

Costs of Meeting the EU's LULUCF Target through Restricting Roundwood Harvests

Maarit KALLIO^{1*}

¹*Norwegian University of Life Sciences, Faculty of Environmental Sciences and Natural Resource Management, PO Box 5003, N-1432 Ås, Norway*

Received 13.04.2026; accepted 29.07.2026

Abstract – The European Union (EU) has a target for greenhouse gas emissions and removals from land use, land-use change, and forestry in 2030. Within the time frame to 2030, reducing roundwood harvests in managed forests appears to be the only measure capable of substantially increasing forest carbon sinks. The resulting reduction in global net emissions would be considerably smaller than the increase in the EU forest sink because lower harvest levels in the EU are partly offset by increased production elsewhere, and the climate benefits associated with harvested wood products decline. This study assesses the economic costs faced by the EU and its Member States if the latter restrict harvests to meet their targets. Two alternative background settings for policy implementation are considered: one with market-driven harvests and the other with stagnating EU harvests. Under the assumptions made, a comparison of the economic value generated by the forest sector with and without harvest constraints suggests that France, Germany, Finland, Poland, and Sweden would face the highest costs, amounting to several billion euros over the period of 2026–2035. A few EU countries would gain modestly. Outside the EU, the United States, Canada, Brazil, and Russia are the largest economic beneficiaries. The estimated costs vary across Member States, while at the EU level, they are € 1000 per tCO₂ or more during 2030–2035 when accounting for the direct and indirect effects related to forest sector production. In addition, there would be induced effects on the rest of the economy.

Keywords – Climate Policy; forest sector; forest carbon sink; harvested wood products.

1. INTRODUCTION

The regulation of greenhouse gas (GHG) emissions and removals from land use, land use change, and forestry (LULUCF) supports the EU's 2030 climate targets [1]. The target carbon sink for this sector is –310 Mt CO₂ by 2030. During 2026–2030, EU member states (MS) must contribute according to their share of the EU's managed land area. Managed forests are central to achieving this target. Most MS do not seem to meet their 2021–2025 forest carbon sink reference levels, and given the current trends, the stricter 2030 target appears difficult to achieve [2], [3].

Increasing forest sinks is sometimes referred to as a low-cost option for climate change mitigation [4]. However, within the time frame of the LULUCF policy, the reduction of roundwood harvests in managed forests is practically the only means of achieving a considerable increase in forest sinks. However, many studies have shown that harvest

* Corresponding author.
E-mail address: maarit.kallio@nmbu.no

Maarit KALLIO  <https://orcid.org/0000-0002-5393-761X>

restrictions are inefficient in reducing GHG emissions. Reduced harvests in the EU would be partly offset by higher production elsewhere [5]–[8]. This harvest leakage would decrease the carbon sinks outside the EU [3], [8]. In addition, the global consumption of harvested wood products (HWPs) is expected to decline because of the increasing prices of wood products caused by roundwood supply reduction [5]–[8]. This would slow the growth of carbon stored in HWPs compared to development without policy intervention. If the EU met its LULUCF targets, the carbon pools in sawn wood and mechanical forest products would increase less. Some wood-biomass-based products might also be replaced by more GHG-intensive materials and fuels, which would increase emissions in the energy sector. The shrinking climate benefits associated with HWPs and the decrease in forest sinks in the rest of the world (RoW) would partly offset the climate benefits achieved by increasing EU forest sinks [3], [8]. These factors would weaken the effectiveness of the policy and raise its costs. For climate, it is the change in global GHG emissions that matters, not what individual countries report in their climate accounts.

An indicative calculation in [3] suggests that achieving net emission reductions through harvest restrictions could be very costly for EU citizens paying for the policy. This challenges the view that forest carbon sinks are low-cost mitigation options. Surprisingly, few studies have assessed these economic costs. Schulte *et al.* [8] find global GHG savings from EU environmental policies, but they do not examine the policy costs for EU MS.

