Methodology & Models

The main model applied for this scenario analysis is the GLOBIOM-China specification within the GLOBIOM framework, where the baseline of the forestry sector for China is developed in detail. For the EU27 and the USA, the developments in the business-as-usual are based on earlier work described in deliverable 7.1. We calculated carbon storage in harvested wood products (HWP) and bioenergy with carbon capture and storage (BECCS) using the same methodology as D7.2 (available on www.forestnavigator.eu/resources/).

This approach integrates both temporary (HWP) and permanent (BECCS) carbon pools in assessing the total climate mitigation impact of wood-based policies. HWP carbon storage follows the IPCC production approach (IPCC 2019) and is based on historical production and trade data (FAOSTAT, 1961–2020). HWP represent temporary carbon pools, with product half-lives ranging from 0 to 35 years, and typically store a small fraction of total forest carbon due to biomass losses during harvest and processing. In contrast, BECCS provides a permanent carbon sink, with net negative emissions calculated as the product of harvested bioenergy carbon, the fraction of bioenergy deployed with carbon capture (from the MESSAGE model), and the assumed carbon capture efficiency. The MAGNET model is applied in parallel with similar scenarios focusing on socio-economics and the economy-wide context. Finally, an additional analysis on wood supply chains corrects FAOSTAT data for re-exports and expresses these final trade flows in industrial roundwood equivalents.

3.1. GLOBIOM

The GLOBIOM model follows a bottom-up approach based on detailed grid-cell information, providing the biophysical and technical cost of supply, which are matched with the demands at the national/regional levels. The model computes a market equilibrium in 10-year time steps from 2000 by maximizing the sum of consumer and producer surplus subject to technological, resource, and political constraints. At each step, market prices adjust endogenously to equalize supply and demand for each product and region. There are three main forest types in the GLOBIOM model. Managed forest represents all forest areas where harvesting operations take place, which is also the source of industrial roundwood, pulpwood, fuelwood, and residues. Natural forest is represented by undisturbed or primary forests, which mainly provide carbon sequestration and biodiversity value, with no harvest. Finally, newly afforested forest land, which remains unharvested and provides a carbon sink. The managed forests are further divided into forests managed with low intensity (CurL), multifunctional forests (CurM), and high intensity managed forests (Cur), each of these classes is characterized by a share of the MAI (Mean Annual Increment) available for harvest. The GLOBIOM model links to the Global Forest Model (G4M) harmonizing forest growth (MAI) and harvesting potentials (Kindermann et al., 2008), while accounting for trade-offs with other land uses such as cropland and pastures. Carbon dynamics are tracked through changes in standing biomass and harvested wood products, considering the forestry sector to contribute both to material supply and climate mitigation. Finally, the model can simulate forest products allocation to international markets. Further details on the GLOBIOM general model infrastructure are presented in ForestNavigator D6.1. In this specific task, the GLOBIOM-China version of the model was deployed, which includes the representation of 37 market/trade regions (i.e., countries are grouped according to these regions).

3.2. GLOBIOM-China

GLOBIOM-China was developed within the global GLOBIOM framework and enhanced with country-specific data and policies to better capture the characteristics of China's agro-forestry sector (Zhao, H., et al., 2021). GLOBIOM-China was calibrated using several key parameters, including food demand elasticities, crop yield shifts resulting from technological change, grass yields, and bilateral trade for agricultural products.

The baseline scenario for China reflects a set of existing policies, programs, and official plans. First, it incorporates structural changes in Chinese food consumption, particularly the increasing consumer preference for monogastric products and associated shifts in production practices. Second, it assumes a self-sufficiency rate of 95% for three major cereal crops under the baseline scenario, in line with the current domestic self-sufficiency policies. Third, it includes the national policy objective of achieving "zero growth of synthetic fertilizer use after 2020" (MOA, 2015). Finally, forestry policies are represented through the implementation of a zero-deforestation policy, a national afforestation target, and the logging ban in natural forests.

In this task, GLOBIOM-China was further developed with an enhanced representation of the forest sector, incorporating detailed information from China's forest inventory. First, we revised the gridded forest distribution map at a 0.5° spatial resolution for the year 2020. The land-cover layer was derived from the GLC-2015 dataset (Li et al., 2023), while forest management information was derived from Lesiv et al. (2022). To ensure consistency with official statistics, forest areas in the gridded dataset were rescaled to match data from the Global Forest Resources Assessment 2020 (FRA, 2020). For China specifically, the forest area was further adjusted using provincial statistics from the 9th National Forest Inventory (NFI, 2019). This resulted in a total forest area of approximately 220 Mha in 2020, including about 140 Mha of natural forests and 80 Mha of planted forests.

Future changes in China's forest area, including both natural and planted forests, were constrained in the model according to existing policies and plans. Specifically, total forest area is set to reach 230.5 Mha by 2025 under the "Fourteenth Five-Year Plan" for the protection and development of forestry and grassland. It is further projected to expand to 249.6 Mha by 2035 under the National Major Project for the Protection and Restoration of Important Ecosystems (2021-2035). In addition, for managed forests designated for wood harvest, an additional 13 Mha will be established between 2020 and 2035 in line with the National Reserve Forests Construction Plan (2018-2035), which targets 20 Mha of new plantations, of which 7 Mha had already been planted by 2020. In addition, historical production statistics for selected wood products (e.g., plywood) were calibrated using FAOSTAT data in the model.

In terms of harvesting assumptions, China's nationwide logging ban in natural forests, implemented in 2017, was represented by restricting wood supply to planted forests only. Furthermore, no deforestation was assumed after 2020, in accordance with China's stringent forest protection laws and policies. Finally, bilateral trade in forestry products between 2000 and 2020 was calibrated using trade flow data from FAOSTAT.

3.3. MAGNET

MAGNET is a multi-regional, multi-sector recursive dynamic equilibrium model built on neo-classical macroeconomic theory (Woltjer, 2014). MAGNET includes modular extensions to improve the representation of the agricultural, forestry and land use, as well as their related policies. Compared to similar global CGE economic models, MAGNET provides a higher sectorial detail concerning the land-use sectors. The MAGNET database includes 130 sectors, including both agricultural and non-agricultural sectors. These include eighteen primary agricultural sectors, as well as connected processed food sectors, and several forestry-related sectors, such as primary forestry, wood production, and the paper & pulp sector. A detailed exposition of MAGNET and high wood demand scenarios was presented in ForestNavigator deliverable 5.4, and its role in the modelling toolbox in deliverable 6.4. MAGNET was applied using lookup tables of socio-economic indicators in deliverable 7.1, following a standardized set of scenarios. In this deliverable however, we employ direct MAGNET scenario results as a sensitivity analysis regarding the leakage effects calculated by the GLOBIOM-China model.

In MAGNET, the trade flows in the core are only of a monetary nature as they are based on the economic database of the global trade analysis project (GTAP), which were mapped to FAOSTAT items as shown in Table 1. In the plausibility checks and robustness sections, we will compare the physical global wood flows data as constructed in the base year situation, following the procedure outlined in section 3.4 prepared by the team at BOKU, with the trade flows in the MAGNET model.

Table 1: Mapping between FAOSTAT sectors and MAGNET sectors.

Item code	Item description	MAGNET sector
1860	Paper and paperboard, excluding newsprint	Paper & Pulp Products
1875	Wood pulp	
1671	Newsprint	
1670	Industrial roundwood, non-coniferous non-tropical (export/import)	Forestry, logging, and related service activities
1651	Industrial roundwood, coniferous (export/import)	
1657	Industrial roundwood, non-coniferous tropical (export/import)	
1640	Plywood	Wood & Timber products
1874	Fibreboard	
1633	Sawnwood, non-coniferous all	
1632	Sawnwood, coniferous	
1619	Wood chips and particles	
1634	Veneer sheets	

3.4. Assessment of wood supply chains

Bilateral trade data –as is provided by FAOSTAT and output by GLOBIOM– does not necessarily identify the country of primary harvest, but only the country where the last value-added step occurred. These trade flows can hence also contain re-exports. This is due to the fundamental accounting approach of trade-statistics that refer to the last node of value-added, but it hampers the establishment of straightforward links between changes in wood demand in one region and global ecosystem effects due to increased/decreased wood harvest. However, trade data can be corrected for re-exports, allowing to identify the country of primary harvest and thus to appropriately depict ecosystem effects associated with locally disconnected consumption.

Following the approach described in Kastner et al. (2011), the correction for re-exports in this study works under an assumption of proportional origin from imports and domestic production, meaning that a country's consumption as well as its exports will originate in proportional shares from its own production and its imports. Trade flows corrected for re-exports correspond to flows from the country of primary origin (harvest) to the country of apparent final consumption. All wood flows considered in the corrections for re-exports were converted into industrial roundwood equivalents. Included products are paper and paperboard, plywood, wood pulp, sawnwood, wood chips and particles, veneer sheets, newsprint and industrial roundwood. Recovered products (e.g., recycled paper) are excluded as they do not represent a new harvest, and wood fuel is assumed to be consumed domestically only.

The main advantages of this complementary approach are, in short i) the corrected matrix does not contain re-exports, and therefore does not have the problem of double counting trade flows; ii) under the mentioned assumption, the "actual" origin of the material in consumed products is clearly indicated; and accordingly iii) the case that a product will get assigned to a country of origin that does not produce this product cannot occur.

This procedure was applied to data from FAOSTAT on bilateral wood trade for 2017 (discontinued; ends in 2017) and to the global trade results of the 37 modelled world regions in GLOBIOM, to compare supply chains across scenarios and against a recent reference.

4. Scenarios & Data

4.1. Scenario overview

We apply the integrated land-use and agro-forestry assessment model GLOBIOM-China to evaluate forest-based mitigation pathways in China, the EU27 and the United States over a long-term horizon towards 2100. We defined a baseline (business as usual, BAU) scenario reflecting current policies and projected future wood demand for bioenergy and material use trends. This scenario was built on the Shared-Socioeconomic Pathway 2 (SSP2, Fricko et al., 2017) with an intermediate mitigation ambition (RCP4.5), with China-specific developments described in (Zhao, H. et al., 2021) and forestry-sector improvements as detailed in the modelling framework section. A set of policy scenarios is constructed, including mitigation strategies driven separately by bioenergy expansion (HighBIO) and increased wood use for construction (HighCONST), and a combined scenario in which both measures are implemented simultaneously (HighBC). The scenario design (see Table 2 and Table 3) aims to evaluate the impacts of forest-based mitigation policies on regional forest sectors, carbon sinks, and wood product trade in China, the EU27, and the USA, with particular attention to potential carbon leakage across regions.

Table 2: Main scenario setup for the GLOBIOM-China model

Dimensions	***Baseline (BAU)***	**Mitigation (free trade)**	**Mitigation (fixed trade)**
Regional (EU27, China, US) forest based mitigation policies	Baseline (EU27 BASE + CHINA BASE+US BASE)	EU27/CN/US together with high bioenergy and/or construction	EU27/CN/US together with high bioenergy and/or construction
RoW (Rest of the World) mitigation ambition	MESSAGE **RCP4.5** (5.2 W/m2)	MESSAGE **RCP4.5** (5.2 W/m2**)**	MESSAGE **RCP4.5** (5.2 W/m2**)**
Trade tariffs/barriers	SSP2 trade	SSP2 trade	trade (Shipment) forced as Baseline

Table 3: Details scenario overview and assumptions

Scenario	Regional (EU27, China, US) forest-based mitigation policies	RoW (Rest of the World) mitigation	trade forced as Baseline
BAU	SSP2-RCP4.5	SSP2	No
HighBIO	high-bioenergy demand	SSP2	No
HighCONST	high-construction demand	SSP2	No
HighBC	both measures are implemented	SSP2	No
HighBIO-FixTrade	high-bioenergy demand	SSP2	Yes
HighCONST-FixTrade	high-construction demand	SSP2	Yes
HighBC-FixTrade	both measures are implemented	SSP2	Yes

Bioenergy demand for the EU27 is taken from the PRIMES energy system model, while bioenergy demand for China and the US is based on results from the MESSAGE model. The MESSAGE model (Huppmann et al., 2019) provides a structured framework for analyzing energy systems and their environmental impacts, supporting the identification of optimal energy strategies based on different supply alternatives. In the high-bioenergy demand (HighBIO) pathway, bioenergy demand in China, the EU27 and the US is assumed to be consistent with the projected energy system transition under carbon neutrality targets, implying a strong increase in bioenergy deployment consistent with mitigation pathways relying on BECCS (Di Fulvio et al., 2025). The bioenergy demand under the high-bioenergy demand (HighBIO) pathway for the EU27 follows the HIGH scenario from the PRIMES model, as in the earlier deliverables (D7.1), while for China and the US, the bioenergy demand under the HighBIO pathway follows the RCP1p9 scenario from the MESSAGE model. For all remaining regions, bioenergy demand follows the RCP4.5 pathway. This setup leads to substantially higher demand for woody biomass in the policy regions, positioning the forest sector as a key contributor to energy substitution and climate mitigation through bioenergy use.

