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EU policy on forest carbon sinks revisited

A. Maarit I. Kallio *, Elias Garvik

Norwegian University of Life Sciences, Faculty of Environmental Sciences and Natural Resource Management, Norway

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ABSTRACT

The European Union's (EU) policy for Land Use, Land Use Change, and Forestry (LULUCF) sets carbon sink targets for LULUCF for 2021–2030. Managed forests play a key role in achieving them. Using a global forest sector model, we projected forest sector development with and without meeting the sink target during 2026–2030 under the LULUCF regulation. We also assessed changes in the global harvested wood product sink and greenhouse gas effects from material substitution that could result if the targets were met. Moreover, we examined the combined impact of meeting LULUCF goals and one possible implementation of the EU Biodiversity Strategy for 2030, which seeks to conserve 30 % of EU land by 2030. Constant changes in emission statistics and other factors affecting LULUCF sinks complicate impact assessments, introducing uncertainty into our results. Under the assumptions made in this study, achieving sink targets, with or without additional forest conservation, requires an immediate and steep reduction in roundwood harvesting in EU member states and Norway (EU+N). This cut could reach 113–117 million m^3 in 2030–2035 compared to a market-driven scenario, assuming no further policy tightening after 2030. Two-thirds of this decrease is projected to be offset by higher harvesting elsewhere, shifting income from EU+N to other regions and reducing the climate gains. Our indicative calculation suggests that the emission reduction costs could exceed €700/t CO_2. Given the high economic burden and availability of more cost-effective alternatives, the role of managed forests in EU climate policy warrants a reconsideration.

1. Introduction

The European Union (EU) aims to reduce greenhouse gas (GHG) emissions by at least 55 % from 1990 levels by 2030 (European Parliament and the Council, 2023). In recent decades, forests have sequestered a significant share of emissions from other sectors in the EU. Due to the important role of forests and other land-based sectors in mitigating climate change, the EU has adopted a regulation for Land Use, Land Use Change, and Forestry (LULUCF). In its first version (European Parliament and the Council, 2018), each EU member state (MS) was assigned a forest reference level (FRL) defining the level of forest carbon sinks or sources against which the eventual net carbon sequestration in the forests of MSs would be compared in the first period of the regulation, 2021–2025. The amendment of the regulation (European Parliament and the Council, 2023) mainly affects the second compliance period of 2026–2030 and no longer sets specific targets for forests. The goal is to increase the sink of the entire LULUCF sector in the EU to 310 Mt CO_2 by 2030. The burden for achieving the goal is allocated among the MSs based on their shares of managed land area in the EU, instead of their past sinks or sources. Each MS has a binding pathway for the net greenhouse gas uptake of the LULUCF sector for 2026–2030. Although no specific targets are set for forest carbon sequestration, forests remain the primary sinks within the sector. Therefore, enhancing forest carbon sequestration is essential for meeting the target for 2026–2030. Achieving this within five years makes reducing harvest levels virtually the only management action capable of making a substantial contribution.

The recent trends of the forest sinks suggest that many EU countries and Norway are unlikely to meet their FRLs for 2021–2025 (Korosuo et al., 2023). Päivinen et al. (2022) and Kallio et al. (2018) suggest that if the countries had reduced their harvests to meet them, a substantial harvest leakage from the EU to the rest of the world (RoW) would have occurred. Kallio et al. (2018) examined the potential impacts of the EU MS and Norway (EU+N) meeting their FRLs for 2021–2025 and beyond, given that similar FRLs would also apply up to 2030. Their study was carried out before the FRLs were decided upon and relied on

* Correspondence to: Norwegian University of Life Sciences, Faculty of Environmental Sciences and Natural Resource Management, PO Box 5003, Ås N-1432, Norway.

E-mail addresses: maarit.kallio@nmbu.no (A.M.I. Kallio), elias.garvik@nmbu.no (E. Garvik).

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hypothetical values. Päivinen et al. (2022) conducted an updated evaluation using actual FRLs from MS policy documents and compiled data on the harvest levels consistent with them. With a few exceptions, their estimates for FRL compatible harvest levels for 2021–2025 were consistent with the respective estimates by Korosuo et al. (2020).

The harvest levels identified as consistent with FRLs in earlier studies are no longer a relevant starting point when assessing the second compliance period of the LULUCF regulation (2026–2030). As described above, the EU's sink target and its allocation among MS have changed. The earlier estimates for harvest levels aligned with the FRLs are not necessarily applicable even to the period 2021–2025. Several factors explain this, and we consider the following to be among the most important: LULUCF carbon accounting rules have evolved as they are constantly refined through scientific research. This methodological evolution has caused a mismatch between previously estimated harvest levels and sink relationships. In addition, forest growth in many countries has differed from what was assumed when FRLs were prepared.

Other policies beyond the LULUCF regulation also influence the use of forest resources and the forest sector in the EU. The EU Biodiversity Strategy 2030 (EUBDS) (European Commission, 2020) is one of these. EUBDS is the EU's response to the global biodiversity crisis and works in tandem with the Kunming-Montreal Global Biodiversity Framework (The United Nations., 2022). It requires the protection of 30 % of the EU's land and sea areas by 2030, with strict protection for at least one third of these areas, including all primary and old-growth forests. This expansion of the protected area network will reduce commercially available wood resources in the EU. Dieter et al. (2020), Schier et al. (2022), di Fulvio et al. (2025), and Kallio and Rannestad (2025) examine the impact of EUBDS on the EU and the global forest sector. They suggest that EUBDS would lead to a reduction in EU harvests and forest industry production, while a substantial proportion of these reductions would be offset by increased activities in RoW. Comparing the results of the EUBDS policy impacts with those of Päivinen et al. (2022) on LULUCF suggests that, depending on the assumed allocation and extent of protected areas, the impacts of EUBDS on the EU forest sector would be considerably smaller (di Fulvio et al., 2025; Kallio and Rannestad, 2025) or roughly equivalent (Dieter et al., 2020; Schier et al., 2022) as those that would arise if EU member states achieved FRLs of the 2018 LULUCF regulation by reducing their harvests. However, as EUBDS is implemented simultaneously with the LULUCF regulation, it is of interest to explore the joint impacts of these policies.

The reduction in harvestable wood resources in the EU—due to the expansion of protected areas under EUBDS or due to MS implementing policies to enhance their forest sinks—increases roundwood prices and, consequently, raises the prices of harvested wood products (HWPs) in the EU and globally. This leads to a decline in HWP consumption. Consequently, the carbon sink of HWPs (annual increase in carbon stored in the carbon pool of HWPs) decreases globally compared to the scenario without policies that reduce roundwood harvests in the EU. Some HWPs may be replaced by products made from materials with higher GHG footprints, leading to increased emissions in the energy sector. These effects should also be considered when examining the impacts of LULUCF policies on the forest sector and climate change mitigation. Johnston and Radeloff (2019) projected the global development of HWP sinks. They suggest that these sinks will peak around 2030, while remaining positive throughout the period until 2065. They examined various shared socioeconomic pathways, and their results cannot be directly linked to the specific policies.

The impact of the revised LULUCF policy on the forest sector for 2026–2030 has not been considered in previous studies. The significant differences between the amended regulation and its predecessor merit such an investigation. Additionally, earlier studies were conducted before major shifts in global geopolitics and trade caused by Russia's invasion of Ukraine in 2022 and before EUBDS was formulated. This highlights the need to assess how achieving LULUCF policy targets for 2026–2030 would affect the EU and the global forest sector. This study aims to carry out such an assessment. In addition, our research makes other important contributions: (i) it provides a more detailed, region-specific report on harvest and production leakage, (ii) it examines the effects of the LULUCF policy on carbon sinks of HWPs, (iii) it evaluates potential changes in GHG emissions by substituting HWPs with products made of other materials, and (iv) by combining findings (ii) and (iii) with rough estimates of carbon stock changes in forests due to altered harvest levels globally, it offers an indication of the policy's cost-effectiveness in terms of the unit cost of saved CO_2 emissions. As countries are obliged to comply with LULUCF regulation, it is important to address the costs of that at least to some extent.

2. Material and methods

2.1. Scenarios

Our research is based on scenario analysis. We compare a reference scenario, "Base", assuming no additional policy measures, with two alternatives in which roundwood harvests in the EU MS and Norway are restricted to meet their LULUCF sink targets for 2026–2030 (European Parliament and the Council, 2023). In the scenario "LULUCF-BD", these targets are implemented without EUBDS. In the scenario "LULUCF+BD", EUBDS is implemented simultaneously. The scenarios summarized in Table 1 were extended to 2035 and quantified using a global forest sector model, FORMEQ, discussed in Section 2.2.