This study aims to assess the costs to the EU and its MS if the EU's LULUCF sink target is achieved by reducing the harvests in the MS. The costs will be assessed in absolute terms and per tonne of atmospheric emissions in CO₂-eq, reduced globally. The study extends the analysis in [3], which provided a preliminary and indicative cost analysis, by improving the methodology used in the cost assessment by accounting for country- and product-specific factors and considering mitigation costs at the member state level. The projections for forest sector production in the baseline scenario presented in [9] and [3], compared with the policy scenario in [3], provide a background setting for the analysis. For the sensitivity analysis, an alternative background setting in which EU harvests stagnate in the base scenario is introduced.

2. MATERIAL AND METHODS

2.1. Scenarios on Global Forest Sector Production with and without Policy

The comparison of global forest industry production and roundwood harvests in scenarios with and without harvest reductions, which are assumed to be needed to meet the EU carbon sink target, forms the basis for evaluating policy costs to the EU MS. Two background settings for policy implementation were considered. In the base scenario, BASE, EU harvests are driven by developments in the global forest product markets, as projected in [9] and [3]. While this scenario is consistent with projections in other modelling and forecasting studies (e.g., [6], [7]) the growing harvest prognoses may face criticism due to environmental sustainability concerns. In addition, it is of interest to see if the projected harvest increases in the EU affect policy costs. Therefore, an alternative baseline, BASEstagna, was provided for the sensitivity analysis. Global forest sector development is also market-driven in BASEstagna, but the EU MS are not permitted to harvest more than their 2021–2022 average levels [10].

In the policy scenario LULUCF, MS are required to meet their assumed forest sink targets as defined in [3] (see column J of Table A.2, p.10–11, in [3]), except for Poland. Poland's forests have recovered fast, and the forest sinks have increased considerably from those reported in the period used as benchmark in [3]. In the policy case, the allowable roundwood

harvest in Poland was set at 42.5 Mm³, equivalent to the 2024 harvest levels. The forest sink has declined from that reported in the LULUCF accounting data used in [3] e.g., in Austria, Czechia, Finland, France, and Germany. These countries have drifted further apart from their sink goals despite a decline in roundwood harvests. Some revisions in the emission figures were due to methodological changes. To be conservative regarding the assumed harvest restrictions, they were not tightened from those in [3]. A similar forest growth recovery to that in Poland could occur also in other countries. The 2030 harvest constraints were applied until 2035.

The BASE and LULUCF scenarios are presented, in [9] p. 5–6 and [3] p. 2–3, respectively. Forest sector developments in these scenarios, and in the additional scenario BASEstagna, where EU harvests were tied to 2021–2022, were produced with the global forest sector model FORMEQ [11]–[12]. Scenario developments in BASE and LULUCF follow closely those in [3], even when the GDP growth figures were updated with newer figures from the IMF [13], with the Polish harvests in the LULUCF scenario making an exception. Despite some duplication, scenario developments are briefly discussed in Section 3 to provide background for the main aim of this study: policy cost calculations.

2.2. Evaluating the Net Change in Global Greenhouse Gas Emissions

For cost calculations, it is necessary to evaluate how much GHG savings are attained by shifting from baseline development to a LULUCF policy scenario where EU MSs constrain their harvests. The net change in emissions between these scenarios includes the difference between forest sinks due to changes in harvests and the difference in HWP carbon stocks and substitution benefits owing to changes in HWP consumption. The assumptions made for their calculation follow [3]. Because of their importance for the analysis, they are presented below.

2.2.1. HWP sinks based on the development of apparent consumption in the scenarios

HWP sinks were estimated following the Tier 2 approach for UNFCCC carbon accounting [14], using same assumptions on decay rates (k), product lifetimes, and carbon contents (c_f), see Table 2 in [3]. Hence, carbon stocks in HWP pools were modelled with a first-order decay function, where decay constant is defined as $k = \ln(2)/HL$, and HL represents the half-life of the product in years. Unlike in [14], carbon stocks at the beginning of each year t , $C(t)$, were calculated based on apparent domestic consumptions, $Q(t)$, instead of production levels. The stock in a given HWP carbon pool in year $t+1$ is estimated as

$$C(t+1) = e^{-k}C(t) + \frac{1-e^{-k}}{k}c_fQ(t). \quad (1)$$

An increase in carbon stock represents a carbon sink, while a decrease indicates a source. Calculations started from 1961, or from the earliest year for which apparent consumption could be derived [10]. Carbon stock changes were converted to CO₂ using the factor 1 t C = 12/44 t CO₂. For more thorough explanation of functions used in Tier 2 method, see [15].