In the high-construction demand (HighCONST) pathway, mitigation is driven by an expansion of wood use in the construction sector, aiming to reduce emissions from cement and steel production while enhancing long-term carbon storage in harvested wood products, consistent with timber-based building transition scenarios (Mishra et al., 2022). In this pathway, construction-related wood demand in China, the EU27, and the US is assumed to double relative to the baseline since 2030, reflecting an accelerated shift toward wood-intensive building practices in all three regions (Table 5).

Building on the policy scenarios described above, we introduce additional scenarios with bilateral trade flows of forestry products as targeted in the scenarios fixed (FixTrade) at baseline levels. For detailed assumptions of scenarios, please see Table 2. This design is intended to isolate the extent to which regional mitigation policies in China, the EU27, and the US affect forest sector outcomes in the rest of the world (RoW) through international wood trade. Thus, under the FixTrade scenario setting, the trade is forced for each region with all trade partners, including trade between the EU27, China and the US. By comparing outcomes with and without trade fixation, the framework enables an explicit assessment of market-mediated spillovers, including changes in wood production, forest and harvested wood product carbon stocks, and associated leakage effects on forest carbon sink outside the policy regions.

Table 4: Solid bioenergy demand from woody biomass under different scenarios (EJ yr^{-1})

Scenario	Region	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
BAU	China	8.3	5.6	5.3	5.5	5.5	5.6	5.8	6	6.3	6.7	7.2
	EU27	2.2	2.6	3.5	4.1	5.1	5.5	5.5	5.5	5.5	5.5	5.5
	US	4	2.9	3.1	3.2	3.2	3.2	3.3	3.5	3.7	3.9	4.2
HighBIO	China	8.3	5.6	5.3	5.9	6.3	7.3	8.3	9.1	9.7	10.2	10.6
	EU27	2.2	2.6	3.5	4.4	7	7.6	7.6	7.6	7.6	7.6	7.6
	US	4	2.9	3.1	3.4	3.7	4.2	4.8	5.3	5.6	5.9	6.1
HighCONST	China	8.3	5.6	5.3	5.5	5.5	5.6	5.8	6	6.3	6.7	7.2
	EU27	2.2	2.6	3.5	4.1	5.1	5.5	5.5	5.5	5.5	5.5	5.5
	US	4	2.9	3.1	3.2	3.2	3.2	3.3	3.5	3.7	3.9	4.2
HighBC	China	8.3	5.6	5.3	5.9	6.3	7.3	8.3	9.1	9.7	10.2	10.6
	EU27	2.2	2.6	3.5	4.4	7	7.6	7.6	7.6	7.6	7.6	7.6
	US	4	2.9	3.1	3.4	3.7	4.2	4.8	5.3	5.6	5.9	6.1

Table 5: Sawnwood for construction demand (Mt yr^{-1})

Scenario	Region	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
	China	7	11	24	25	25	24	23	23	23	23	23
BAU	EU27	27	25	26	27	29	30	30	31	32	32	32
	US	32	20	27	30	33	35	37	38	40	41	41
	China	7	11	24	25	25	24	23	23	23	23	23
HighBIO	EU27	27	25	26	27	29	30	30	31	32	32	32
	US	32	20	27	30	33	35	37	38	40	41	41
	China	7	11	24	50	50	48	45	46	46	46	46
HighCONST	EU27	27	25	26	55	57	59	61	62	63	64	64
	US	32	20	27	61	65	69	73	77	80	82	83
HighBC	China	7	11	24	50	50	48	45	46	46	46	46
	EU27	27	25	26	55	57	59	61	62	63	64	64
	US	32	20	27	61	65	69	73	77	80	82	83

4.1.1. MAGNET scenarios

The MAGNET scenarios, presented in a dedicated results section 5.3, follow the HighCONST and HighCONST-FixTrade scenarios[i] including China and the USA, as described in the section above. For MAGNET, the FixTrade scenarios were implemented by imposing the trade volumes of forestry, wood, and paper products on the values in the baseline scenario. This was done through calibrating trade preference parameters for each of the policy regions regarding trade with the rest of the world. Fixing only the trade volumes in these scenarios, the MAGNET model can find new solutions such as changes in production volumes, intensification, and price levels.
These scenarios were run as standalone scenarios together with the baseline scenario, also present in the lookup tables for the earlier deliverables (D7.1). In earlier discussions of MAGNET results, mainly in deliverable 5.4, it was noted that MAGNET lacks systematic biophysical constraints or dedicated policy instruments limiting forest and agricultural uses (e.g. harvest bans). Indeed, while it implements a constraint of maximum available land (Meijl et al., 2006, Eickhout et al., 2009) it does not limit intensification or harvesting of any of the land users, thus often displaying a potentially high harvest level as a result of harvest intensification. This will contrast especially with the GLOBIOM results in China, as high increase in harvest *is* allowed in the MAGNET setting while more constrained in GLOBIOM.

4.2. Indicators assessed

We focused on six indicators of the forest sector development in the different scenarios: 1) Roundwood harvest volumes; 2) Energy plantation harvest volumes; 3) Net trade of wood products; 4) Wood harvest leakage; 5) Carbon sink and carbon sink leakage; and 6) Changes in forest carbon storage. In more detail:

1) Roundwood harvest volumes provide a direct measure of the pressure on forest resources.

2) Energy plantation harvests reflect the contribution of dedicated biomass crops to the total wood supply.

[i] For MAGNET the bioenergy demand scenarios are omitted, as in the current version bioelectricity data in China is incomplete.

3) Net trade trends of wood products are used as a measure of regional market competitiveness and shifts in global supply chains.

4) Wood harvest leakage is defined as the difference between non-fixed and fixed trade scenarios, which quantifies the extent to which domestic demand-side policies displace harvesting activities in the EU27, China and the USA to the rest of the world.

5) Forest carbon sink and carbon sink leakage, where carbon sink leakage is defined as the difference in forest carbon sequestration between non-FixTrade and FixTrade scenarios, capturing the extent to which domestic demand-side policies alter regional forest carbon sequestration

6) Changes in forest carbon storage, which reflect long-term variations in forest carbon stocks and indicate the cumulative impact of harvesting and regrowth under different scenarios.

5. Results

5.1. Baseline & core scenario results

5.1.1. Roundwood harvest volumes

Global roundwood harvest volumes show divergent regional trends under the high wood demand scenarios (Figure 1 a-e). In the EU27 and the USA, both HighBIO and HighCONST scenarios lead to increased harvest levels, with the combined High-BC scenario exerting the greatest pressure, reaching 564 and 762 $Mm^3\ yr^{-1}$ by 2100, in the EU27 and the USA, respectively (Figure 1 b-c). In the EU27, the impact of bioenergy demand on roundwood harvest remains relatively limited, as additional demand is largely absorbed by energy plantation harvests (e.g., energy crops) (Figure 1 b). In contrast, in China and the USA, an increase in bioenergy demand leads to a more pronounced increase in roundwood harvest from forests. However, harvest volumes in China decline under high wood demand scenarios, dropping 22 $Mm^3\ yr^{-1}$ under HighCONST scenario relative to the baseline in 2100 (Figure 1 a), as the country increasingly relies on imports to meet domestic demand.

The rising demand in policy regions (China, the EU27, and the USA) boosts wood harvests in the Rest of the World (RoW). Under the HighCONST and HighBC scenarios, RoW harvest volumes rise to 3,062 and 3,036 Mm^3 in 2100, with the largest increases observed in Canada, Brazil, and the Congo basin (Figure 1 d), reflecting the role of these regions in filling the supply gap created by policy-driven demand increase.

However, when bilateral trade is restricted in the FixTrade scenarios (i.e., trade volumes for the three policy regions are fixed at baseline levels to avoid harvest leakage mediated by a higher demand level), the harvest displacement is significantly reduced (Figure 1 f-j). Forcing bilateral trade (FixTrade) increases the necessity for domestic production in policy regions under High-CONST/BC scenarios to meet demand, and conversely leads to a comparative decrease in harvest volumes in the RoW. Under the FixTrade scenarios, the total harvest in the RoW decreases by 252 and 232 Mm^3 relative to the non-fixed trade scenarios (HighCONST and HighBC) in 2100 (Figure 1 i), while the global total harvest volume shows a net relative decrease of 157 and 188 Mm^3, in HighCONST and HighBC respectively.

These changes in harvest volumes are accompanied by changes in forest management and spatial allocation. In particular, shifts in harvesting intensity are reflected by the reallocation of forest area across different management systems. When we analyse the development of production forests and multifunctional forests, which differ in management intensity, with production forests characterized by higher intensity, we observe significant differences. Under the FixTrade scenarios, the EU27 and the USA experience an expansion of coniferous production forests alongside a decline in multifunctional forest areas (Figure 2 k–o; Figure 3 k–o). This pattern indicates a shift toward more intensive forest management systems when trade is fixed at baseline levels, as domestic production is scaled up to compensate for limited import capacity.

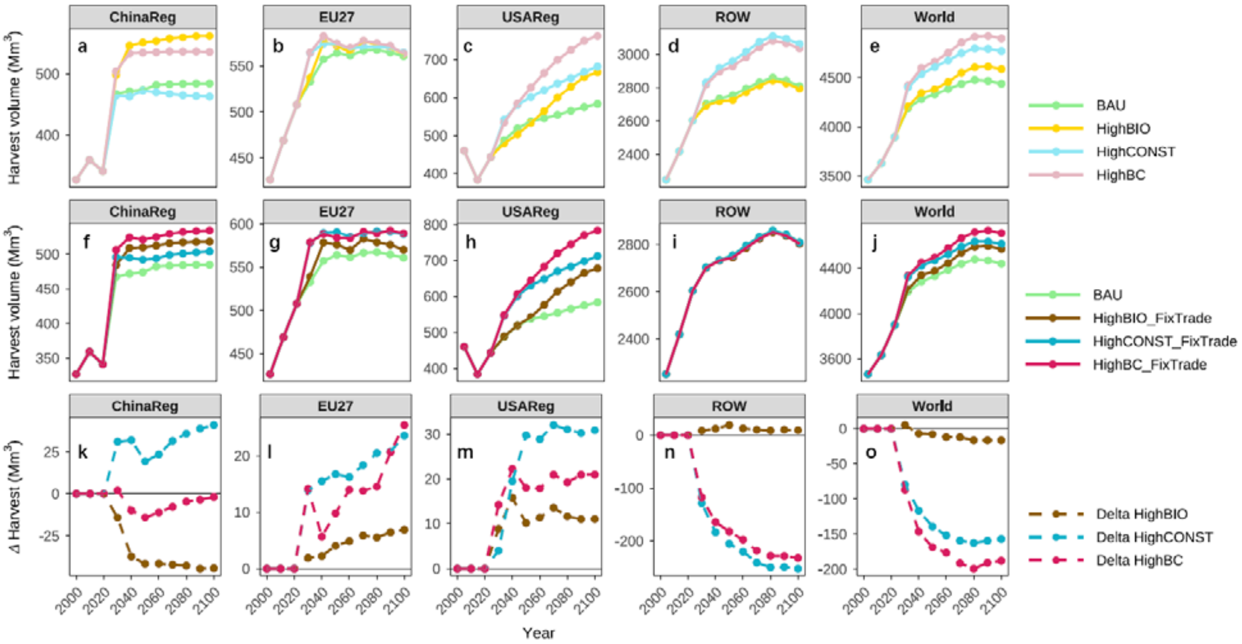

Figure 1: Roundwood harvest volumes across different scenarios and regions. Panels (a–e) show the absolute roundwood harvest volumes (Mm^3 yr^{-1}) for specific regions and the global total from 2000 to 2100, while panels (f–j) present results under FixTrade (i.e., bilateral trade is restricted to baseline (BAU) levels). Panels (k–o) display the absolute differences in harvest volumes (Mm^3 yr^{-1}) between the Fixed-Trade scenarios and the corresponding Non-Fixed-Trade scenarios (Fixed minus Non-Fixed). The analysis covers the period 2000–2100 with a 10-year time step. The region RoW (Rest of the World) represents all global regions excluding China, the EU27, and the USA.