The Base scenario and the assumed EUBDS implementation follow Kallio and Rannestad (2025). Modelling the EU LULUCF policy required additional assumptions. First, we needed to determine a plausible allocation of each country's LULUCF sink goal between forest land and other LULUCF categories. Second, we had to identify harvest levels that could reasonably be assumed to align with the forest sink goals for 2026–2030. Appendix 1 provides a detailed discussion of these assumptions, including the data on past sinks and harvests. No forest policy changes were assumed in countries outside the EU+N in the scenarios.

The EU's total LULUCF sink target for 2030 is set at −310 Mt of CO_2. This goal is based on 2020 emissions statistics and may be subject to change. The target is allocated to the MS by their shares of the total managed land within the EU (European Parliament and the Council, 2023). To define the forest sink goals in 2030 for the MS for our analysis, we assumed that, in each MS, land use categories other than forests would be able to reduce their emissions or increase their carbon sinks by 10 %, with forests supplying the remainder. To estimate what level of roundwood harvests could be sustained to meet the assumed sink target, we used alternative approaches as discussed in Appendix 1. First, we compared the countries' recent and past harvest levels to the respective forest carbon sinks. Additionally, we calculated estimates of what harvest level would have produced the target sink by considering the latest data on forest sink and roundwood harvest, the assumed carbon content of wood, and biomass expansion factors for roundwood. Based on the

Table 1
Scenarios addressed.

Base	The market-driven reference scenario with no new policies. The assumptions follow Kallio and Rannestad (2025) and include trade restriction due to war in Ukraine. The EU, North America and group of other countries are not trading forest products with Russia and Belarus.
LULUCF-BD	Everything else is as in Base, but the countries are forced to meet their assumed forest sink goals during 2026–2030. The goal for 2030 is repeated for 2031–2035. The assumptions on the goals are elaborated in Appendix 1.
LULUCF+BD	Everything else as in LULUCF-BD, but new protection areas are added in the EU and Norway to satisfy the 10 % strict and 30 % non-strict area conservation goals. These will be established gradually during 2025–2030 to cover the EUBDS protection targets applied at MS level. The assumptions are detailed in Kallio and Rannestad, (2025).

resulting estimate for the target-sink-compatible roundwood harvest level in an MS in 2030, we defined a linear path for harvest constraints from the observed 2021–2022 average roundwood harvest to 2030. The procedure aims to mimic the approach of the LULUCF regulation, which defines a trajectory between the average 2020–2023 LULUCF sink and the 2030 goal. The harvests were not allowed to exceed the resulting levels in 2026–2030, even though policy allows some annual deviations from the path (European Environment Agency, 2024). A deficit in the sink in one year would, however, tighten the target for the subsequent years. The compatible harvest for the entire EU in 2030 was calculated at 476 Mm^3 under bark. This includes both industrial roundwood and fuelwood. The fuelwood harvests were assumed to be constant at their last observed values in the scenarios. Norway has committed to following the first LULUCF regulation (European Parliament and the Council, 2018). The compatible harvest levels for Norway were defined with reference to this.

There is considerable uncertainty in our figures for target-sink-compatible harvest potentials, as they are based on the evaluation of statistics at a given time point. Several factors cause fluctuations in countries' LULUCF emissions over time, not only in forestland but also in other land-use categories. One such factor is the annual weather conditions. Also, for instance, the distribution of harvests among size classes and regions affects the impact of harvests on forest sinks. An important external factor influencing countries' compliance with the regulation is the continuous development of emission calculation methods, which evolve with advances in scientific knowledge. Consequently, the statistics on past emissions—and thus the gap to the LULUCF target—are constantly changing.

The post-2030 LULUCF policy has not yet been determined. We assumed that the 2030 harvest constraint would remain in place for 2031–2035. This assumption may be considered conservative, given the EU's progressively tightening climate goals.

The EU Biodiversity Strategy 2030 targets 30 % of land to be legally protected by 2030, with one- third under strict protection, including all primary and old-growth forests. The allocation between MS and protected land types is undecided. Kallio and Rannestad (2025) illustrate one potential EUBDS implementation using simplified assumptions, focusing on additional hectares required. We adopted their assumptions to combine the LULUCF targets with EUBDS implementation in the scenario LULUCF+BD. As forests are among the most biologically diverse habitats (Aerts and Honnay, 2011), targets were assumed to be met in forests before other land types. Non-strict forest protection was increased until either 30 % of the forest or total land was protected, and strict forest protection was increased until either 10 % of the forest or total land was strictly protected. Targets were applied to each MS separately and could be exceeded if a country had non-strictly protected natural and old-growth forests beyond existing conservation areas. Norway, with its own 30 % conservation goal, was assigned the same target. Roundwood harvests were not allowed in strictly protected areas. In non-strictly protected areas, 30 % of the land area was assumed to be available for roundwood production. The roundwood supply functions in the FORMEQ model were adjusted accordingly for 2026–2030. Data on conservation areas were obtained from Forest Europe (2020), UNECE (2024), Eurostat (2024a), OECD (2024), and Hannerz and Ekström H (2023)). Additional data for assumptions on conservation and old-growth forests came from Schier et al. (2022), Jonsson et al. (2019), Svensson et al. (2022), Räty et al. (2023), Syrjänen et al. (2024), and PEFC (2022). Data on assumed additional hectares of conserved forest land are given in Table A.4. in the supplementary material (S.1.)

In the scenarios, it was assumed that demand for pulpwood-sized wood for energy does not increase. For the EU, the assumption is in line with the EUBDS (European Commission, 2020), suggesting that the use of whole trees for energy purposes should be minimized. Fuelwood harvests that were kept fixed in the model runs include some roundwood.

2.2. The global forest sector model, FORMEQ

The Forest Market Equilibrium Model (FORMEQ) is a spatial partial market equilibrium model for the global forest sector. It represents the behaviour of producers and consumers under the assumption of perfectly competitive markets. In such settings, individual agents (consumers, producers, and traders) act as price-takers, maximizing their welfare or profit. FORMEQ is a "partial equilibrium" model because it only includes the forest sector endogenously, while other economic activities are treated as external background conditions. The term "spatial" refers to the distribution of goods and prices across countries and regions rather than detailed geographic mapping. FORMEQ divides the world into 117 regions (112 countries and one aggregated region per continent, including countries with fewer forest sector activities), which engage in international trade in forest products. Market equilibrium —quantities produced, consumed, exported, and imported in each region, along with the equilibrium prices— is solved using nonlinear mathematical programming under the General Algebraic Modeling System (GAMS). Because the model incorporates trade between regions, it is suited for analyzing shifts in production and trade patterns across regions arising from policy interventions, including potential leakage effects.

The FORMEQ currently includes 35 forest sector products, of which 17 are final or semi-finished products corresponding to product categories in FAO (2024) for paper, paperboard, mechanical forest industry products, and dissolving pulp. The remaining products include various grades of roundwood, chemical pulps for papermaking, sawmill residues, and recycled paper.

A brief description of how the forest industry, roundwood producers, and consumers are defined in the model and how the model is solved is presented below. The reader may also refer to Kallio (2021, pp. 4–6, DOI: 10.1016/j.forpol.2020.102364; 2024, pp. 377–383) and (Kallio, 2024). Earlier applications of the model include e.g., Päivinen et al. (2022) who studied the effects of meeting the FRLs used in the first compliance period of the LULUCF.

The model adopts an activity-analysis approach to represent the supply of forest products: a variety of separable activities are specified in each region to supply roundwood, fuelwood, recycled paper, mechanical forest industry products, pulp, paper, and paperboard. The production set can be constrained by capacity limits or other upper bounds associated with the individual activities.

A set of Leontief-type production technologies is applied to the forest industry. These specify the volume of inputs required and the by-products generated when activity l in country I produces one unit of its primary output. Depending on the process, the input factors may consist of wood and pulp grades, capital, labour, electricity, and an aggregate category of other inputs. Technologies for pulp and paper are defined at the mill level using data from the RISI., (2017)), complemented and updated with additional engineering-based sources and company websites. Technologies for mechanical forest industries are defined primarily using engineering data and available national sources but are often supplemented by coefficients that balance the country's material use in the FAOSTAT data (FAO, 2024). The maximum availability of recovered paper is tied to regional paper consumption in the previous period and assumed recycling rates.

Roundwood producers are represented by upward-sloping inverse supply functions parameterized such that supply elasticities are consistent with the previously estimated or assumed values for roundwood assortments in a country at the observed (reference) harvest level from FAOSTAT (FAO, 2024) and price (derived from national statistics and export and unit input values for roundwood in FAOSTAT). The roundwood supply functions are updated (shifted) periodically in accordance with the volume elasticity of supply and the change in growing stock volume. This change is calculated based on harvests in the previous period, forest growth rates, and removals of productive forest volume due to potential conservation set-asides. The roundwood supply in

FORMEQ is explained in more detail in Supplementary Material S.2.