2.2.2. Production stage substitution benefits from using HWP

Substitution benefits from HWPs, often referred to as avoided emissions, occur when wood-based products replace alternative materials providing the same function, but with higher GHG footprint [16]. The emission savings achieved through this material substitution are expressed as carbon displacement factors. To compare substitution impacts across scenarios, representative values reported in the literature are applied and transformed into unit measuring fossil GHG savings per unit of wood product consumed. Table 3 in [3] displays the coefficients used. For the

purposes of the climate impact analyses of LULUCF policy, it is meaningful to calculate the change in substitution benefits owing to a change (typically decline) in HWP consumption owing to the harvest constraints in the LULUCF scenario. It was assumed that 95 % of the volume of HWPs consumed in a baseline scenario but not in the LULUCF scenario would be replaced by other materials.

2.2.3. End-of-life stage substitution benefits from using HWPs

A share of the carbon in HWPs leaving the stock (Eq. 1) was assumed to be used for bioenergy and to provide savings in fossil GHG emissions. These savings were quantified based on country-specific emission factors of energy production. One tonne of carbon in wood biomass was considered to correspond to 0.764 tonnes of oil equivalent of primary energy. Energy-sector emission factors taken from [3] are based on the EDGAR data [17] and adjusted in line with countries' Nationally Determined Contributions under the UNFCCC [18]. Despite positive developments in climate change mitigation in China and India, coal is expected to remain a dominant energy source in these countries until 2035 [19]. For these, the carbon intensity of coal was applied.

No data on current energy recovery rates of HWP waste are available world-wide. Also, the focus should be on plausible future recovery levels which should reflect the assumption of increasing global efforts to reduce fossil emissions. Like in [3], it was assumed that 85% of otherwise landfilled HWP waste in the EU and 70 % in RoW would be utilized for energy.

2.2.4. Changes in carbon sinks of forests

Cost analysis requires information on the differences in global forest carbon sinks across scenarios rather than on absolute sink levels. These were calculated based on the differences in global roundwood harvest volumes across the scenarios. Using a carbon content of 0.22 tC/m³ [20], 12 % bark content, a biomass expansion factor of 1.3 for roundwood over bark [21], and the conversion factor 44/12 from carbon to CO₂, one cubic meter of roundwood under bark (u.b.) harvested corresponds to approximately 1.2 tCO₂. This figure illustrates the change in carbon stored in the aboveground biomass under the assumption that all biomass associated with harvested trees is subject to immediate oxidation. It does not account for the possible deadwood that may be removed from the forest during harvesting or left on-site to support biodiversity. Belowground carbon was not considered because of the lack of data and substantial uncertainty associated with it. Stump and root system is not oxidized immediately but its decay occurs over an extended period.

Schulte *et al.* [8] assess that policy-induced cuts in EU roundwood harvests lead to carbon leakage to RoW that is 27 % greater than the respective harvest leakage rate. Their leakage patterns, primarily toward North America, and to a lesser extent Asia and South America, resemble those in this study. This would support the assumption that harvest shifts from the EU to RoW do not yield loss in the forest sink that would be lower than if these harvests would continue to be carried out in the EU. When considering the CO₂ coefficient applied to harvest change in this study (1.2 tCO₂/m³ u.b.), it must also be noted non-harvested trees continue growing and sequestering carbon. Meta-analysis [22] suggests that an additional tonne of wood carbon harvested from temperate or boreal forests causes a median reduction of 1.33 t and mean reduction of 1.02 t in forest carbon stock over 0–30 years. Such effect would apply not only in the EU but also in RoW with increasing harvests. The figures appear logical considering the relationship between the biomass growth in mature forests and the rents used to guide harvest decisions, e.g., in Nordic countries. The effects discussed in [8] and [22] were not accounted in the sink calculation in this study. Based on their magnitudes, the carbon leakage higher than the harvest

leakage [8] should decrease the calculated global carbon savings more than the positive additional sink growth effect of reduced roundwood harvests in the EU [22] would increase it.