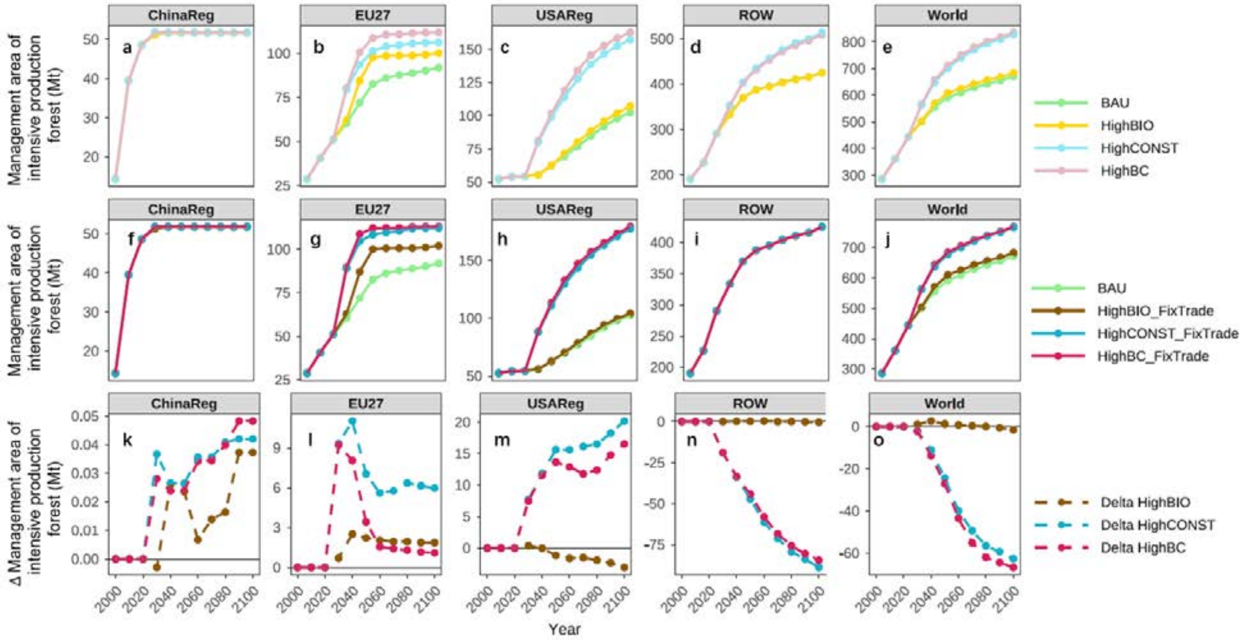

Figure 2: Forest management area of intensive production forests (Cur) (Mha)
across different scenarios and regions. Panels (a–e) show trends under BAU and high wood demand scenarios, while panels (f–j) present results under FixTrade. Panels (k–o) present the corresponding differences between the FixTrade and Non-FixTrade scenarios (Fixed minus Non-Fixed), where positive values indicate area increases and negative values indicate area decreases. The analysis covers the period 2000–2100 with a 10-year time step. The region RoW (Rest of the World) represents all global regions excluding China, the EU27, and the USA.

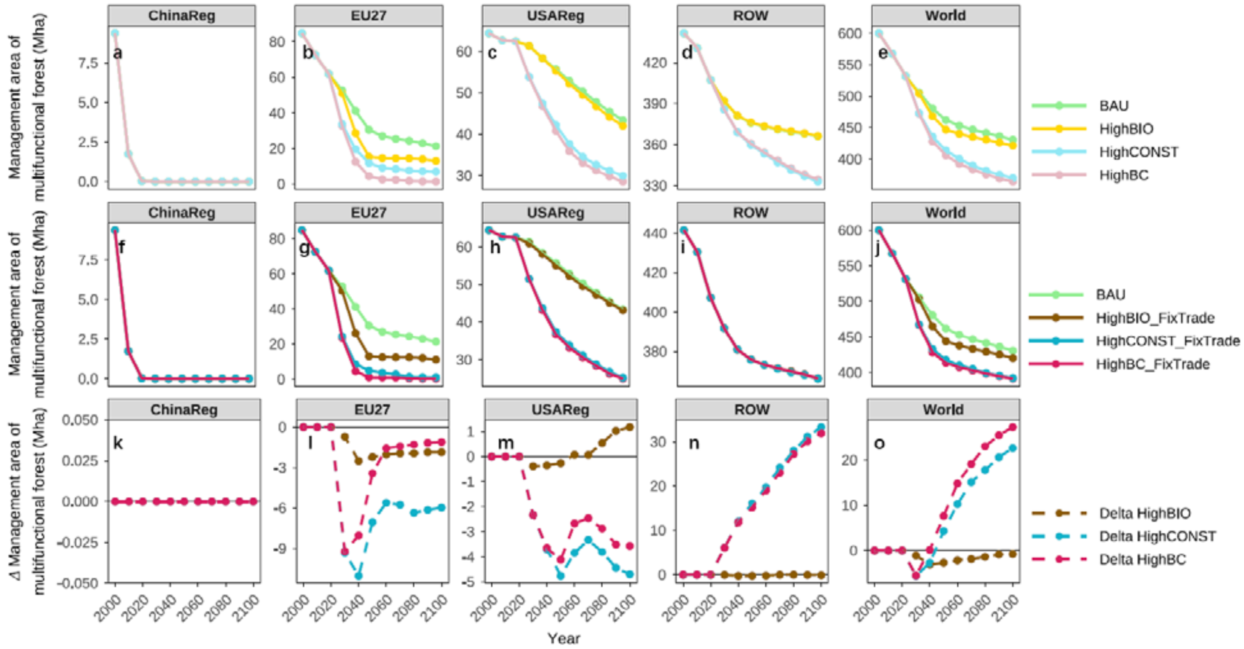

Figure 3: Forest management area of multifunctional forests (Cur_M) (Mha) across different scenarios and regions. Panels (a–e) show trends under BAU and high wood demand scenarios, while panels (f–j) present results under FixTrade (i.e., bilateral trade is restricted to BAU levels). Panels (k–o) present the corresponding differences between the FixTrade and Non-FixTrade scenarios (Fixed minus Non-Fixed), where positive values indicate area increases and negative values indicate area decreases. The analysis covers the period 2000–2100 with a 10-year time step. The region RoW (Rest of the World) represents all global regions excluding China, the EU27, and the USA.

In summary, higher wood demand in the EU27, China and the USA raises global roundwood harvest, but the location of this additional harvest depends on the trade assumptions. Under free trade, the increment lands largely in the RoW, whereas fixing trade at baseline levels reroutes significant harvest back to the policy regions and shifts forest area towards more intensively managed production systems.

5.1.2. Energy plantation harvests

The harvest volumes from energy plantations show a significant upward trend, particularly under scenarios with high bioenergy demand (Figure 4 a-j): Energy plantation harvests increase substantially across the three policy regions (China, the EU27, and the USA) to meet bioenergy targets, rising from nearly zero in 2020 to 1,291 and 1,292 Mm^3 yr^{-1} by 2100, respectively, in the HighBIO and HighBC scenarios.

However, regional variations exist under different demand drivers. While bioenergy demand triggers growth of energy plantations harvest, the HighCONST scenario leads to a decrease in energy plantation harvest volumes in the USA by approximately 19 Mm^3 relative to the baseline in 2100 (Figure 4 c). This is likely due to the increased availability of wood by-products from the construction sector, which provides a secondary supply of biomass and reduces the need for energy plantations wood.

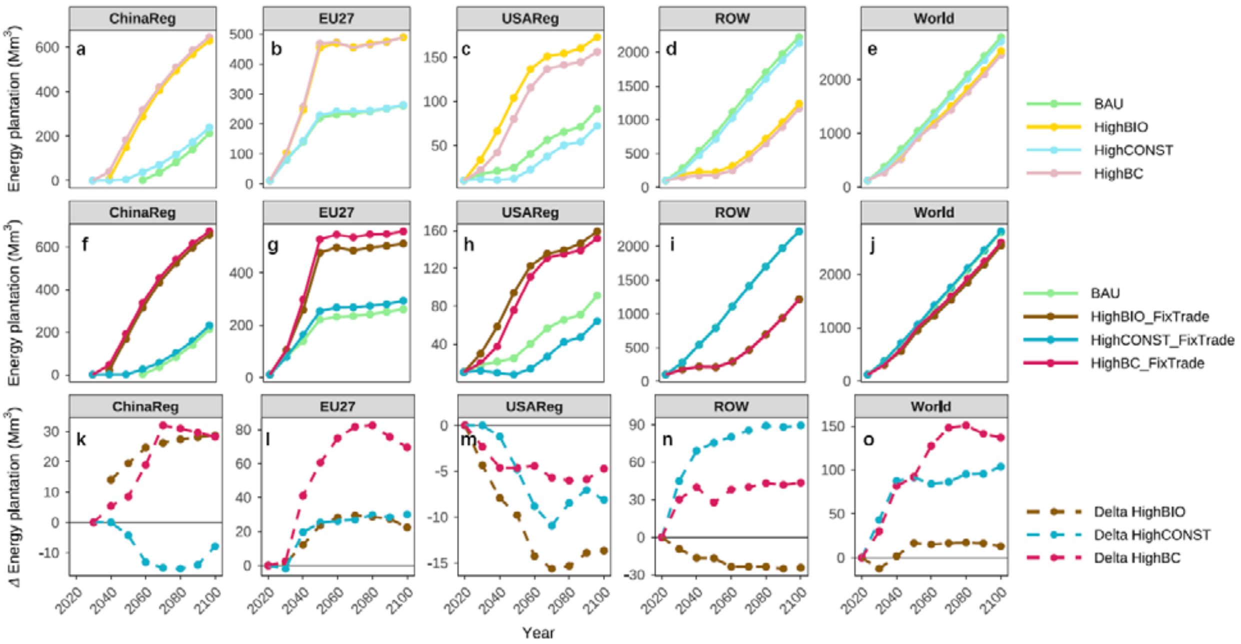

Figure 4: Energy plantation harvest volumes across different scenarios and regions. Panels (a–e) show the absolute energy plantation harvest volumes (Mm³ yr⁻¹) for specific regions and the global total, while panels (f–j) present results under FixTrade (i.e., bilateral trade is restricted to BAU levels). Panels (k–o) display the absolute differences in energy plantation harvest volumes (Mm³ yr⁻¹) between the FixTrade scenarios and the corresponding Non-FixTrade scenarios (Fixed minus Non-Fixed). The analysis covers the period 2000–2100 with a 10-year time step. The region RoW (Rest of the World) represents all global regions excluding China, the EU27, and the USA.

When bilateral trade is restricted to baseline levels (FixTrade), the reliance on domestic energy plantations is further intensified (Figure 4 f-j). Under the FixTrade HighBIO/BC scenarios, energy plantation harvesting in policy regions increases by an additional 37 and 93 Mm^3 in 2100 (Figure 4 f-h), as policy regions are forced to meet their bioenergy requirements through intensified domestic production rather than international biomass trade. Under the FixTrade HighCONST scenario, the RoW shows an increase in energy plantation harvests after fixing trade, reaching an additional 89 Mm^3 by 2100 (Figure 4 i). With trade fixed, the RoW is no longer allowed to export as many wood products to the policy regions, and its overall timber production is somewhat lower than under free trade. As a result, the forestry by-products that would normally be available for bioenergy are reduced, and RoW compensates by slightly increasing domestic energy crop production to meet its internal energy demand.

5.1.3. Net trade of wood products

The regional net trade of wood products undergoes significant transformations under high wood demand scenarios (Figure 5 a-e), as policy regions adjust their trade balances to accommodate increased consumption. In the HighCONST and HighBC scenarios, the three policy regions (China, EU27, and USA) exhibit changes in trade relative to the baseline (BAU): the EU27 and USA show decreases in net exports, while China shows an increase in net imports (Figure 5 a-c). This trend is characterized by a reduction in outward shipments and a simultaneous increase in imports from the Rest of the World (RoW) to relieve domestic harvesting pressure. A particularly notable shift occurs in the EU27, which transitions from a net exporter in 2020 to a net importer by 2100 (Figure 5 b), driven by the substantial surge in domestic timber requirements under the HighCONST and HighBC combined high-demand targets.

The FixTrade scenarios restrict the policy regions' ability to outsource their wood demand, where bilateral net trade is forced to remain at baseline levels. Under these constraints, the net export volume from the RoW to policy regions is reduced by 339 Mm³ compared to the non-fixed HighBC scenario in 2100 with similar results observed under the HighCONST scenario (Figure 5 i). Without the flexibility to increase imports, the EU27 and the USA are compelled to meet their high-demand targets through intensified domestic production, where multi-functional forest was converted to production forest (Figure 2 and Figure 3).