Consumers of final and semi-finished products are represented by the regional inverse demand functions. These are specified as linear, non-increasing functions, and parameterized by assuming that the data on estimated or assumed elasticities from the literature apply to the observed reference quantity (apparent consumption from FAOSTAT, FAO, 2024) and price. Demand functions are defined to evolve in line with projected GDP developments.

Like most other market equilibrium models for the forest sector (e.g., GTM, Kallio et al., 1987, and Salo and Kallio, 1987; GFPM, Buongiorno et al., 2003; EFI-GTM, Solberg et al., 2003, and Kallio et al., 2004), FORMEQ finds the competitive market equilibrium by solving a non-convex optimization problem that combines the profit-maximising behaviour of price-taking individual agents. In equilibrium, each agent operates at its optimum, given the prevailing market prices and the choices of other agents. At the same time, all material balances are satisfied such that, for every product and region, consumption plus imports equals domestic production plus exports. The model is thus cast into an optimization problem that maximises the difference between consumers' and producers' surpluses, net of transportation costs, across all regions and forest products. The model constraints include material balance requirements and limitations arising from agents' production and consumption possibilities. Kallio (2021, p.6, DOI: 10.1016/j.forpol.2020.102364; 2024, pp. 377–383) presents the model formulation in mathematical notation.

The solution is computed one year at a time, with the relevant parameters updated after each period before moving on to the next period. For this study, the model horizon was set to 2035, which we considered appropriate given the EU LULUCF target for 2026–2030.

For this study, the model was updated with recent data for forest industry production capacities (FAO, 2024; websites of forest industry companies), energy costs (Eurostat, 2024b), labor costs (International Labor Organization, 2024; World Bank, 2024), and GDP projections (International Monetary Fund, 2024).

2.3. Calculating HWP sinks and substitution benefits

2.3.1. HWP sinks

Whether HWP consumption provides a carbon sink in a region depends on the balance between carbon accumulation and decay in HWP stocks. If the increase in stock due to new consumption is higher than the decay of the existing stock, we have a sink. We use a standard method for tracking HWP carbon sinks in countries (IPCC 2006a). However, instead of considering the stock based on the amount of HWPs produced from locally harvested wood in a country, we examine the stocks based on countries' consumption of HWPs. This approach allows us to track where the stock is located and where it decays. HWPs leaving the stock may be used for bioenergy in that region, and we use the information on the stock decay in calculating the substitution effects at the end of life of the products (Section 2.3.2). From a global climate perspective, the location of the ultimate use of wood harvested from a region for HWP production is irrelevant. Tracking all biomass flows in detail would add unnecessary complexity to the analysis.

We use the first-order decay function to track the decline in the volume of carbon in HWP pools (IPCC 2006a). The rate at which carbon is removed from the pool, k, is defined as $k = ln(2) / HL$, where HL represents the half-life, i.e., the number of years required to lose half of the material currently in the pool. We calculate the stock of carbon, $C(t)$, at the beginning of year t using Eq. (1) based on the regional HWP consumption volumes $Q(t)$. If the change in carbon stock $\Delta C(t)$ from C(t) to C(t + 1) is positive in a region, the HWP pool in that region is a carbon sink; otherwise, it is a carbon source. The HWP carbon content, c_f (MgC per unit of product consumed), and HLs applied in Eq. (1) are given in Table 2.

Table 2
The assumed mean lifetimes and carbon contents for the Harvested Wood Products (HWPs). Half-life (HL) is a mean lifetime multiplied by ln(2). Source: IPCC, 2014; IPCC, 2006a; IPCC, 2006b. The data for textile pulp is authors' assumption.

HWP category	Mean lifetime (years)	Carbon content, c_f, per unit of product (1 t = 1 Mg)
Paper & Paperboard	2.9	0.386 tC/t
Wood-based pulp for textiles	4.3	0.400 tC/t
Softwood sawnwood	50.5	0.225 tC/m^3
Hardwood sawnwood	50.5	0.280 tC/m^3
Plywood	36.1	0.267 tC/m^3
Other Panels & Boards	36.1	0.269 tC/m^3

$$C(t+1) = e^{-k} \cdot C(t) + \left[\frac{(1-e^{-k})}{k}\right] \cdot c_f Q(t) \quad (1)$$

For $t = 0$, the stock and inflow into it are based on the apparent consumption of HWPs (production+ imports-exports) in 1961–1965, or earliest other data available in FAO (2024). To convert the quantities of carbon C to CO_2, we use the conversion factor 1 C = 44/12 t CO_2.

2.3.2. Substitution benefits

Carbon substitution benefits related to HWPs (also called avoided emissions) arise when wood products replace non-wood products with the same function but a higher carbon footprint (e.g., Sathre and O'Connor, 2010). These benefits occur in two phases: in the production stage, when a wood product replaces a non-wood product, and at the end-of-life (EoL), when wood products can provide renewable thermal energy while most non-wood substitutes cannot (except, e.g., cotton). Carbon displacement factors (DFs) measure the amount of emissions savings achieved by substituting a product with an equivalent wood product (Leskinen et al., 2018). DFs are often reported as a ratio of the difference in emissions resulting from the use of non-wood and wood alternatives to the difference in the amount of wood used in wood and non-wood alternatives (or carbon in that wood). In contrast, we use the fossil carbon savings per unit of wood product consumed. This approach is not only easier to communicate but also straightforward to apply directly to projected consumption quantities in the scenarios.

2.3.2.1. Carbon replacement in the production stage of materials. We assumed that sawnwood, plywood, panel products, pulp for textile production, and paperboard have positive DFs during their production stage (Table 3). The considerable uncertainty regarding the end-uses of HWPs, the materials they replace, and the GHG emissions avoided due to such replacements should be considered. It is not feasible to detail the relevant factors for all the world regions considered in this study. We used what we perceived to be typical values based on earlier studies and applied the same numbers to all regions. However, because we are

Table 3
Assumed carbon replacement factors. Main data sources: Sawnwood: Leskinen et al., (2018); Hurmekoski et al. (2020); Panel products: Leskinen et al. (2018), Suter et al. (2017), Knauf et al. (2015); Papers for packaging: Knauf et al. (2015), Hurmekoski et al. (2020); Pulp for textiles: Shen and Patel, (2010); Shen et al. (2010); Rüter et al. (2016), Spinnova, (2024).

Harvested Wood Product	Carbon displacement factor, tonne of CO_2 per unit of product consumed
Sawnwood	0.82 tCO_2/m^3
Panel and board products	0.49 tCO_2/m^3
Paper and paperboard for wrapping and packaging	1.98 tCO_2/m^3
Rest of papers	0 tCO_2/m^3
Pulp for textiles	3.47 tCO_2/m^3

interested in how the substitution effects change if the EU forest sink target is achieved, it must be noted that it is typically the consumption of HPWs produced in the EU that adjusts downward, whereas the production of these same HWPs may increase in other regions. Therefore, the typical substitution factors related to products of EU origin can be perceived as the most relevant.

In the LULUCF scenario, rising HWP prices due to a tightened wood supply tend to reduce demand from industries and private consumers who use these products for purposes such as packaging, construction, furniture, and textiles. However, it is likely that not all this demand will shift to alternative materials. We assumed that 95 % of the volume of HWPs consumed in the Base scenario but not in the LULUCF scenarios would be replaced by other materials.

2.3.2.2. Carbon replacement in the EoL stage of materials. The calculation of EoL substitution benefits from HWP consumption was based on the amount of carbon leaving the HWP pool in a region each year, as shown by Eq. (1). A portion of this wood biomass was assumed to be recovered and incinerated for energy, replacing other energy sources and their associated emissions. One tonne of carbon from wood biomass was assumed to correspond to approximately 0.764 tonnes of oil equivalent (toe) of primary energy.

Except for paper and paperboard, reliable data on the proportion of recovered HWP waste are limited. Although this proportion may currently be low, future energy scarcity and countries' climate change mitigation efforts are expected to increase it. The figures we used — 85 % in EU+N and 70 % in RoW — should be considered assumptions for the potential recovery rates in 2030–2035, rather than estimates of the current recovery in specific countries. The EU's legislative framework for waste (European Parliament and the Council, 2008) sets recovery targets for textiles, packaging, and construction waste, suggesting that the EU may further improve the recycling of materials. Non-recyclable wood-based materials can be incinerated to produce energy.