2.3. Evaluating the Changes Caused by Harvest Restrictions in Economic Income in EU MS

To calculate proxies for the changes caused by the LULUCF harvest constraints in the production value of forestry and logging activities in MSs, the changes in the harvests of coniferous and non-coniferous roundwood were multiplied by their nominal weighted average unit export and import values in MSs in 2023–2024, calculated based on [10]. So derived output value includes direct and indirect economic effects [23]. For comparison, dividing Eurostat data [24] on “Output in the forestry and closely related activities” in 2023 (latest available) by harvest volumes in 2023 [10] would have given, on average, 1.75 times higher value generation per harvested cubic meter than that used in this study. Hence, the proxies used for output value in forestry do not seem to exaggerate the output value changes generally.

The change in the value of forest industry production in a MS was quantified by multiplying the production changes with the respective average unit trade values of forest industry products [10]. The change in the value of the projected consumption of domestic or imported roundwood and pulp was deducted from that value to avoid double counting domestic inputs and to exclude the value of imported wood and pulp. Like the EU forestry, the forest industries largely rely on the inputs that are produced domestically or within the EU [25]. The EU also hosts important producers of chemical used in pulp and paper manufacturing and suppliers of machinery to forestry and forest industries.

In addition to the output value including direct and indirect effects (own value added, and purchases of inputs from other sectors), the forest sector contributes to the national economy through induced effects. These arise, for instance, as employees of the industry and of the industries supplying it spend their income on domestic (or EU area) products and services [23]. Such effects were based on estimates in [26]. Dividing the sector’s SAM multiplier by its indirect effect multiplier produces a multiplier that can be applied to the output value. When not identical, these multipliers become almost the same for woodworking industries as for pulp and paper industries. The lower of the two was used to calculate an induced effect multiplier for forest industry output. The average value across the MS became 1.14 for forestry and 1.29 for the forest industry. The data remained missing for Bulgaria, Czechia, Hungary, and Luxembourg. For them, low figures from other MS with low value were applied: 1.07 to forestry (as in Austria) and 1.12 for industries (as in Slovakia). For comparison, the total effects (direct + indirect + induced) per harvested cubic meter in forestry derived by applying this method to 2019 data were compared to figure obtained dividing the total effects in [27] by roundwood harvests for a sample of countries. For some countries (Finland, Spain), the method in this study provided lower values than [27]. For some countries (France, Germany, Sweden) somewhat higher values were obtained. This comparison is indicative only, as roundwood harvests contain also fuelwood with lower price and output value. In some countries (e.g., France), this share may be large. In this study, the fuelwood harvests were kept constant in the scenarios. Hence, the changes in output value happen solely in industrial roundwood harvests, which have more economic importance. While there are uncertainties related to the method used to calculate proxies for economic effects in this study, it might be expected that they do not lead to serious overestimation of the economic costs.

3. RESULTS

3.1. Policy Costs under the Background Setting of Market-Driven EU Harvests

In the BASE scenario, the EU (EU27) roundwood harvests are projected to reach 542 Mm³

(u.b.) in 2030 and increase to 562 Mm³ (u.b.) by 2035. This increase is slightly lower than that projected in other studies [6], [7]. The growth is mainly driven by the globally increasing demand for sawn wood, panel products, and chemical pulp. Globally, the baseline roundwood harvests are projected to be around 4300 Mm³ in 2030, and 4 400 Mm³ in 2035. In the LULUCF scenario, EU27 harvests reach 453 Mm³ (u.b.) by 2035. During 2030–2035, the average decline in roundwood harvests in the LULUCF scenario vs. BASE is –97 Mm³ in the EU and –33 Mm³ in the whole world. Table 1 summarizes the average annual change in production in the EU forest sector owing to the LULUCF harvest constraints during 2030–2035.