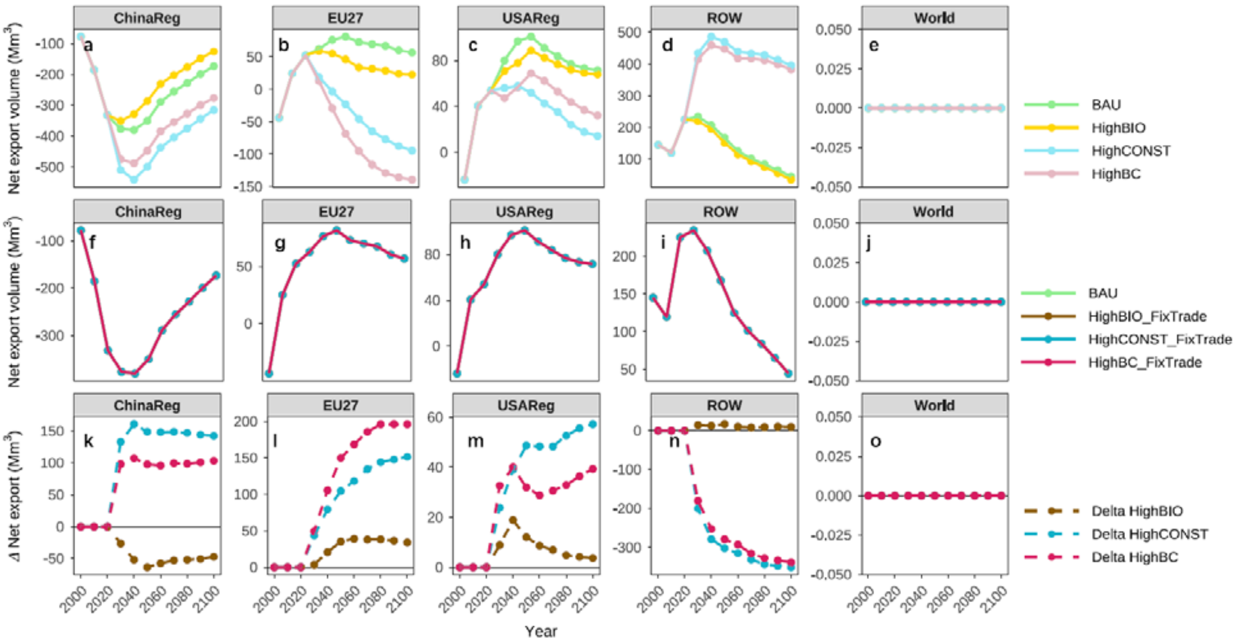

Figure 5: Net trade of wood products across different scenarios and regions from 2000 to 2100 using a 10-year time step. Panels (a–e) show the net trade of wood products (Mm³ yr⁻¹). Positive values indicate net exports, while negative values indicate net imports. Panels (f–j) present results under FixTrade (i.e., bilateral trade is restricted to BAU levels). Panels (k–o) display the corresponding differences in net trade (Mm³ yr⁻¹) between the FixTrade scenarios and the corresponding Non-FixTrade scenarios (Fixed minus Non-Fixed). The values greater than zero indicate increased export and decreased import after forcing bilateral trade. Results for the World (e,j,o) validate that net trade worldwide is equal to zero.

5.1.4. Wood harvest leakage

The displacement of timber harvesting, measured as the difference between the non-fixed-trade and fixed-trade scenarios, captures the extent of harvest leakage triggered by regional policies. In the HighCONST and HighBC scenarios, increased wood demand in policy regions (China, the EU27, and the USA) leads to a significant leakage of timber harvesting to the Rest of the World (RoW). By 2100, leakage to the RoW reaches approximately 252 and 232 Mm³ (Figure 6 b-c).

These volumes represent a notable redistribution in harvesting activities. Notably, for every unit of roundwood harvest reduction within the policy regions, there is a corresponding leakage (i.e., harvest increase) of over one unit in the RoW. This partly reflects regional differences in production and processing conditions, which can influence how harvest reductions in one region are offset elsewhere. Nevertheless, the volumes remain modest in a global context, accounting for approximately 5% of the total global roundwood harvest.

In contrast, a reverse harvest leakage is observed in the HighBIO scenario (Figure 6 a), where leakage is defined based on changes in harvest from natural forests, excluding shifts of harvest to energy plantations (i.e., leakage to other land-use types). As bioenergy demand increases, the expansion of energy plantations provides an alternative feedstock, thereby reducing reliance on traditional roundwood harvests from natural forests, which generates the negative leakage to RoW natural forest harvest. Additionally, the negative leakage is partly reinforced by increased domestic wood harvest for bioenergy in the policy regions, which generates more wood by-products and thereby reduces wood imports or increases exports from these regions to the RoW.

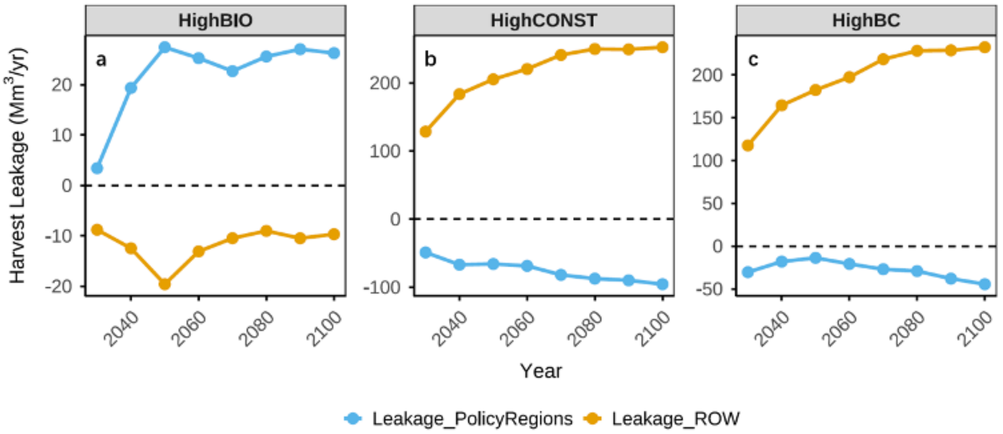

Figure 6: Wood harvest leakage volume (Mm^3 yr^{-1}) across policy regions (aggregating China, the EU27, and the USA) and the Rest of the World (RoW). Leakage is calculated as the difference between the Non-FixTrade scenarios and the FixTrade scenarios (Non-Fixed minus Fixed), from 2030 to 2100 with a 10-year time step. Positive values indicate an increase in harvest under the Non-FixTrade scenario relative to the corresponding FixTrade scenario, while negative values indicate a reduction in harvest relative to the FixTrade scenario.

5.1.5. Forest carbon sink and carbon sink leakage

The dynamics of the forest carbon sink reflect the cumulative impact of harvesting intensity and forest regrowth across different scenarios. Globally, while forests continue to function as a carbon sequester, the carbon sink rate (where negative values represent carbon capture) begins to slow down after 2030 (Figure 7 e).

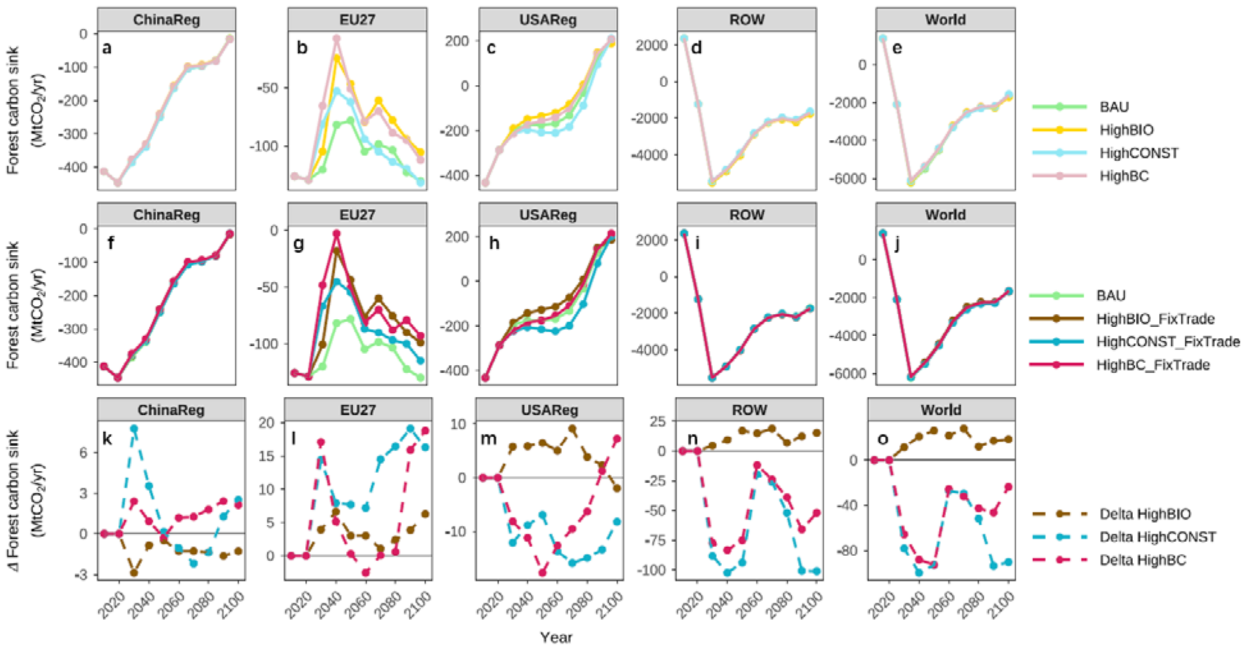

Figure 7: Forest carbon sink rates (i.e., changes in forest carbon stocks) across different scenarios and regions. Panels (a–e) show the forest carbon sink rate (Mt CO_2 yr^{-1}) for regions (China, the EU27, the USA, and Rest of the World representing all global areas excluding the former regions) and the global total (World) from 2010 to 2100 using a 10-year time step. Negative values indicate carbon sequestration (carbon uptake), while a shift toward zero represents a weakening sink and values over zero represent emissions. Panels (f–j) present results for carbon sink under FixTrade (i.e., bilateral trade is restricted to BAU levels), and panels (k–o) show the corresponding differences between FixTrade and Non-FixTrade scenarios (Fixed minus Non-Fixed). Positive differences indicate a reduction in carbon sink rates (i.e., weaker carbon sequestration) under trade restrictions.

For the overall trends, the forest carbon sink in China goes down to zero by 2100 (Figure 7 a), and the sink in the EU27 is initially reduced more strongly than under the baseline but gradually recovers over time, approaching but remaining slightly below baseline levels by the end of the century (Figure 7 b). In contrast, the USA exhibits a continuous decline in carbon sequestration, with forests transitioning from a net sink to a net carbon source by 2100 (Figure 7 c). In the EU27 and the USA, the absolute value of the carbon sink rate decreases under the HighBIO and HighBC scenarios relative to the baseline (Figure 7 b-c), indicating a reduction in the net carbon sequestration capacity as harvesting pressure intensifies to meet bioeconomy targets.

It should be noted that no post-hoc adjustment was applied to the forest carbon sink estimates for matching national GHG inventories, this means that the values reported here reflect only the carbon pools endogenously represented in the model (primarily above-ground biomass), and do not include additional pools such as deadwood or soil carbon.

The shift in harvesting activities to the RoW induces a significant forest carbon sink leakage. By comparing the non-fixed and fixed trade scenarios, we observe that the increased wood demand in policy regions directly undermines the carbon sequestration potential of forests in the RoW under the HighCONST_FixTrade and HighBC_FixTrade. By 2100, the difference in the RoW carbon sink between these scenarios reaches 101 Mt CO_2 yr^{-1} in the High-CONST scenario and 52 Mt CO_2 yr^{-1} in the High-BC scenario (Figure 8 b-c). Crucially, each unit of carbon reduction achieved within the policy regions is countered by an increase of more than one unit of carbon loss outside the policy regions. This illustrates that the production in policy regions is generally characterized by higher management efficiency and productivity, which results in a smaller carbon emission per unit of wood compared to the leakage-induced harvesting in the RoW.

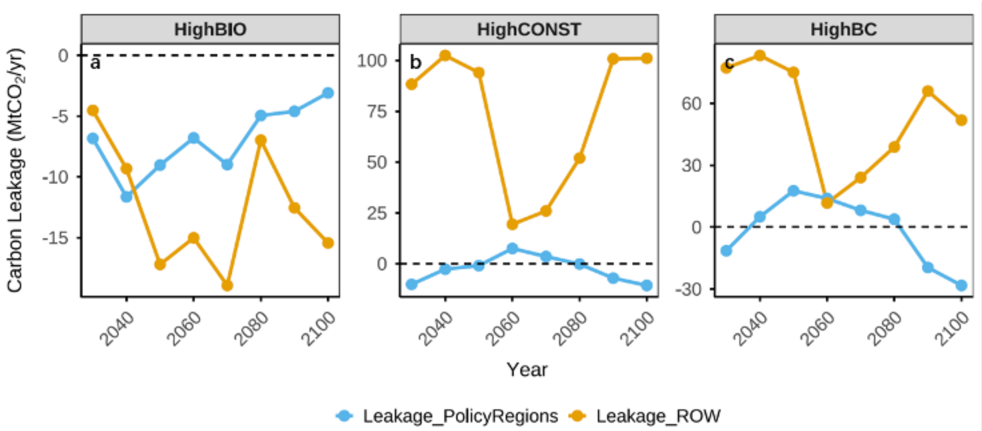

Figure 8: Forest Carbon sink leakage across policy regions and RoW. Panels (a–c) show the carbon sink leakage (Mt CO_2 yr^{-1}), calculated as the difference between the Non-FixTrade scenarios and the FixTrade scenarios (Non-Fixed minus Fixed), from 2030 to 2100 with a 10-year time step. Positive values indicate a decrease in sequestration capacity under the Non-FixTrade scenario relative to the FixTrade baseline, while negative values indicate an increase in sequestration capacity relative to the FixTrade baseline. Leakage_PolicyRegions refers to the aggregate of China, the EU27, and the USA, while leakage_RoW represents the harvest changes in all global areas excluding these three regions.