The volume of CO_2 emissions that could be replaced by HWPs at their EoL was determined based on the assumed composition of countries' primary energy use for heat and power production each year. Data on the current carbon intensities of primary energy were collected from the EDGAR database (European Commission, 2024). We assumed that countries with emission reduction goals, as reported in their Nationally Determined Contributions (NDCs) to the UNFCCC (2024), would achieve them. Thus, we assumed that the carbon intensity of primary energy would decline in line with these goals, starting from the 2022 data. For example, we assumed a 55 % reduction in the EU Member States by 2030 compared to 1990 levels. For countries reporting reductions relative to a business-as-usual scenario, the reductions were converted to absolute emission values, and a reference year for the carbon intensity of primary energy production and total emissions in CO_2-eq was selected for comparison. For countries without clear emission reduction goals, we assumed no decline in the carbon intensity of energy. China and India, the largest coal users worldwide, have no 2030 emission-reduction targets and no plans to phase out coal by 2035 (International Energy Agency, 2024). For these two countries, the carbon intensity of coal was applied.

3. Results

3.1. Developments in the EU and global forest sector

The BASE scenario, as well as the assumptions on EUBDS implementation in the LULUCF+BD scenario, follow Kallio and Rannestad (2025), who provide a more detailed description. We focus on the sectoral impacts projected when EU MS and Norway are required to achieve the assumed LULUCF forest sink targets for 2026–2030, as discussed in Section 2.1 and the Appendix. The results of the LULUCF-BD and LULUCF+BD scenarios were similar to each other. Because the assumed EUBDS implementation is just one of many possible outcomes of that policy, we mostly refer to the numbers for the LULUCF policy only. Most of the discussed impacts are slightly stronger when EUBDS is implemented simultaneously.

3.1.1. Roundwood harvests and prices in EU+N and RoW

3.1.1.1. Harvests in the EU+N. Roundwood harvests in EU+N are projected to reach 558 Mm^3 in 2030 and increase to 582 Mm^3 by 2035 in the Base scenario (Fig. 1). In the EU region only, the respective figures are 545 Mm^3 and 563 Mm^3. The main drivers of this are the growth in sawnwood, panel products, and chemical pulp production and increased roundwood exports from the EU. Achieving the assumed LULUCF targets for 2026–2035 would require a substantial reduction in EU harvests, not only compared to the future harvest levels projected in scenario Base but also relative to current harvests. The sharp reduction would occur regardless of EUBDS implementation (Fig. 1). Under the LULUCF constraints, EU+N harvests would need to fall rapidly to 451 Mm^3or 455 Mm^3, depending on whether EUBDS policy is included. In the EU region only, the respective figures are 439 Mm^3 and 441 Mm^3. For the EU, this represents a return to the harvest levels last seen before 2010 during the global financial crisis. The small difference between EUBDS+BD and EUBDS-BD scenarios suggests that the assumed EUBDS implementation has little effect on the aggregate EU-level outcome in this analysis. This does not exclude the possibility that the impacts of simultaneous implementation could be significant for an individual country alone.

3.1.1.2. Harvests in the world and RoW. Nearly two-thirds of the EU+N roundwood harvests decline under the two alternative LULUCF scenarios are projected to be offset by increased harvests elsewhere. The global roundwood harvest projected for 2035 is 4417 Mm^3 in the Base scenario and 4372 Mm^3 in LULUCF-BD. The difference of approximately 45 Mm^3 is far smaller than the 127 Mm^3 harvest drop in EU+N in 2035, as RoW countries increase their harvests by approximately 82 Mm^3 . Table 4 summarises how harvest changes in the LULUCF-BD scenario, due to achieving the assumed forest sink target in the EU, are distributed across countries in 2035. North America has the largest share of projected harvest leakage (38 %), followed by South America (25 %), largely driven by Brazil and Chile. Roundwood harvests are also projected to increase notably in Russia, Indonesia, and China. While some of this growth might come from new fast-growing plantations in, e.g., Brazil, Indonesia, and China, the projected scale and timing of the rise suggest that the required land area would be so large that significant pressure on natural forests is unavoidable. Fig. 2 shows the breakdown of roundwood harvest changes in 2035 by region and wood category.

3.1.1.3. Prices of roundwood. Sawlog and pulpwood prices are projected to rise by 2030 and 2035 in the Base scenario, with hardwood prices increasing more than those of softwood. Enforcing the assumed forest sink targets for EU+N will tighten roundwood supply, pushing wood prices higher in both Europe and RoW. In EU+N, coniferous sawlog prices are, on average, 18 % higher in 2030–2035 under LULUCF-BD than under Base, while coniferous pulpwood prices are 38 % higher. For hardwood sawlogs and pulpwood, the respective increases compared to Base are 8 % and 32 %. In RoW, roundwood prices rise less than in EU+N, with percentage increases being roughly half of those projected for EU+N. The turnover in roundwood sales at the mill gate in the EU27 decreases by 4.4×10^9 € under LULUCF-BD compared to Base in 2035, while it increases by 23.9×10^9 € in RoW. In the EU, higher roundwood prices partially compensate forest owners for the earnings lost due to reduced production. In RoW, forest owners not only harvest more wood but also benefit from higher prices for their harvests.

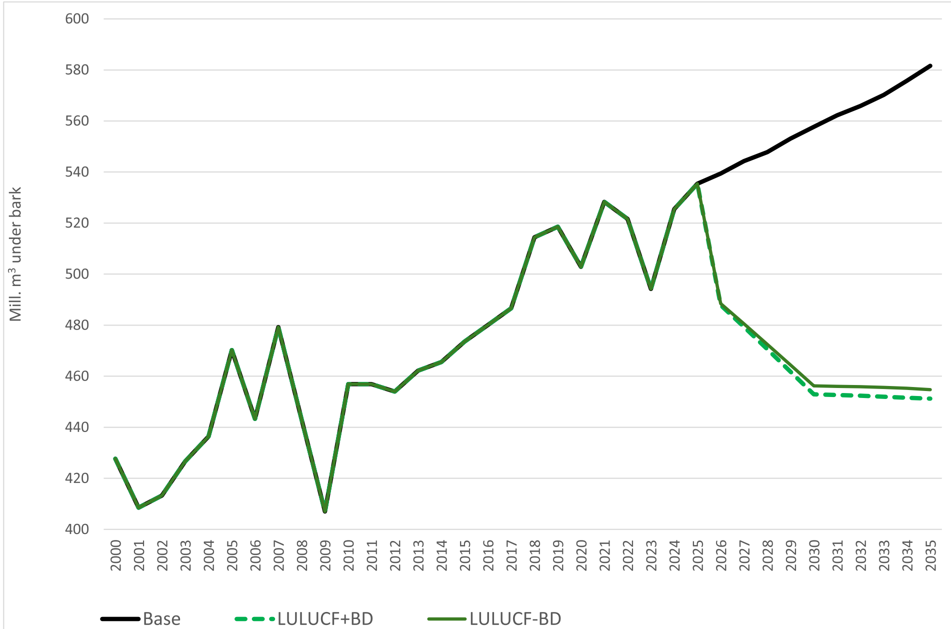

Fig. 1. Roundwood harvests in the region, including EU and Norway, as projected in the reference scenario (Base) and in scenarios where forest sink targets are achieved with (LULUCF+BD) and without (LULUCF-BD) the assumed implementation of the European Biodiversity Strategy 2030. The values for 2000–2023 are from FAOSTAT (FAO 2025). Mill. m^3 under bark.

Table 4
Percentages of the countries' shares of roundwood harvest decrease in EU+N and countries' shares of harvest increase in the Rest of the World, respectively, in scenario LULUCF-BD. These harvest changes are with respect to the baseline level in 2035. For RoW, countries that increase their harvests by 0.2 Mm^3 or more are included.