TABLE 1. AVERAGE CHANGE IN ANNUAL FOREST SECTOR PRODUCTION IN EU27 AVERAGE OVER YEARS 2030–2035, LULUCF SCENARIO –BASE SCENARIO

Country	RwC	RwN	RwAll	S&Plyw	Panels	Pulp	P&Pb
	1000 m ³	1000 m ³	1000 m ³	1000 m ³	1000 m ³	1000 t	1000 t
Austria	–2340	–262	–2602	–20		–28	
Belgium	118	25	143		82	–144	5
Bulgaria	–1099	–660	–1760	–194	–11	–89	
Croatia	–121	–382	–503	–131	–18		
Czech Republic	1174	103	1276	–371		–106	
Denmark	87	23	109	22	–8		96
Estonia	–3545	–2391	–5937	–113	–22	–69	
Finland	–12 502	–3038	–15 540	–3117	–145	–84	
France	–10 364	–6730	–17 093	–2794	–3469	–776	–144
Germany	–15 761	–1673	–17 434	–6556	–1822		562
Greece	13	10	24	6			
Hungary	70	125	194	–171			116
Ireland	–1322	–7	–1329	–259	–360		
Italy	–363	–162	–525	–84	–29		54
Latvia	–1764	–1113	–2877	–957	–90		
Lithuania	–150	–101	–251	–166	–23		
Luxembourg	13	5	19	–18			
Netherlands	35	9	44	–34			–50
Poland	–13 136	–3194	–16 330	–394	–294	–1473	–6
Portugal	24	37	60	150			
Romania	467	291	759	–218	–130		45
Slovakia	–294	–437	–731	–91		3.76E–05	–52
Slovenia	232	99	331	–46			–5
Spain	–1932	–2122	–4054	–184	–10	–410	23
Sweden	–11 240	–1680	–12 919	–554	–15	–1347	–564
EU	–73 700	–23 225	–96 926	–16 294	–6364	–4526	80

Source: Projected by FORMEQ forest sector model. RwC = Roundwood, coniferous; RwN = Roundwood, non-coniferous; RwAll = Roundwood, all species; S&Plyw = sawn wood and plywood; Panels = includes rest of the mechanical forest industry products other than those in SwPlyw; Pulp = Chemical pulp, all grades (including dissolving pulp); P&Pb = Paper and paperboard: all grades.

Given the assumptions in Section 2.2, the global net harvest decline of 33 Mm³ owing to the harvest constraints in the EU provides a global forest sink increase of 39.1 Mt CO₂/a during 2030–2035. The harvest decline comes with a decline in forest product consumption which decreases HWP sinks. Under the assumptions in Section 2.2, the HWP sink decline is on average 9.2 Mt CO₂/a in 2030–2035. This is dominantly caused by the decreased global production and consumption of relatively long-lived sawn wood and panel products.

Some of the consumption that would take place in the BASE scenario potentially shifts to non-wood materials in the LULUCF scenario. Given the assumptions in Section 2.2, the increase in fossil CO₂ emissions owing to the production of non-wood substitutes for wood products is 11.6 Mt CO₂/a. Moreover, without the decline in forest product consumption in the LULUCF scenario, more HWPs could be incinerated at the end of their life, substituting 1.5 Mt CO₂/a of fossil emissions in 2030–2035. Summing the above biogenic (–29.9 Mt CO₂/a) and fossil (+13.1 Mt CO₂/a) GHG components yields an average removal of 16.8 Mt CO₂/a from the atmosphere in 2030–2035.

Table 2 summarizes the change in the value of output in the EU and the climate change mitigation costs based on assumptions in Section 2.3. Saving circa 17 Mt CO₂/a of biogenic and fossil GHGs globally due to LULUCF policy comes with a cost of approximately 1100 €/t CO₂ for the EU27 on average.