5.1.6. Changes in carbon storage

The long-term impact of wood-based policies is synthesized in the total carbon storage across different pools, including forest biomass, new plantations (PLA), harvested wood products (HWP), and bioenergy with carbon capture and storage (BECCS). The calculation of BECCS net negative emissions follows the same methodology as D7.2: it is based on the harvested bioenergy carbon content, the fraction of bioenergy deployed with carbon capture, and the assumed carbon capture efficiency. Unlike HWP, which are temporary carbon stores, BECCS provide a permanent carbon sink, allowing both temporary and permanent pools to be integrated in the assessment of total climate mitigation. Under the HighBIO, HighCONST, and HighBC scenarios, all three policy regions and the RoW exhibit an overall increase in total carbon storage by 2100 compared to the 2020 baseline (Figure 9 a-c).

In China and the EU27, a distinct growth in carbon storage is observed under the HighBIO and HighBC scenario (Figure 9 a-b), primarily driven by the large-scale deployment of BECCS, which offsets localized harvesting pressure. In contrast, the USA shows an increase under the High-CONST scenario (Figure 9 c). This growth is largely attributed to the expansion of the HWP pool, reflecting the long-term carbon sequestration in construction materials. These results suggest that, while high wood demand increases harvesting, the strategic integration of wood into long-lived products and energy systems with carbon capture can result in a net increase in regional carbon stocks.

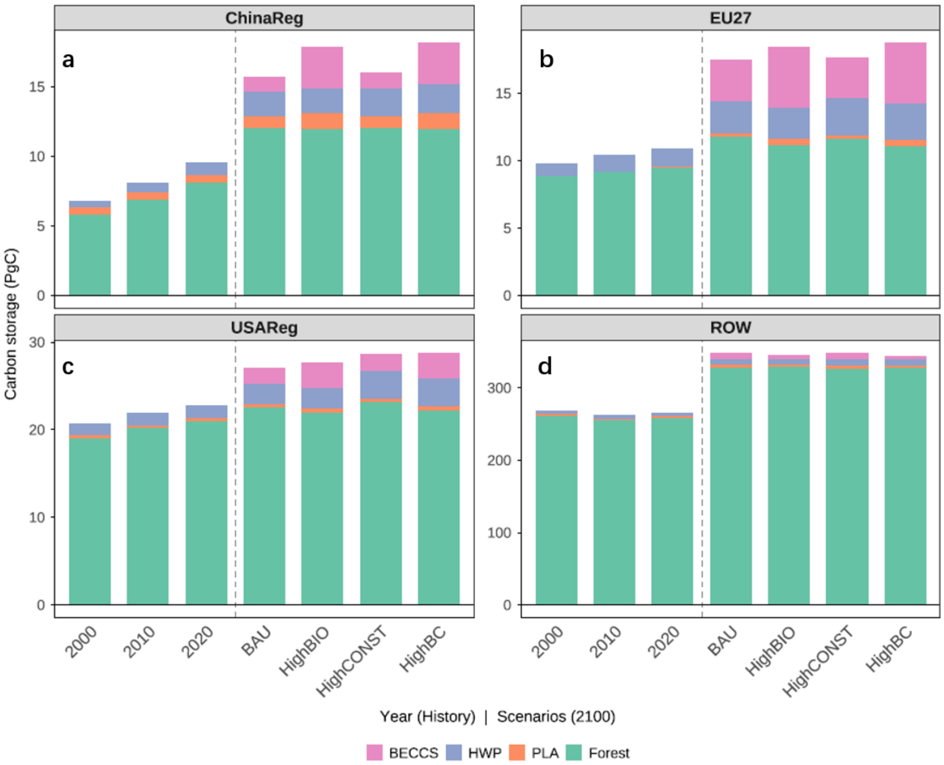

Figure 9: Total carbon storage across different scenarios and regions. The stacked bar charts display total carbon storage (PgC) for the years 2000, 2010, and 2020 under the BAU baseline, alongside the projected storage for all four scenarios in 2100. Each bar is composed of four distinct carbon pools: BECCS, Harvested Wood Products (HWP), New plantations (PLA), and Forest biomass (Forest).

5.1.7. Summarizing GLOBIOM-China results

Overall, increased wood demand increases harvesting, shifts trade patterns toward greater import dependence in policy regions, and weakens forest carbon sinks. Fixing trade at baseline levels redistributes production and carbon impacts back to policy regions (China, the EU27, and the USA). Higher wood demand increases global roundwood harvest, with the strongest response under HighBC and clear intensification of forest management in the policy regions. Consistent with this, forest area shifts even more toward more intensively managed systems under constrained trade conditions. Energy plantation harvest increases under HighBIO and HighBC, but declines under HighCONST, likely due to increased availability of wood by-products from the construction sector, which provide an alternative biomass supply and reduce reliance on dedicated energy crops.

In the HighCONST and HighBC scenarios, increased demand in policy regions shifts part of the roundwood harvesting burden to the RoW, indicating clear harvest leakage under flexible trade. Although the absolute leakage remains small relative to global harvest, the response is strong, with more than one unit of increase in the RoW per unit reduction in policy regions. By contrast, HighBIO shows reverse harvest leakage, as bioenergy expansion shifts production toward energy plantations and reduces pressure on natural forests. Higher wood demand in policy regions reduces net exports and increases reliance on imports from the RoW under flexible trade. Under FixTrade scenarios, trade flows are fixed at baseline levels, limiting the ability to expand imports from the RoW and shifting supply adjustments back to domestic production, thereby reducing the role of external sources in meeting additional demand.

Forest carbon sinks remain negative but weaken after 2030 across scenarios, with reduced forest carbon sequestration rate in the EU27 and the USA under HighBIO and HighBC due to increased harvesting. Shifts in harvesting to the RoW lead to forest carbon leakage. Under flexible trade, the forest carbon sink in RoW declines relative to FixTrade, indicating that each unit of carbon reduction in policy regions is offset by more than one unit of carbon loss elsewhere, thereby reducing the global sink under the HighCONST and HighBC scenarios. This reflects the shift of production to less efficient systems in the RoW, whereas production in policy regions is characterized by higher management efficiency, productivity, and more effective use of by-products, leading to lower overall carbon losses under FixTrade. Despite weaker carbon sinks, total carbon storage increases in all three policy regions by 2100. In China, this is mainly driven by BECCS deployment, while in the USA it is largely associated with the expansion of harvested wood products.

5.2. Plausibility checks and robustness analysis: International wood trade

To assess the scale of potential changes in the global wood trade network and assess uncertainty levels, we compared international wood supply chains from the GLOBIOM scenarios (2020-2100) with observed trade patterns in 2017. This analysis draws on FAOSTAT wood trade statistics for the four regions: China, the EU27, the USA, and the rest of the world (RoW). Bilateral trade data from both GLOBIOM and FAOSTAT were combined with production data and corrected for re-exports, allowing us to trace primary wood flows embodied in traded products (expressed in industrial roundwood equivalents) from the country of primary harvest to the country of apparent consumption.

At the global level, GLOBIOM estimates lower production volumes for 2020 than those reported by FAOSTAT for 2017, with a gap of approximately 8% (- 78Mt dry matter per year). This difference is mostly due to an underestimation of production (incl. exports) levels in the RoW (- 82Mt DM/yr) and China (by 8.5Mt DM/yr). In contrast, production levels (incl. exports) are slightly overestimated in the EU27 (+8.4Mt DM/yr) and the USA (+4.5Mt DM/yr) (Figure 10).

Despite lower overall production, GLOBIOM simulates higher total trade volumes between the four regions for 2020 (+22 Mt DM/yr) compared to FAO-based data for 2017. This is largely explained by higher exports from the USA and RoW to China (+5 Mt DM/yr and +11 Mt DM/yr, respectively), and increased exports from the USA to the RoW (+12 Mt DM/yr). Significant relative discrepancies are also observed in several bilateral supply chains, including primary wood flows from China to the USA, from the EU27 to the USA, and from the USA to both the EU27 and China (Figure 10, Figure 11).

All scenarios lead to increased primary wood production in all regions, with strongest increases until 2100 in China and USA, both in comparison to FAO-2017 and GLOBIOM-2020. In the baseline and fixed trade scenarios, total trade volumes are smaller by 26% in 2100 relative to 2017 (FAOSTAT), after spiking at +35% in 2030 due to drastically increased flows to China (+81%), as well as from the USA to the EU27 (Figure 10). Until 2100, China's imports decline again and drop to 40% below the 2017 level, while exports remain relatively stable at a low level. Until 2100, the EU27 decreases exports to all regions but has a similar level of imports as in 2017, indicating increased domestic consumption (Figure 13). Exports from the USA to RoW are generally modelled to be drastically larger than they were reported from FAO for 2017 (+105% in 2017; +81% 2100); within GLOBIOM however, the USA export flows in 2100 are smaller than in 2020 (-27% in total) (Figure 14). Imports of the USA are decreased until 2100 (relative to FAO 2017), especially from RoW (-9Mt DM/yr) (Figure 13 and 14).

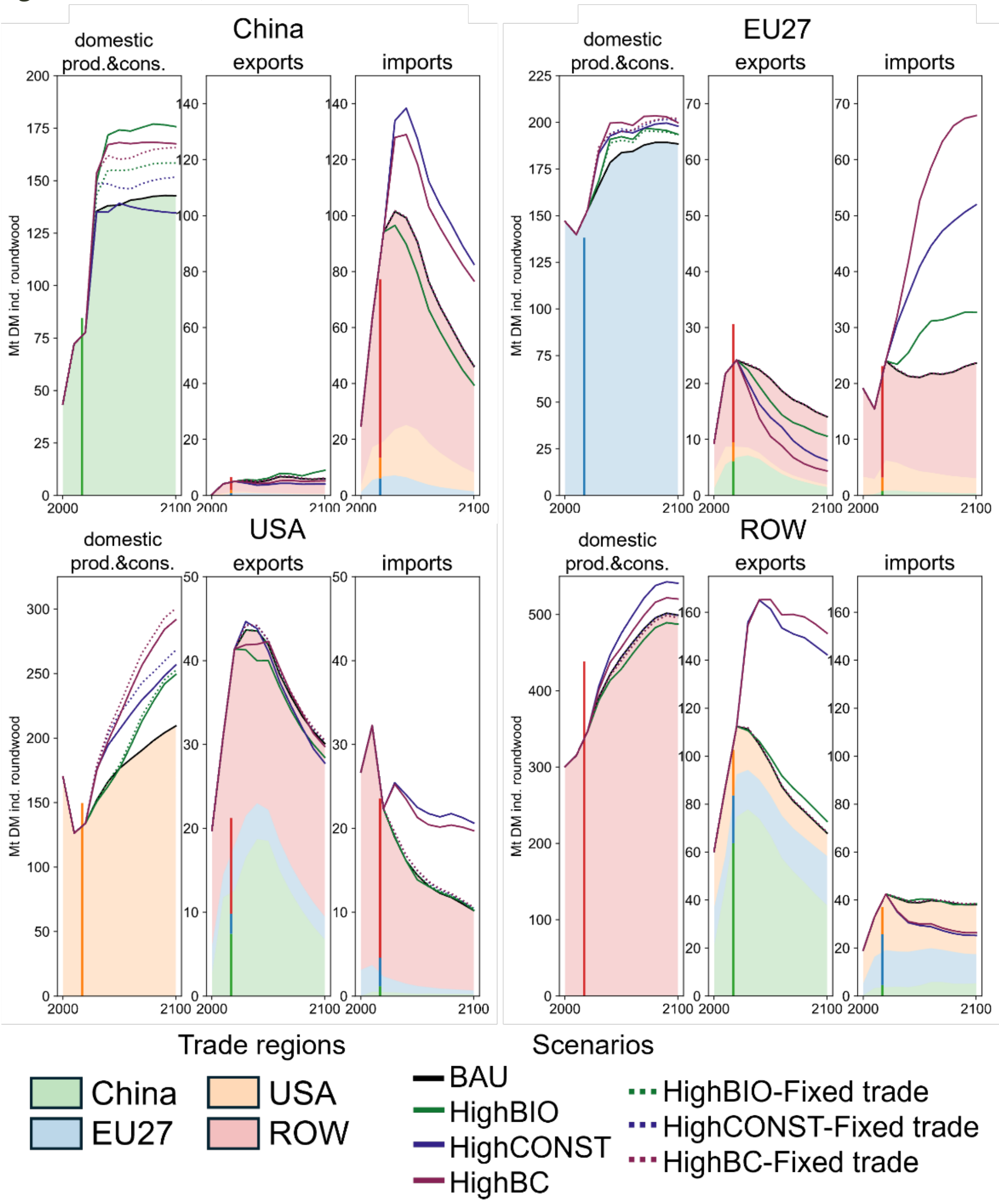

Figure 10: Production and flows of industrial roundwood equivalents between region of primary harvest and region of apparent consumption (re-export corrected). GLOBIOM results are presented as stacked areas for baseline scenario "BAU" and lines representing the total of six alternative scenarios. Darker bars give the actual situation in 2017, derived from FAOSTAT bilateral wood trade statistics. The three figures per region depict wood that is produced and consumed domestically ("domestic prod.&cons"), produced domestically and exported ("exports"), and produced non-domestically but consumed domestically ("imports").