Countries in the EU+N region		Countries in the Rest of the World (RoW)	
Poland	26.0 %	The United States	27.3 %
France	15.5 %	Brazil	17.1 %
Germany	15.3 %	Canada	10.2 %
Finland	13.8 %	Russia	6.3 %
Sweden	12.4 %	Indonesia	4.2 %
Estonia	5.0 %	Chile	4.2 %
Spain	3.9 %	China	3.8 %
Latvia	2.8 %	Belarus	2.5 %
Austria	2.7 %	New Zealand	2.2 %
Bulgaria	1.7 %	Turkey	2.1 %
Ireland	1.1 %	VietNam	2.0 %
The Slovak Republic	1.1 %	India	1.8 %
Croatia	0.6 %	Australia	1.7 %
Italy	0.6 %	Argentina	1.4 %
Lithuania	0.5 %	Malaysia	1.2 %
Portugal	0.1 %	Thailand	1.1 %
Cyprus	0.0 %	Japan	1.1 %
Luxembourg	0.0 %	South Africa	1.0 %
Greece	0.0 %	The United Kingdom	0.9 %
Netherlands	0.0 %	Iran	0.7 %
Denmark	-0.1 %	Mexico	0.7 %
Hungary	-0.2 %	Ukraine	0.7 %
Belgium	-0.2 %	Nigeria	0.7 %
Slovenia	-0.3 %	Uruguay	0.6 %
Czechia	-0.7 %	Switzerland	0.5 %
Romania	-0.7 %	Bosnia-Herzegovina	0.3 %
Norway	-0.8 %	Paraguay	0.3 %
		South Korea	0.3 %
Total EU+N	100 % of −127 Mm^3	Total	96.9 % of + 82 Mm^3

3.1.2. *Forest industry production in EU+N and RoW*

Increased production costs for the forest industry, due to higher roundwood prices, cannot be entirely transferred to product prices. Therefore, demand for the products declines. In EU+N, the production of pulp (-16 %), sawnwood and plywood (-13 %), and the rest of the mechanical forest industry products (-11 %) declines in LULUCF-BD compared to Base. The values in parentheses refer to the decline projected for 2035. Paper and paperboard production, which is more reliant on recycled fibres, is more resilient and decreases the least.

Almost two-thirds of the decrease in projected sawnwood and plywood production in EU+N in LULUCF+BD leaks to RoW, with North America and Russia increasing their supplies. Products that rely more on pulpwood and chips are more difficult to replace. For panel products, this may be largely due to their relatively low sales prices, which cannot support a significant increase in production costs. Producers compete for a limited pulpwood supply, a situation worsened by the reduced availability of sawmill residue. Regarding pulp production, the high investment costs and large operational scale make it difficult to establish new pulp mills within the considered timeframe. Fig. 3 shows the changes in the projected production when the forest sink requirement is enforced in LULUCF-BD compared to the market-driven projection in Base.

3.2. *Difference in the climate effects of HWPs between LULUCF and Base scenarios*

3.2.1. *Decline in HWP carbon sink due to decreased consumption in LULUCF scenario*

The data from Section 2.3 were applied to the projected consumption figures for countries to evaluate how the global HWPs carbon sink is affected when the goals for forest carbon sinks in the EU+N are attained as assumed. In Base, the global HWP carbon sink is projected to increase from 305 Mt CO_2 in 2023–346 Mt CO_2 by 2035. Nearly two-thirds of this growth results from the rising consumption of plywood and other mechanical board products, while close to one-third is due to increased sawnwood consumption. The sink contribution from short-lived paper products and textile pulps is much smaller, accounting for only 3 % of the total sink in 2035. These proportions are similar when the EU+N region is examined separately.

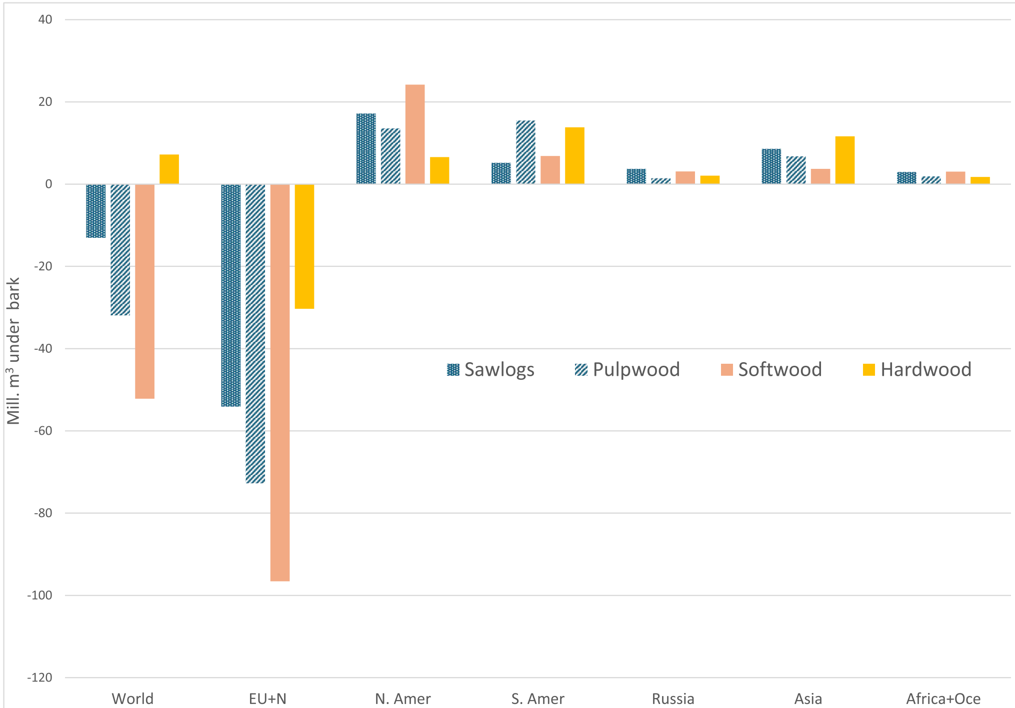

Fig. 2. Change in harvests by wood categories in 2035 when LULUCF-BD is compared to Base (mill. m^3 under bark). EU+N includes the 27 EU Member States and Norway, N.Amer refers to North America, S.Amer to South America, and Oce to Oceania. Softwood and hardwood refer to coniferous and non-coniferous industrial roundwood.

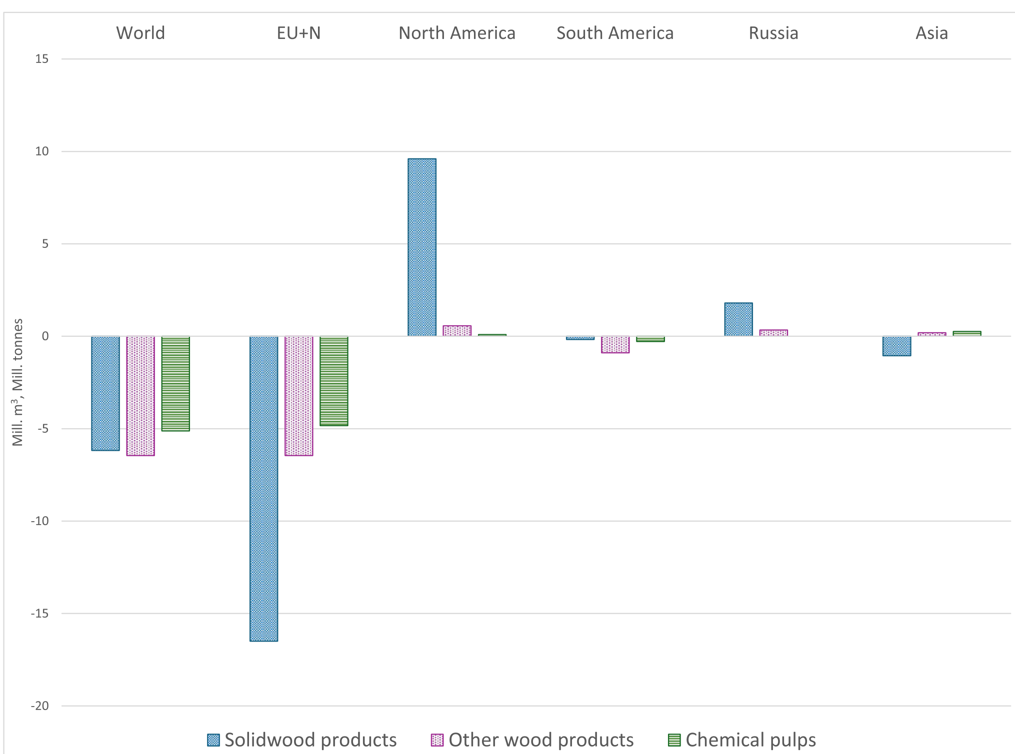

Fig. 3. The projected change in forest industry production from scenario Base to scenario LULUCF-BD in 2035 (Mill. tonnes for pulp, otherwise mill. m^3). Solidwood products refer to sawnwood, plywood and veneer. Other wood products refer to the rest of the mechanical boards and panels.

In the LULUCF-BD scenario, the HWP sink in 2035 is 10.8 Mt CO_2 lower than that in the BASE scenario. This reduction is observed for all product categories, and the relative shares of each category in the global HWP sink remain largely unchanged compared to BASE. There are some minor fluctuations in the sink difference between LULUCF-BD and Base during 2030–2035, but the average annual difference over this period is 10.6 Mt CO_2.