Without fixed trade, the HighBIO scenario leads to similar shifts compared to 2017, but with higher imports of EU27, especially from RoW, and higher exports of China in general. In the HighCONST and HighBC scenarios of GLOBIOM primary wood embodied in trade is higher in 2100 (+12% and +18% respectively) than in 2017 (FAO). Exports from RoW (to China and EU27) are considerably higher than in 2017, and than in the baseline and fixed-trade scenarios, indicating the leakage effect in these pathways. Exports from the USA to China and the EU27 are higher than in the baseline and fixed-trade scenarios, but lower to RoW. This leads to an increase in imports to China relative to 2017 in both scenarios, while exports of China to RoW are notably smaller than in 2017 and the other scenarios. Imports to EU27 from RoW increase most drastically, by +141% (HighCONST) and +214% (HighBC) (Figure 11).

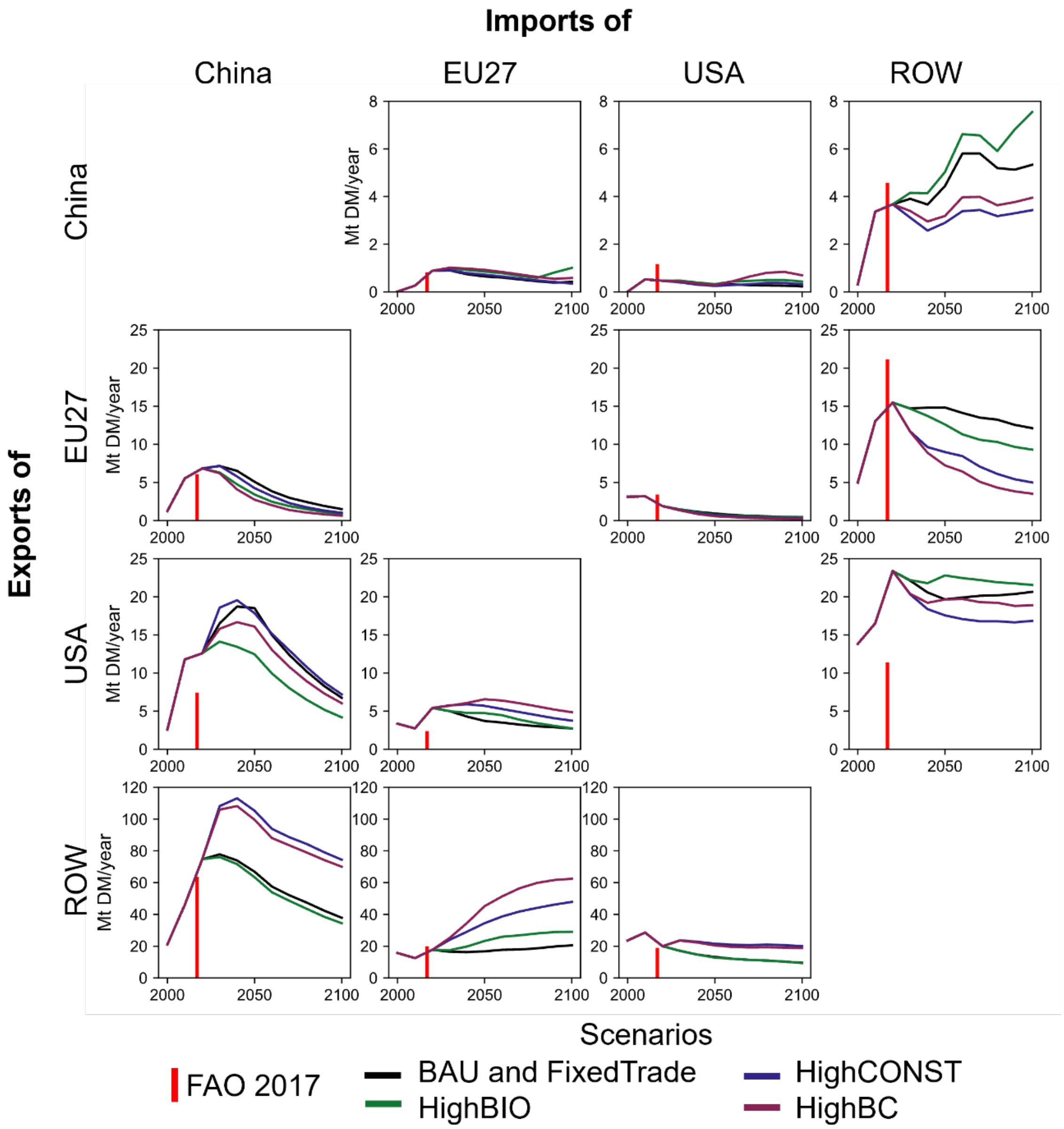

Figure 11: Re-export corrected trade flows of embodied primary wood (Mt dry matter of industrial roundwood equivalents) per region and scenario.

The correction for re-exports does not change the general assessment of the leakage effect of the policy pathways modelled in GLOBIOM meaningfully. As described in 5.1.4, harvest leakage to RoW is highest in the HighCONST scenario, where all policy regions have reductions in harvest relative to the Fixed Trade scenario (Figure 12). Looking at individual policy regions, China is the only region with a higher harvest in the HighBIO and HighBC scenarios relative to the Fixed Trade scenarios, leading even to the observed reverse harvest leakage in the HighBIO scenario.

Overall, the comparison of the GLOBIOM results for 2020 with FAO-reported data for 2017 reveals several discrepancies that likely exceed what can be explained by the three-year time difference alone. For the interpretation of scenarios this baseline discrepancy is relevant, for example regarding exports of USA, as it is partly larger than differences between scenarios, pointing to structural challenges in modelling.

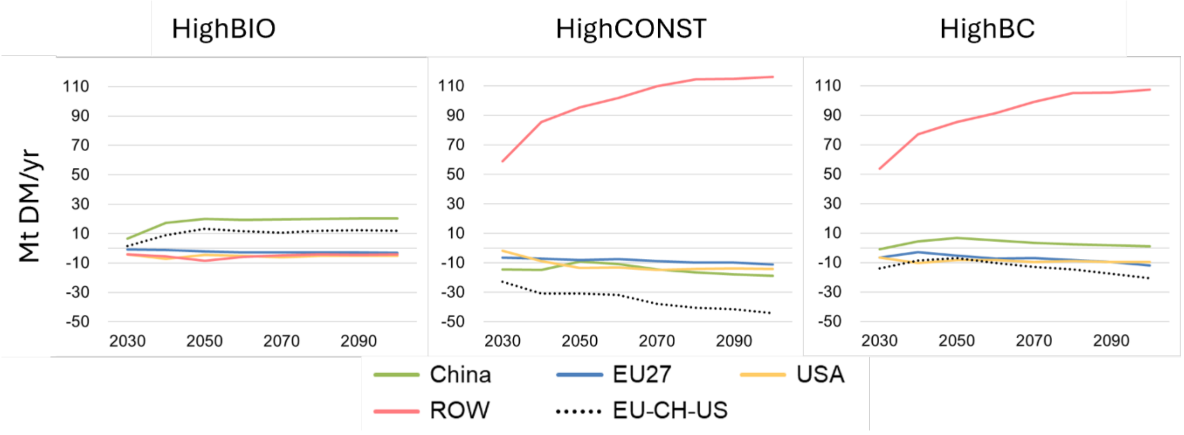

Figure 12: Leakage effect of policy pathways. Difference of regional production of primary wood (Mt dry matter of industrial roundwood equivalents) between Non-FixedTrade scenarios and the FixedTrade scenarios. Positive values indicate an increase in harvest under the Non-FixedTrade scenario relative to the corresponding FixedTrade scenario, while negative values indicate a reduction in harvest relative to the FixTrade scenario.

The comparison of these re-export-corrected trade flows with the original FAO trade statistics and outputs of GLOBIOM depicting bilateral trade without correction for re-exports is shown in Figure 13. Overall, the correction for re-exports leads to a closer alignment of GLOBIOM with FAO, indicating that re-exports might be proportionally overestimated in GLOBIOM and supporting a future research focus on corrected trade fluxes to increase robustness of results. In 2020, the EU27 has the highest re-exports compared to China and the USA. Its re-exports amount to 34 Mt DM/yr, making up 58% of total reported exports and imports of EU27. China, a large net-importer, re-exports 11 Mt DM/yr (69% of total exports and 11% of total imports). The USA re-exports 9 Mt DM/yr (18% of total exports and 29% of total imports). For all regions, however, trade across regions is small compared to intra-regional trade, i.e., trade between two RoW countries, and domestic consumption.

At the bilateral level, we find that non-corrected trade is substantially higher than re-export corrected trade for most trade flows between region pairs, as is the case, for example, for exports from the EU27 to RoW (Figure 13). This can indicate two cases (or their combination):

a. the reported exporting region, here the EU27, is not the primary origin of the primary wood; it processed primary wood from a third-party region and exported the processed product to the importing region, here RoW.
b. the reported importing country (RoW) is not the final consuming region; it imported primary wood from the reported exporting region (EU27), processed it and re-exported it to a third-party region.

The same explanations apply to most other trade-flows, e.g., China to the EU27 or the RoW to the EU27 or the RoW to China, etc. As the only exception, we find the opposite pattern for trade flows from the USA to China: here, non-corrected trade is smaller than re-export corrected trade. This indicates that primary wood from the USA was processed in a third-party region, and eventually (re-)exported to and consumed in China.

In the scenarios modelled with GLOBIOM, the total share of re-exports decreases until 2100 towards 21% (HighBC) to 29% (baseline and Fixed Trade scenarios). For exports from the EU27, however, we find that re-exports increase until 2100, especially for scenarios with higher bioenergy use.

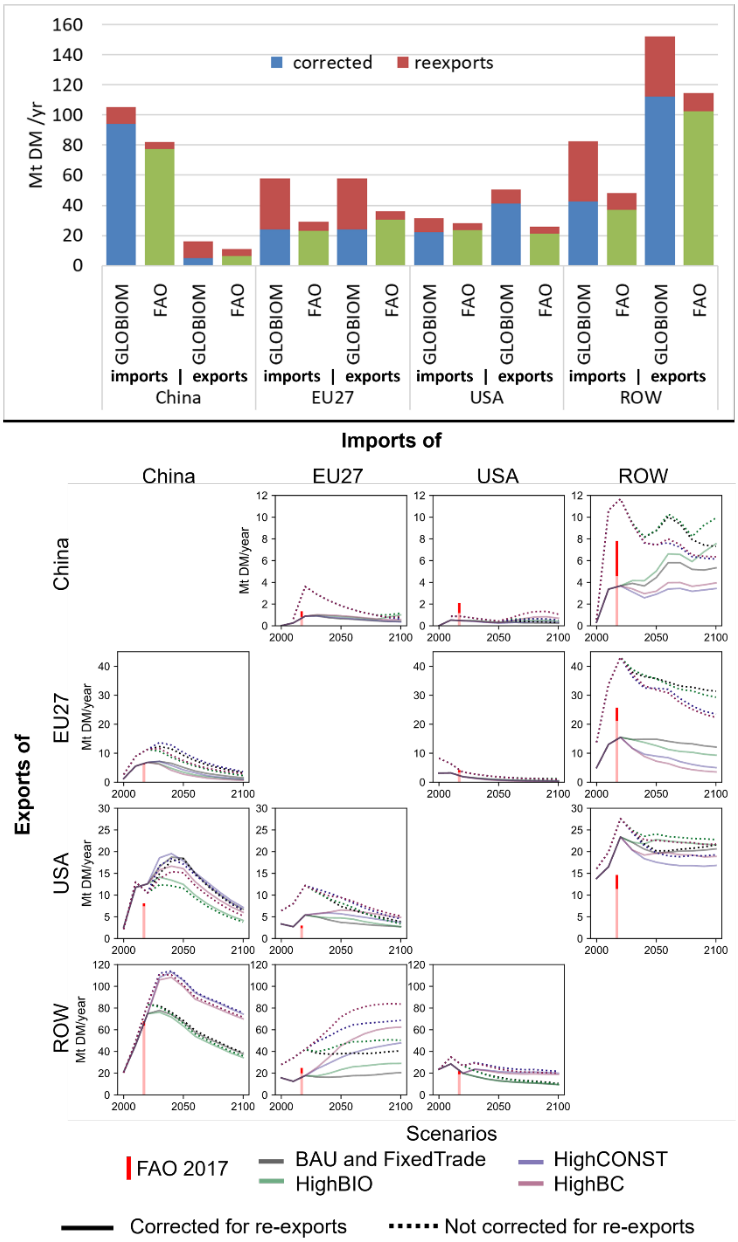

Figure 13: Effect of correcting for re-exports for imports and exports of embodied primary wood given in Mt dry matter of industrial roundwood equivalents per region and scenario, for GLOBIOM results and FAO statistics from 2017. Regional totals for 2020 (GLOBIOM)/2017 (FAO) are shown in upper panel; bi-regional results are shown in lower panel, with (corrected flows for FAO in light red).

5.2.1. Comparison of global wood flows base data

This section aims to compare the global wood flows data as constructed in the base year situation, following the procedure outlined in section 3.4 prepared by the team at BOKU (further referred to as the 'BOKU data'), with the trade flows in the MAGNET model (whose scenarios will be presented in section 5.3 below). Figures 14, 15, and 16 visualize international trade flows among four key regions — China, the EU27, the United States, and the Rest of the World — for three main commodities: Forestry & Logging, Paper & Pulp Products, and Wood & Timber Products.

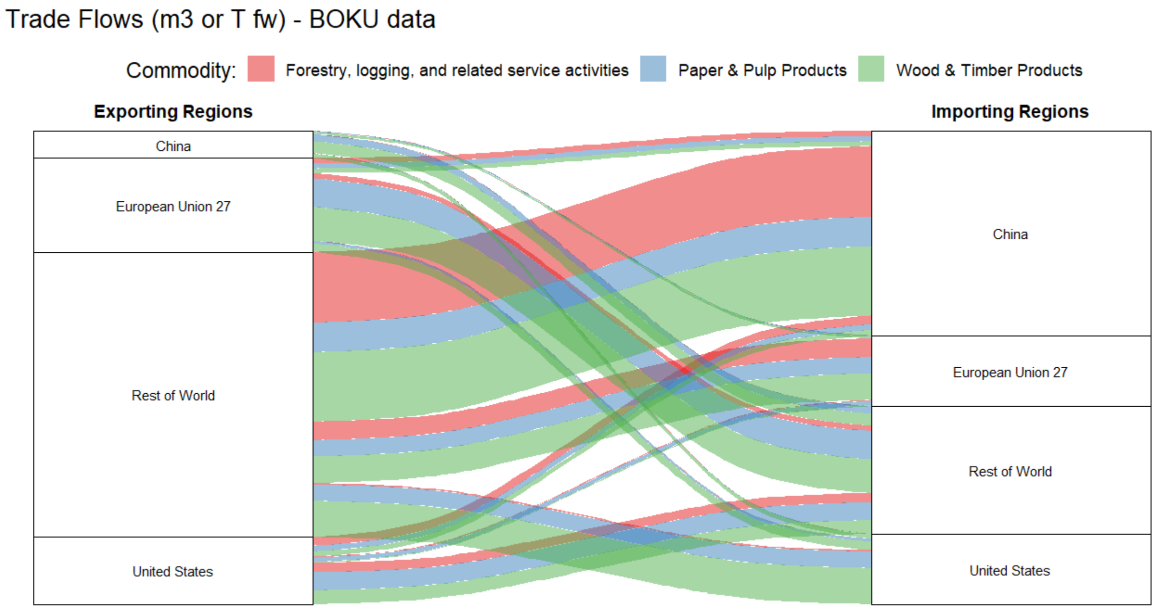

Figure 14: 2017 Trade flows (in m^3 or tons of fresh weight) of main forestry-related products across major global traders and the rest of the world (FAO/BOKU data).

In the BOKU dataset (Figure 14), which measures flows in physical units (m^3 or tons of fresh weight), Wood & Timber Products dominate overall trade volumes. The EU27 emerges as the primary global exporter, besides the Rest of the World. Although flows of Forestry & Logging (red) and Paper & Pulp (blue) appear smaller in magnitude, they still reflect significant trade. This suggests that, in physical terms, the EU27 plays a central role in global wood supply chains, particularly as a key exporter of raw and semi-processed materials.

For reference, the dataset directly derived from GLOBIOM for the year 2020 is presented in Figure 15. At this aggregated level, the relative quantities between the BOKU and GLOBIOM are well aligned in this high-level trade flow comparison. A more detailed comparison, including its interpretation within the GLOBIOM scenarios, is presented in section 5.2.

In contrast, the MAGNET dataset (Figure 16), expressed in monetary terms (million USD), shows a more balanced distribution across the three commodity groups. The relative importance of Paper & Pulp Products increases substantially, reflecting their higher unit value compared to raw timber. Overall, while the BOKU data emphasize physical trade volumes dominated by raw materials, the MAGNET data reveal the concentration of economic value in higher value-added products like pulp and paper. Together, these views illustrate the structural differences between material and monetary trade perspectives and reaffirm the EU27's role as both a major producer and key consumer hub within global bio-based value chains.

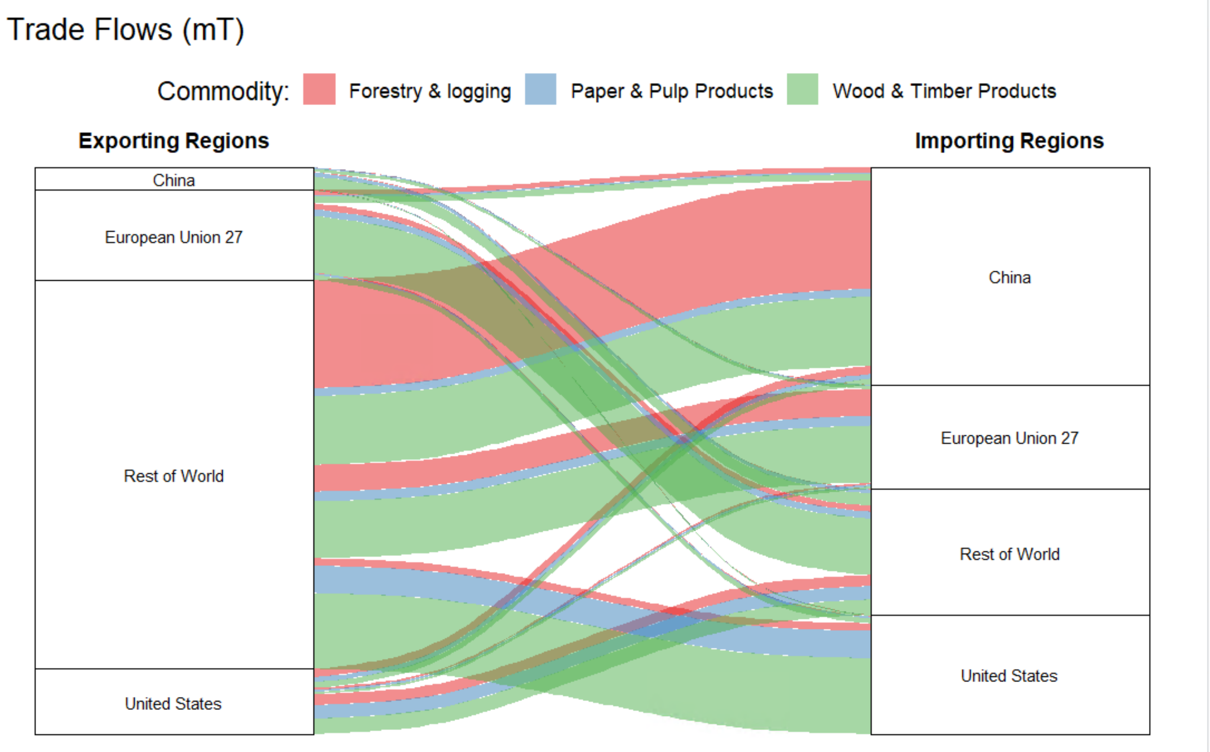

Figure 15: 2020 Trade flows (in m³ or tons of fresh weight) of main forestry-related products across major global traders and the rest of the world (GLOBIOM data).

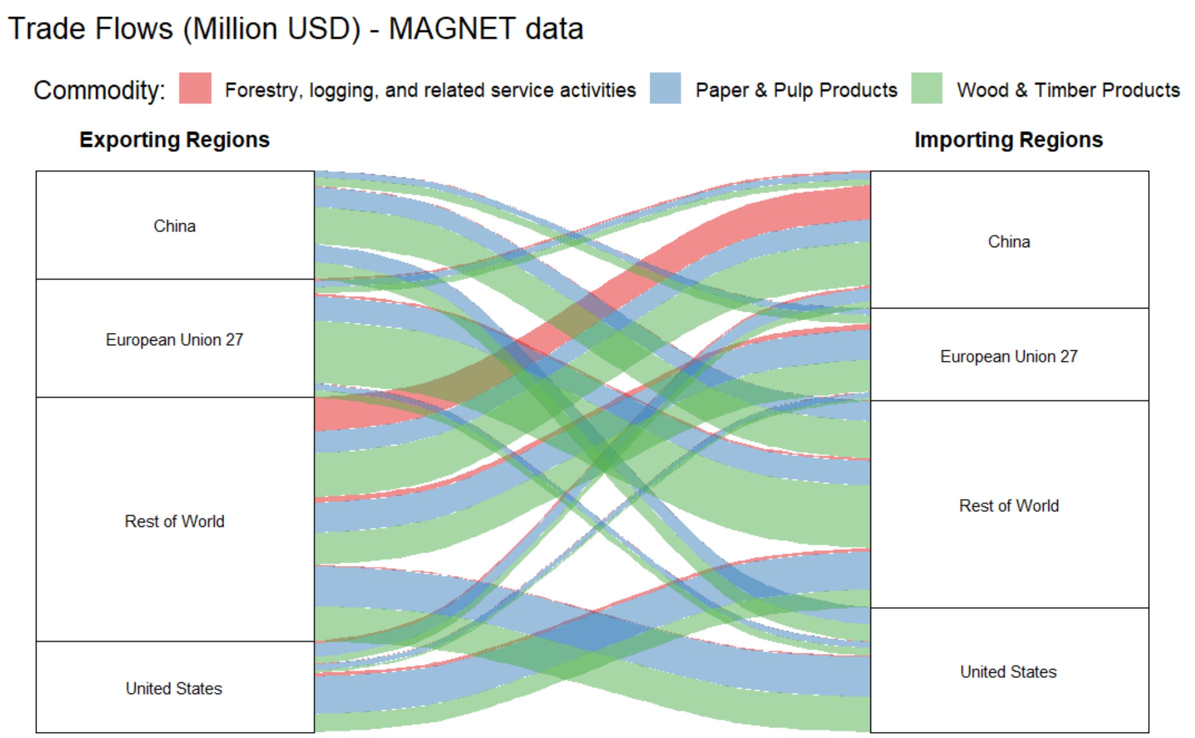

Figure 16: 2017 Trade flows (in million US dollars) of main forestry-related products across major global traders and the rest of the world (GTAP/MAGNET data).

5.3. Plausibility checks and robustness analysis: MAGNET scenario results

In the baseline scenario results, the MAGNET scenarios project a higher harvest volume compared to the GLOBIOM results, especially in China, as the harvest bans are not part of the MAGNET implementation. In general, with no biophysical restraints implemented, MAGNET allows a more dynamic increase in harvest volumes. This, combined with a more flexible demand system, is one of the main reasons why, in the results, the differences between the free and FixTrade scenarios are smaller for MAGNET. This is clear from Figure 17 which collects the scenario results and where, especially for the EU27 and the USA, harvest levels are almost identical across the high demand scenarios and for the RoW, the overall difference between all scenarios, including baseline, is very small. China, although initially requiring more imports to meet demand, this effect is diminishing by the end of the century. Although the HighCONST scenario results in higher exports from the rest of the World, there is only a small effect on production in RoW, as domestic demand decreases due to higher prices, while also productivity increases due to price incentives.