3.2.2. *Increased emissions due to replacing wood by other materials*

3.2.2.1. Production stage. Compared with a counterfactual scenario without HWP production, and assuming that all production generates substitution benefits, as shown in Table 3, the total global substitution effect is calculated at 1238 Mt CO_2 in 2023, rising to 1434 Mt CO_2 by 2035. The largest benefits arise from the use of paperboard as a substitute for plastics, followed by sawnwood and plywood, which are predominantly used in construction. While these figures are of little relevance on their own, they provide a reference point for examining the changes in these benefits when shifting from Base to the LULUCF scenarios. The substitution effects at the production stage are projected to be on average 14.1 Mt CO_2/a lower during 2030–2035 in the LULUCF-BD scenario than in Base, if each non-produced HWP unit is fully replaced by alternative materials.

However, our assumption that up to 95 % of the foregone consumption of wood products is substituted by their assumed non-wood substitutes reduces the respective average substitution effect difference between LULUCF-BD and Base to 13.4 Mt CO_2/a.

3.2.2.2. End of life stage. Using the data and assumptions outlined in Section 2.3.2, the annual EoL substitution effects from using the outflow of wood from HWP sinks to produce energy are estimated to be 433 Mt CO_2 globally in 2023, rising to 448 Mt CO_2 in 2035 in the baseline projection. In the LULUCF-BD scenario, these emission savings are, on average, 1.8 Mt CO_2/a lower during 2030–2035 than in Base. Although CO_2 emissions from energy production are assumed to decrease in several countries, the difference in the end-of-life substitution figures between scenarios does not decline over the years.

3.2.3. *Total effects of the changes in HWP consumption globally*

When we summarize the decline in the HWP sink and the foregone substitution effects in the production and EoL stages of the HWPs due to enforcing the assumed forest carbon sink target in scenario LULUCF-BD, the loss in climate benefits globally ranges from 26.2 Mt CO_2 in 2030–27.8 Mt CO_2 in 2035, with an average of 25.8 Mt CO_2 per year during 2030–2035. This loss of climate benefits should be weighed against the increase in climate benefits resulting from the global expansion of forest carbon sinks under the LULUCF policy to assess the policy's overall net contribution to climate mitigation. The economic loss due to the decline in the EU forest sector may be reflected in the context of the resulting net effect on climate.

4. Discussion

To calculate the global net carbon savings that could be obtained by achieving the EU's LULUCF policy targets for 2030, an estimate of the change in the global carbon sink is required. However, the FORMEQ model used in our analysis is simple in its forest dynamics, as it focuses on simulating timber supply as a function of endogenous roundwood prices and changes in growing stock volumes of forests at the country level. The model does not track forest carbon sinks. To obtain a coarse estimate of the carbon sink in above-ground tree biomass, one could assume that one cubic meter of roundwood under bark can be assigned a carbon content of 1.2 tCO_2. This is based on a carbon content of 0.22 tC/m^3 (IPCC, 2006b), a bark content of 12 %, and a biomass expansion factor of 1.3 for roundwood over bark (Penman et al., 2003). By scaling this up, a decline in roundwood harvesting globally by 39.6 Mm^3 (u.b.) from the Base scenario to the LULUCF-BD scenario during 2030–2035 would result in CO_2 savings of approximately 47.5 Mt CO_2/a. The figure does not account for variations in species, age, or growth conditions. If that is used as an estimate for forest carbon saved from harvests owing to the LULUCF policy globally and considering the lost climate benefits due to the decreased consumption of HWPs (circa 25.8 Mt CO_2/a), the average climate benefit obtained in LULUCF-BD vs. Base is then 21.7 Mt CO_2/a during 2030–2035.

To address the magnitude of the cost for EU countries to achieve the LULUCF goal for forests in EU+N, the projected global net decrease in CO_2 in the atmosphere can be evaluated against the economic loss due to the shrinking forest sector in the EU. EU+N was projected to harvest a total of 113.2 Mm^3 /a less during 2030–2035 if LULUCF sink targets were imposed in the scenario LULUCF-BD, compared with the market-driven scenario Base. In addition, adverse effects were projected for the EU's forest industry. The decline in economic activities in the EU forest sector also leads to negative economic impacts on sectors that provide products and services to the forest sector, which both decrease the income of citizens, income that could be reinvested in the economy.

Applying the average export unit value of 122 €/m^3 of roundwood trade globally in 2022–2023 from FAOSTAT (2024) to the EU+N harvest reduction of 113.2 Mm^3 /a and considering the saved GHG emissions of 21.7 Mt CO_2/a, the cost of saving 1 t of CO_2 is 634 €. Using the average import unit value (137 €/m^3), removing one tonne of CO_2 costs 713 €/t. However, these figures ignore the impacts of the policy on forest industries and the spillover effects on the rest of the economy. These multiplicative effects may be significant. Li et al. (2022) suggest that forestry and logging have multiplicative effects of the order of 1.55–1.85. Using these figures provides a cost range of 983–1320 €/t CO_2. These costs do not account for the real price increases of roundwood and forest industry products projected in the scenarios, as they were calculated from past global wood prices reported by FAOSTAT.

One might argue that the above estimate for forest carbon sink savings of 47.5 Mt CO_2/a is too low because it does not fully reflect the dynamics of carbon sinks, as trees left standing continue to absorb carbon and contribute to soil carbon accumulation. A meta-analysis by Soimakallio et al. (2022) found that each tonne of additional wood carbon removed from temperate or boreal forests through roundwood harvests results in a median reduction of 1.33 tonnes in forest carbon stock over 0–30 years, with a mean reduction of 1.02 tonnes across studies. This corresponds to an annual sink decrease of less than 2 % per additional tonne of carbon harvested. If we increase the previously assumed annual forest sink savings by 5 % — bringing them to about 50 Mt CO_2/a — the revised carbon savings (24.1 Mt CO_2/a) yield a carbon price range of 887–1191 €/t CO_2-eq.

Even if we ignored the changes in substitution and sink effects related to the decreased use of HWPs, given the above coarse estimate for the global forest sink saving being of the right order of magnitude, the cost of GHG emission savings resulting from EU+N countries meeting their LULUCF target for 2030 is many times higher than the market carbon prices of the EU Emissions Trading System. It also exceeds the estimates of the Social Cost of Carbon (Tol, 2023; Rode et al., 2021). There are more economical means of cutting emissions, such as decreasing the use of fossil fuels, afforestation, and carbon capture and storage (International Institute for Sustainable Development, 2025).

Our baseline projection for EU harvests up to 2035 is in line with other comparable simulations, e.g., those of Schier et al. (2022) and di Fulvio et al. (2025). Nevertheless, any future projections are subject to substantial uncertainties related, for example, to overall economic growth, changes in forest product demand patterns, and policies affecting international trade. Baseline harvest levels could therefore be lower than those presented in this study; for example, if sanctions on Russia were lifted and the EU imported roundwood and forest products from that region. Regardless of the baseline level, reductions in harvests within a region in response to a policy measure lead to harvest and potentially carbon leakage. Such leakage occurs because the market demand for wood products cannot always be met by shifting to non-wood substitutes at prices that consumers are willing to pay for. Furthermore, finding good substitutes is not always possible (consider, e.g., sanitary papers). The demand for forest products is typically inelastic with respect to price (Rougieux and Damette, 2018; Buongiorno, 2015).

However, a decline in the supply of some HWPs may result in fewer leakages and spillover effects. One example is the use of fuelwood. Fuelwood harvests in the EU27 increased by 45 Mm^3 from 2000 to 2023 (FAOSTAT, 2025). While reducing these harvests in EU+N could be partly offset by wood imports, the resulting price increase should encourage consumers to seek alternative heating sources. While this measure is likely unpopular among citizens facing higher heating costs, governments could step in with subsidies. Currently, treating emissions from wood biomass combustion as carbon neutral also incentivizes their use in the energy sector, while the emissions are calculated in another sector, LULUCF. This is one of the gaps in the EU's climate policy formation highlighted by Ellison et al. (2011), (2014) that remain in the LULUCF regulation. Another weakness is that only HWPs produced domestically from domestic roundwood are accounted for in the HWP stocks in climate accounting, whereas HWPs produced from the country's roundwood exports to other countries are not included.

On a broader scale, reducing household fuelwood use globally would be a more cost-effective climate strategy than enhancing forest carbon sinks by limiting harvests from forests that are managed for economic purposes. In this study, we kept the fuelwood harvest and demand constant. We also did not account for the use of harvest residues and the impact of their reduced supply owing to lower roundwood harvests. For example, in Sweden and Finland, the supply of harvest residues commonly used for energy could decline. Further research is required to explore these aspects.