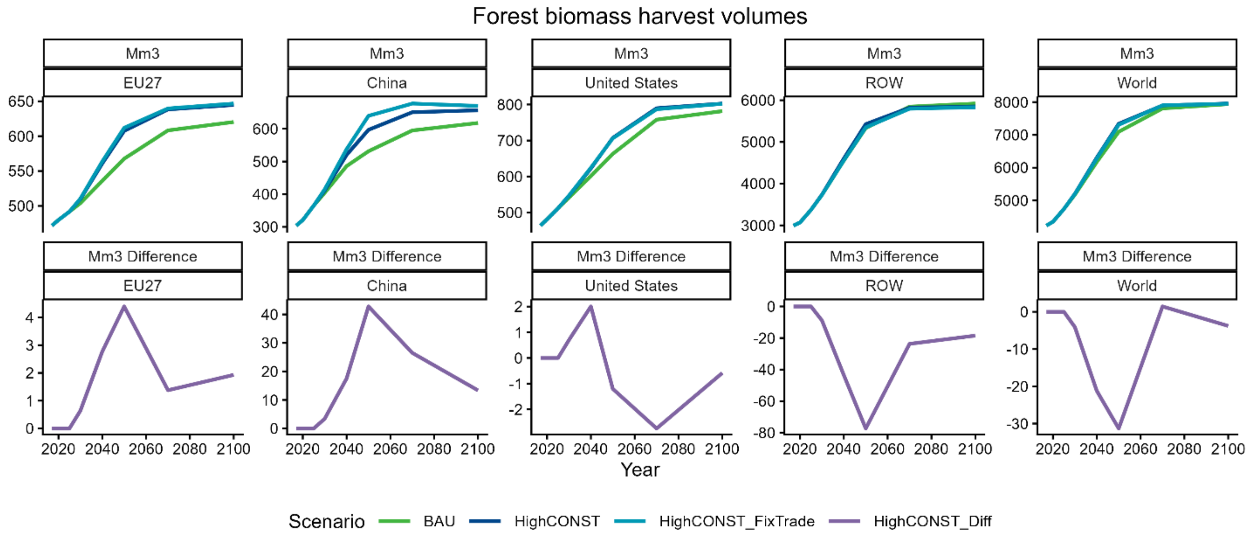

Figure 17: Forest biomass harvest volumes in MAGNET BAU and HighCONST scenarios. The top panels show the absolute results for the scenarios. The bottom row displays the absolute differences in harvest volumes (Mm^3) between the FixTrade scenarios and the corresponding free Trade scenarios (Fixed minus Free).

Figure 18 summarizes the main leakage effect between the policy regions and the RoW. It shows a peak leakage of 77 Mm^3 in the RoW, accompanied by a reduction of -45 Mm^3 in the policy regions, with both effects declining substantially after 2050. This is a substantially lower leakage when compared to the GLOBIOM results in Figure 6, with over 250 Mm^3 and below -100 Mm^3 sustained up to 2100. In MAGNET, it is thus clear that more internal compensation by increased production is possible, leading to lower overall leakage rates than those observed in the main GLOBIOM scenarios.

The wood harvest leakage effects past 2050 are greatly diminished as the policy regions show a general decrease in demand mainly driven by population decline, especially for the EU a strong effect of drop in wood demand for construction is observed in the baseline after 2050 while production levels are maintained. For the total policy region this can be summarized in the domestic use versus production of primary forestry (Figure 19), which clearly shows the decline of domestic use of forestry and wood productions towards the end of the century in the policy regions, whereas it continues to increase in the RoW while only marginally being affected by the HighCONST scenario.

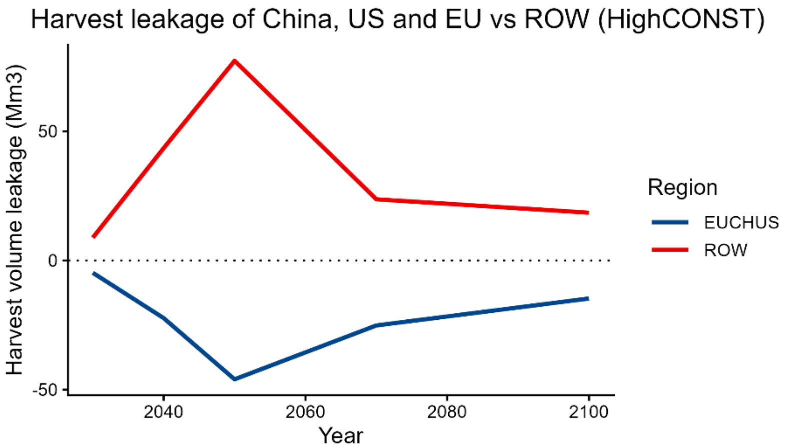

Figure 18: Summarized harvest leakage effect in MAGNET between policy regions (EUCHUS) and rest of the world (RoW) in the HighCONST scenario. The figure shows the wood harvest leakage (Mm³), calculated as the difference between the Non-FixTrade scenarios and the FixTrade scenarios (Non-Fixed minus Fixed) summarized for the combined policy regions and RoW.

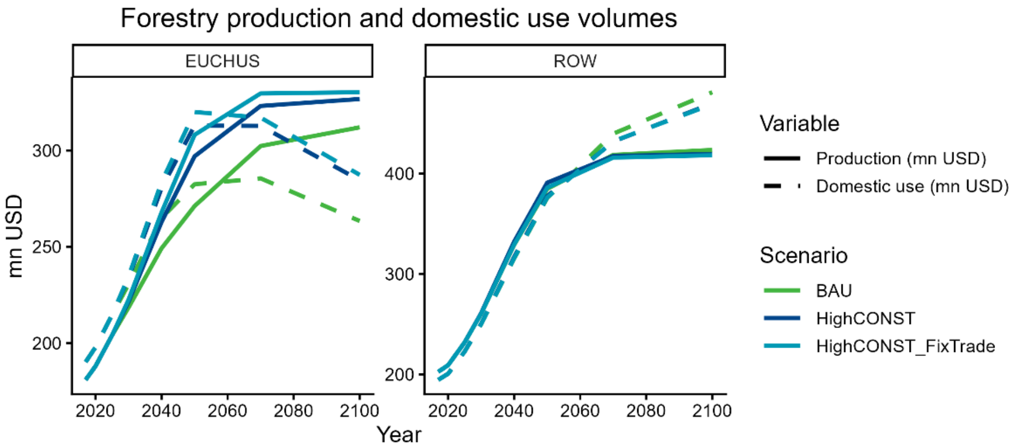

Figure 19: Production and domestic use volume of forestry products in MAGNET (expressed in million USD) in policy regions (EUCHUS) and rest of the world (RoW)

To showcase the importance of the harvest ban policy implementation in the scenarios, the GLOBIOM-China scenarios were defined and calculated without the harvest ban in China. As is clear from Figure 20 below, if the harvest ban in China is not considered, the harvest volume would be higher and closely follow the trends in MAGNET results. Although we will not show a full leakage analysis here, this clearly shows that a more flexible increase of local production in the model setup is important and would more easily alleviate import requirements.

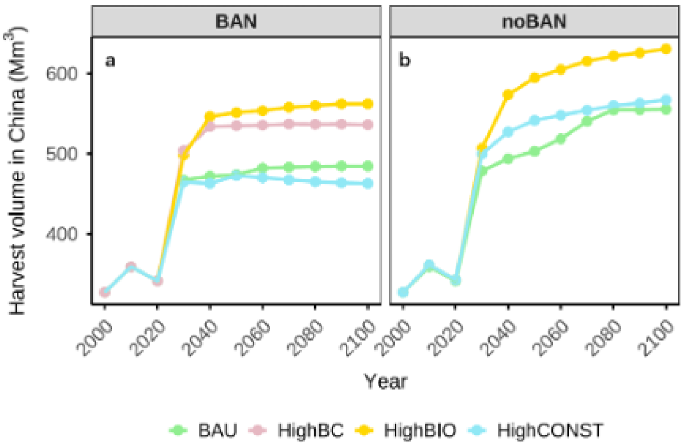

Figure 20: Set of contrasting GLOBIOM scenarios with harvest ban (BAN) and excluded (noBAN) from scenario settings.

6. Discussion

We find that high wood demand in China, the EU27 and the USA drives increases in global roundwood harvests and promotes a shift toward more intensively managed production forests. This result is consistent with recent studies on global wood demand growth. Arendarczyk et al. (2025), for example, project that global wood demand may increase by 27–102% by 2100, mainly through more intensive forest management and higher yields.

With regard to construction material demand, Nepal et al. (2021) show that large-scale deployment of mass timber construction increases sawlog production, timber prices, and pressure on global markets. In the context of bioenergy demand, Favero et al. (2023) highlight that the carbon outcomes of forest-based bioenergy expansion strongly depend on market responses, harvest dynamics, timber prices, management investments, and the allocation of forest land.

Our results for the HighCONST and HighBIO scenarios similarly show that increased wood demand in policy regions, under conditions of flexible trade, shifts part of the harvesting pressure to the RoW, thereby generating substantial harvest leakage. Specifically, each unit of harvest reduction in policy regions is associated with more than one unit increase in RoW harvests, accompanied by a decline in carbon sinks. Di Fulvio et al. (2025) report comparable dynamics, showing that EU bioeconomy and conservation policies can lead to spatial redistribution of harvesting and trade, reducing net exports from policy regions while increasing harvesting pressure elsewhere. Quantitatively, the leakage rates estimated in this study are broadly consistent with the range reported in the meta-analysis of Pan et al. (2020), which synthesised findings from forest and energy sector studies and showed that leakage can offset a substantial share of domestic mitigation gains, depending on policy stringency and model coverage. Our findings also align with the assessment by Schulte et al. (2025) for the Swedish forest sector, which concludes that only coordinated international policy cooperation can effectively minimise leakage and maximise climate mitigation benefits. Daigneault et al. (2025) reach a comparable conclusion for U.S. forest policy, emphasising that the carbon balance of forest-based mitigation depends on responses in non-policy regions.

Saal et al. (2017) further emphasise the importance of wood-processing residues in reducing pressure on primary harvests and improve resource-use efficiency. This is consistent with our observation that, under fixed-trade conditions, policy regions tend to increase the utilisation of by-products and residues.

In this deliverable, leakage effects are estimated by comparing a policy scenario under free trade with the same policy scenario under fixed bilateral trade. This scenario design is more stylised than the conventional comparison between a policy scenario and a baseline scenario. However, this approach was chosen deliberately to isolate the trade component in the analysis and to assess to what extent mitigation outcomes are mediated through international trade. It should be acknowledged, however, that the FixTrade scenario does not represent a realistic policy instrument. In practice, there is no single mechanism that would force net trade to baseline levels across all regions while demand continues to expand. The FixTrade scenarios should therefore be interpreted as analytical constructs designed to explore the role of trade in shaping leakage effects, rather than as feasible policy pathways.

7. Conclusion

Overall, increased wood demand in the policy regions leads to higher harvesting levels, shifts trade patterns toward greater import dependence, and weakens forest carbon sinks within those regions. Among the scenarios investigated, the combined bioenergy and construction scenario (HighBC) produced the strongest global response, requiring substantial intensification of forest production in the policy regions and resulting in a global decline in forest carbon sinks due to leakage effects outside these regions.

Fixing trade at baseline levels redistributes production and carbon impacts back to the policy regions (China, the EU27, and the USA). This results in even more intensive forest management systems and further reduction of forest carbon sinks in the policy regions. In both the HighCONST and HighBC scenarios, increased demand in policy regions shifts part of the roundwood harvesting burden to the RoW, indicating clear harvest leakage under flexible trade conditions. Although the absolute magnitude of leakage remains relatively small compared with global harvests, the relative response is substantial: higher wood demand in policy regions reduces their net exports and increases dependence on imports from the RoW under flexible trade.

Under the FixTrade scenarios, bilateral trade flows are fixed at baseline levels, limiting the ability of policy regions to increase imports from the RoW. As a result, supply adjustments occur primarily through increased domestic production, thereby reducing the role of external sources in meeting additional demand. Under flexible trade conditions, the forest carbon sink in the RoW declines relative to the FixTrade scenarios, indicating that each unit of carbon sink reduction avoided in the policy regions is associated with more than one unit of carbon loss elsewhere, leading to an overall decline in the global forest carbon sink.

Despite weaker carbon sinks, total carbon storage (including HWP and BECCS) increases in the three policy regions by 2100 under scenarios with higher biomass demand. In China, these gains are driven primarily by BECCS deployment, while in the USA, they are largely associated with the expansion of harvested wood products.

The MAGNET scenarios provide a sensitivity analysis of the main leakage-effect conclusions and suggest that leakage effects are smaller when greater intensification and expansion of harvest area are allowed. In the MAGNET model, which does not impose the same biophysical constraints as the GLOBIOM model, a larger share of increased production demand can be met through expanded domestic production within the policy regions. This contrast is particularly pronounced in China, where GLOBIOM imposes a strict constraint on the expansion of managed forest area.

An additional analysis compared the standard GLOBIOM results with a version incorporating re-export corrections. The results indicate that correcting for re-exports does not meaningfully change the overall assessment of leakage effects of the policy pathways analysed in GLOBIOM. However, the re-export analysis highlights the importance of accounting for these flows, as non-corrected trade volumes are considerably higher than re-export-corrected volumes for many bilateral trade relationships.

Taken together, these findings demonstrate that ambitious regional forest and bioeconomy policies can generate net carbon storage benefits, but only if they are complemented by internationally coordinated governance mechanisms capable of addressing carbon leakage and its associated impacts on global forest carbon sinks.

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