It should be noted that harvest leakage is not equivalent to carbon leakage (Daigneault et al., 2025). Schulte et al. (2025), based on simulations with the GLOBIOM model, suggest that for a geographical distribution consistent with our study, harvest leakage induced by EU environmental policy was accompanied by a carbon leakage rate that exceeded the harvest leakage rate. This issue was not addressed in the present study.

Another key consideration is the impact of harvest leakage on biodiversity outside the EU. When reductions in harvesting within the EU lead to increased harvesting elsewhere, the RoW biodiversity may be negatively affected. Fischer et al. (2023) and Kallio and Rannestad (2025) suggest that EUBDS alone could increase the risk of biodiversity loss in RoW. The scale of harvest leakage required to meet the LULUCF targets would be much larger, potentially causing greater harm to biodiversity in RoW than the benefits gained by EUBDS within the EU. The tight timeline for meeting LULUCF targets would not allow sufficient time to establish new plantations in RoW to compensate for reduced harvests in EU+N. For sawlogs, the first harvest from plantations established today would take longer to materialize than that considered in this study. Therefore, the potential increase in harvest is likely to come from natural forests in RoW.

The amended LULUCF regulation (European Parliament and the Council, 2023) sets more ambitious carbon sink targets than its predecessor. This comes at a time when only a few countries in EU+N are expected to meet their FRLs for the first compliance period of 2021–2025 (e.g., Korosuo et al., 2023). Additionally, forest growth has slowed in several countries with significant amounts of productive forest areas (Laudon et al., 2024, Gribbe et al., 2024, Le Monde, 2023), and reliance on domestic wood and subsequent harvest levels have risen following the cessation of trade with Russia and Belarus. MSs have very little control over forest carbon sinks because there is no legislation in place for constraining harvests, and such legislation might be problematic to arrange. Importantly, MSs do not affect the weather conditions that influence forest growth and biomass decay. Another issue we did not consider is that the implementation of the EUBDS alongside LULUCF sink goals should further increase the harvest reductions needed to achieve the potential target carbon sinks in the future when CO_2 sequestration rates decline in maturing protected forests (Petersson et al., 2022; Räty et al., 2024).

Continuous changes in countries' LULUCF accounting methods, along with annual fluctuations in emissions due to uncontrollable factors such as weather or insect outbreaks, pose challenges and create uncertainty for policy evaluations such as this study. Comparing countries' 2022 GHG inventory submissions with those of 2021, the gap to the target appears to have increased in some countries due to the revision of past numbers (e.g., Finland and Germany). Changes in the positive direction have occurred, for instance, in Czechia and Poland. In Poland, the forest sink was temporarily low during 2019–2021, when the country's forests were affected by drought and bark beetle attacks (Knutzen et al., 2025). The sink recovered in 2022, increasing by 12.5 Mt CO_2 compared with 2021, despite a harvest increase of 2.5 Mm^3 (FAO, 2024). In this light, the harvest reductions in Poland assumed to be necessary for attaining the LULUCF target in the scenarios above may have been exaggerated in this study. If similarly rapid sink recovery occurs in other countries affected by recent droughts or insect outbreaks, the same consideration may apply to them as well. In addition, positive changes in forest cover in some countries may help reduce the gap to the sink target in the coming years. When assessing how a smaller change in EU harvest levels between the baseline and LULUCF scenario—resulting from a lower baseline projection and/or higher harvest allowances under the LULUCF regime than those assumed in this study—might affect our results, it is important to note that the climate benefits in the EU from moving from the baseline to the LULUCF scenario would also be reduced. Simultaneously, the harvest leakage rate is unlikely to decline, as smaller volumes should be easier to offset by shifting harvests to other locations than larger volumes.

5. Conclusions

As expected, based on previous studies, reducing roundwood harvests in the European Union and Norway (EU+N) to meet the LULUCF sink target for 2026–2030 is projected to cause significant harvest leakage. Our results suggest that approximately two-thirds of the harvest reduction in EU+N would be offset by increased harvesting in the rest of the world (RoW). The leakage percentage is lower than in earlier studies, likely due to new trade restrictions between Russia and the EU and the larger absolute harvest reductions required under the revised LULUCF policy. North America, Brazil, Russia, Indonesia, and Chile are projected to gain the largest shares of increased harvests. This leakage would result in a substantial transfer of income from EU+N to RoW while delivering modest climate benefits. The implementation of the EUBDS alongside LULUCF policies is projected to have a relatively small additional effect at the EU or global level.

Compared with the market-driven baseline scenario, the LULUCF policy decreases harvest levels globally despite the increase in harvests in RoW. Thus, it is likely to increase forest carbon sinks. This benefit would be partially offset by the reduced climate benefits from harvested wood products. Therefore, the net climate gain might be limited and come at a high cost to the EU. Given the economic burden on EU citizens, including reduced economic activity and significant income transfers abroad, the cost per tonne of emissions saved is suggested to be many times higher than the prices observed in the EU Emissions Trading System. Our results suggest that the LULUCF policy, in its current form, is not a cost-effective mitigation measure compared with other available options.

EU+N countries have little control over harvest levels beyond state-owned forests and cannot influence forest growth or weather, both of which shape forest carbon fluxes. Consequently, their ability to meet LULUCF targets is very limited, leaving them to bear the costs of non-compliance with a policy that, based on our findings, seems to offer only limited climate effectiveness relative to its expense.

CRediT authorship contribution statement

A. Maarit I. Kallio: Writing – review & editing, Writing – original draft, Visualization, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Elias Garvik:** Writing – review &

editing, Writing – original draft, Formal analysis, Data curation.

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Declaration of Competing Interest

The authors have no conflicts of interest to declare.

Appendix 1

Assumptions on harvests levels consistent with the EU LULUCF target for 2026–2030

The EU aims to achieve a carbon sink of −310 Mt CO_2 in the LULUCF sector by 2030 (European Parliament and the Council, 2023). This target is allocated among member states (MS) based on their share of the EU's managed land. To assess the potential impacts on the forest sector if this goal is met, we had to make assumptions about how the sink target is distributed between managed forest land and other land uses, as well as which levels of harvest would be compatible with achieving the resulting forest carbon sink target.

Assumptions on allocating to LULUCF target to the forest sink

At the EU level, LULUCF emissions from subsectors other than managed forest land decreased by approximately 5 % per year during 2010–2021, though these reductions varied significantly from year to year and among MS. The declining trend in these emissions plateaued between 2018 and 2021. For future projections, we assume that all MS will work to reduce emissions from non-forest land subsectors, achieving a 10 % improvement from the average levels reported for 2019–2021. The remaining emission reduction target is assigned to managed forests. Based on these assumptions and goals for MS outlined in Regulation (EU) 2023/839 (European Parliament and the Council, 2023), we derived the target values for non-forest subsectors and managed forest land, as presented in Table A.1

Table A.1
Emissions from Fresethe LULUCF sector in the EU Member States (MS) and Norway, based on countries' GHG Inventory Submissions in 2023; the division of the EU's target across MS by the European Parliament and the Council (2023); and the assumed allocation of this target between managed forest land and the rest of the LULUCF sector

Country	Reported carbon emissions. (Negative values refer to carbon sink)			Countries' LULUCF target	Assumed allocation of the target	
	Total 2019–2021	Forest land 2019–2021	Other than Forest land 2019–2021	Total 2030	Other than Forest land 2030	Forest land 2030
	Mt CO_2	Mt CO_2	Mt CO_2	Mt CO_2	Mt CO_2	Mt CO_2
Austria	-4.6	-5.2	0.6	-5.7	0.5	-6.1
Belgium	-0.5	-2.0	1.5	-1.4	1.3	-2.7
Bulgaria	-9.6	-8.3	-1.3	-9.7	-1.4	-8.3
Croatia	-5.9	-5.8	-0.1	-5.5	-0.1	-5.4
Cyprus	-0.3	-0.2	-0.1	-0.4	-0.1	-0.2
Czechia	9.1	11.7	-2.6	-1.2	-2.8	1.6
Denmark	2.5	-2.6	5.1	5.3	4.6	0.8
Estonia	1.8	0.6	1.3	-2.5	1.1	-3.7
Finland	-7.8	-17.3	9.6	-17.8	8.6	-26.4
France	-21.2	-30.2	9.0	-34.0	8.1	-42.1
Germany	-7.3	-43.5	36.3	-30.8	32.7	-63.5
Greece	-5.5	-2.3	-3.2	-4.4	-3.6	-0.8
Hungary	-6.6	-6.1	-0.5	-5.7	-0.5	-5.2
Ireland	6.0	-1.8	7.8	3.7	7.0	-3.3
Italy	-34.9	-31.3	-3.6	-35.8	-4.0	-31.7
Latvia	-1.1	-3.6	2.5	-0.6	2.3	-2.9
Lithuania	-6.3	-6.8	0.5	-4.6	0.4	-5.1
Luxembourg	-0.5	-0.5	0.0	-0.4	0.0	-0.4
Malta	0.0	0.0	0.0	0.0	0.0	0.0
Netherlands	3.9	-2.2	6.1	4.5	5.5	-0.9
Poland	-20.9	-21.6	0.7	-38.1	0.6	-38.7

(*continued on next page*)

Table A.1 (*continued*)

Country	Reported carbon emissions. (Negative values refer to carbon sink)			Countries' LULUCF target	Assumed allocation of the target	
	Total 2019–2021	Forest land 2019–2021	Other than Forest land 2019–2021	Total 2030	Other than Forest land 2030	Forest land 2030
	Mt CO_2	Mt CO_2	Mt CO_2	Mt CO_2	Mt CO_2	Mt CO_2
Portugal	-5.8	-1.2	-4.6	-1.4	-5.1	3.7
Romania	-49.4	-29.6	-19.8	-25.7	-22.0	-3.7
The Slovak Republic	-7.0	-5.6	-1.5	-6.8	-1.6	-5.2
Slovenia	-3.2	-3.0	-0.2	-0.1	-0.3	0.1
Spain	-45.0	-40.3	-4.7	-43.6	-5.2	-38.4
Sweden	-42.0	-37.7	-4.3	-47.3	-4.8	-42.5
EU	-262.2	-296.5	34.4	-310.0	21.1	-331.1
Norway *	-17.1	-21.4	4.3	-14.9	3.9	-18.8

*) Norway is technically not bound by the updated LULUCF-regulation. It's country-goal is calculated using NIR2020 managed land data.

Assumptions on deriving harvest levels compatible with the forest sink target

Column J in Table A.2 presents the harvest levels that we assumed to be compatible with the target sink, whereas columns A–I shows some of the data on calculations used to derive them.

The forest sink target was converted to compatible maximum harvest levels using two main approaches. First, if the forest sink in recent years was close to the assumed 2030 target sink and harvest levels remained relatively stable and consistent with that sink value, we simply selected that harvest level as the representative value for the sink target. Columns G and F in Table A.2 present the harvest levels and the year (or the average of two consecutive years) when the sink was close to the assumed forest sink target value. The italicized values in column G highlight instances where the harvest levels thus obtained clearly contradict recent sink and harvest level pairs, or where the time the assumed target sink was last obtained was considered too distant to be relevant.

More often, we needed to carry out alternative calculations. To derive suggestions for target sink-compatible harvest levels reported in columns H and I, we assumed that harvesting one cubic meter of roundwood (o.b.) removes 1.2 tCO_2 from forests. This estimate is based on a carbon factor of 0.225 tC/m^3 for roundwood in temperate species (IPCC, 2006b), a factor of 44/12 to convert carbon to CO_2, a bark content assumption of 12 % for roundwood, and a biomass expansion factor (BEF) of 1.3 (Penman et al., 2003). For Finland and Sweden, a BEF of 1.35 was used because of the dominance of coniferous species (Penman et al., 2003). We added the calculated harvested carbon based on columns C or E to the reported sink in columns B or D, respectively, to estimate the sink potential before harvests. Then we evaluated the harvest level that could have achieved the target sink, respectively. While this method provided results that appeared plausible for many countries, deriving consistent values proved challenging for certain countries, such as the Czechia, Germany, or Poland, due to significant forest losses caused by storms, droughts, and bark beetle infestations in recent years (Knutzen et al., 2025).

It should be noted that our estimates are based on GHG accounts up to 2021, which were available at the time of the study. Changes in accounting methods, as well as uncontrollable factors—such as weather, storms, insect outbreaks, and subsequent forest recovery—may alter the outlook for the countries.

Table A.2
Assumed goal for the forest carbon sink in 2030; carbon sinks and harvest levels in 2021 and as an average for 2019–2021; and results from alternative calculations used to derive the harvest levels (column J) corresponding to the forest sink goal outlined in Table A.1. Forest carbon sinks are based on national reporting to UNFCCC (2023), while harvest levels are from FAOSTAT (2024). BEF denotes the biomass expansion factor. See text for further information

Country	Forest Sink Goal 2030	Forest sink or source 2019–2021	Harvest 2019–2021	Forest sink or source 2021	Harvest 2021	Year(s) with sink close to target, 2000–2021	Harvest when sink close to targe (in column F)	Harvest based on 2019–2021 data and BEFs 2030	Harvest based on 2021 data and BEFs 2030	Chosen value for max harvest 2030
	$MtCO_2$	$MtCO_2$	Mm^3	$MtCO_2$	Mm^3	Year	Mm^3	Mm^3	Mm^3	Mm^3
	A	B	C	D	E	F	G	H	I	J
Austria	-6.1	-5.2	18	-10.4	18.4	2019–2021	18	17.2	21.9	18
Belgium	-2.7	-2.0	5.2	-2	5.2	*never*		4.6	4.6	4.6
Bulgaria	-8.3	-8.3	5.7	-8.4	5.5	2019–2021	5.7	5.7	5.6	5.7
Croatia	-5.4	-5.8	5.2	-5.8	5	2018	5.4	5.5	5.3	5.4
Czechia	1.6	11.7	32.1	11	30.3	2017–18	22.5	23.7	22.5	22.5
Denmark	0.8	-2.6	3.8	-3	3.8	never		6.6	7.0	6.6
Estonia	-3.7	0.6	10.8	1.1	10.1	*2013*	*7.2*	7.3	6.1	6.1
Finland	-26.4	-17.3	63.5	-10.8	66.7	2015–16	56.3	56.3	54.2	55.2
France	-42.1	-30.2	50.1	-28.5	53.1	2016–17	40.1	40.1	41.8	40.9
Germany	-63.5	-43.5	79.6	-41.9	82.2	*2013*	*62.9*	63.0	64.2	64.2
Greece	-0.8	-2.3	1.4	-2.4	1.4	never		2.7	2.7	2.7
Hungary	-5.2	-6.1	5.5	-6.7	6	*2014–15*	*6.3*	6.3	7.2	7.2
Ireland	-3.3	-1.8	3.9	-1.2	3.9	*2011*	*2.7*	2.7	2.1	2.6
Italy	-31.7	-31.3	16.7	-28.4	15.8	2020	15.8	16.3	13.0	14.7
Latvia	-2.9	-3.6	15.4	-1.6	15.9	*2015*	*16*	16.0	14.8	14.8
Lithuania	-5.1	-6.8	6.6	-6.5	6.6	*2006–05*	8	8.1	7.8	7.8

(*continued on next page*)

Table A.2 (*continued*)

Country	Forest Sink Goal 2030	Forest sink or source 2019–2021	Harvest 2019–2021	Forest sink or source 2021	Harvest 2021	Year(s) with sink close to target, 2000–2021	Harvest when sink close to targe (in column F)	Harvest based on 2019–2021 data and BEFs 2030	Harvest based on 2021 data and BEFs 2030	Chosen value for max harvest 2030
Luxembourg	-0.4	-0.5	0.3	-0.6	0.3	2017	0.4	0.4	0.4	0.4
Netherlands	-0.9	-2.2	3	-2.1	3	Never		4.0	4.0	4
Poland	-38.7	-21.6	42.3	-22.2	43.1	2018	28.1	28.0	29.3	28.7
Portugal	3.7	-1.2	13.6	-2.5	14.5	Never		17.7	19.7	18.7
Romania	-3.7	-29.6	17.2	-29.1	17.8	Never		38.8	39.0	38.9
The Slovak Republic	-5.2	-5.6	8	-6.3	7.7	2019–20	8.2	8.3	8.6	8.5
Slovenia	0.1	-3.0	4.1	-2.9	3.7	*2014*	*5.1*	6.7	6.2	6.4
Spain	-38.4	-40.3	16.9	-40	17.8	2021	17.8	18.5	19.1	18.8
Sweden	-42.5	-37.7	75.3	-37.6	77.3	2016	74.8	71.4	73.4	72.4
EU	-330.9	-296.4	504.2	-288.8	515.1		409.2	475.9	480.7	475.7
Norway	-18.8	-21.4	12.5	-20.4	13.2	2020	12.1	14.6	14.4	14.5

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.envsci.2026.104332.

Data availability

Data will be made available from the authors upon reasonable request. However, the forest sector model includes some proprietary data on forest companies purchased from RISI, which cannot be shared.

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