TABLE 2. AVERAGE CHANGE IN ECONOMIC CONTRIBUTION OF THE EU27 FOREST SECTOR, CONTRIBUTION TO THE GLOBAL LOSS OR GAIN OF GREENHOUSE GAS EMISSIONS, AND AVERAGE COST OF EMISSION SAVINGS PER UNIT, 2030–2035. LULUCF SCENARIO – BASE SCENARIO

Country	Forestry	Forest Industries	Forest sector, total	Induced effects	Total gain or loss	Share of harvest decline	Mitigation cost
	Mill. €/a	Mill. €/a	Mill. €/a	Mill. €/a	Mill. €/a	%	€/tCO ₂
Austria	–238	7	–231	–16	–247	2.6 %	566
Belgium	12	–53	–40	–11	–51		
Bulgaria	–292	–29	–321	–24	–345	1.8 %	1169
Croatia	–91	8	–83	–14	–97	0.5 %	1150
Czech Republic	143	–106	37	–3	34		
Denmark	15	48	62	23	85		
Estonia	–540	–66	–606	–88	–694	5.9 %	697
Finland	–1449	–1150	–2599	–477	–3076	15.6 %	1180
France	–1694	–1807	–3502	–1021	–4523	17.1 %	1578
Germany	–1707	–1061	–2768	–689	–3457	17.5 %	1182
Greece	5	–13	–7	–3	–10		
Hungary	20	–26	–6	–2	–8		
Ireland	–126	–192	–317	–43	–360	1.3 %	1615
Italy	–62	18	–44	–4	–48	0.5 %	545
Latvia	–271	–187	–457	–87	–544	2.9 %	1128
Lithuania	–22	–99	–122	–27	–149	0.3 %	3540
Luxembourg	1	–6	–5	–1	–6		
Netherlands	5	–100	–96	–25	–121		
Poland	–1591	–905	–2496	–440	–2936	16.3 %	1072

Portugal	6	-173	-167	-41	-208		
Romania	102	3	105	10	115		
Slovakia	-65	-54	-119	-13	-132	0.7 %	1077
Slovenia	39	-34	5	-6	-1		
Spain	-408	-143	-551	-98	-649	4.1 %	955
Sweden	-1105	-819	-1925	-472	-2397	12.9 %	1106
EU	-9313	-6939	-16 253	-3572	-19 825		1184

The figures are averages for 2030–2035. Value of roundwood and pulp is excluded from the forest industry's output to avoid double counting domestic inputs and to exclude imports. MS increasing their harvests are not included when calculating the shares of MS declining their harvests and paying for the costs of obtaining a climate gain of circa 17 Mt of CO₂/a. However, the costs in the EU level include also MS gaining economically from the policy.

The cost per tonne of CO₂ saved for an individual MS was calculated by assuming, as in [8], that a country's share of the global net emission reduction is proportional to its share of the EU harvest decline, considering only those countries in which harvests declined. The estimated costs vary substantially, but for several MS, they exceed 1000 €/tCO₂. The considerably higher costs in Lithuania are due to its small contribution to the EU harvest decline and, thus, the small share of CO₂ gain.

The highest absolute annual costs are paid by France, Germany, Finland, Poland, Sweden and Estonia, in this order. When costs per capita are considered using population data of 2025 [28], the highest costs are paid by inhabitants in Finland and Estonia (over 500 €/capita/a), followed by Sweden and Latvia (over 200 €/capita/a). These represent forest-rich countries.

When considering economic gains in terms of turnover in the forest sector, the countries that get the highest share of harvest and production leakage from the EU benefit most. The United States, Canada, Russia, and Brazil are the biggest gainers from the LULUCF policy of the EU.

3.2. Policy Costs under the Background Setting of Stagnant EU Harvests

In the alternative baseline, BASEStagna, where the harvests in EU MS were not allowed to increase from their average 2021–2022 levels, the baseline EU harvest stay at the level 514 Mm³ (u.b.) up to 2035. The LULUCF harvest constraints in the EU force the annual harvest in the EU to be, on average, 59 Mm³ lower in the LULUCF scenario than in the BASEStagna scenario during 2030–2035. Globally, the respective decline is only 20 Mm³. Thus, the harvest leakage from the EU countries reducing harvests to the other EU countries and RoW is 67 %.

Less roundwood will be used to produce panels, pulp and paperboard in the LULUCF scenario than in BASEStagna. This leads to an increase in emissions from the production of materials and fossil fuels substituting wood. With the assumptions in Section 2.2, the increase in fossil emissions is projected to be 8.4 MtCO₂/a in the production stage, and 1.1 MtCO₂ in end-of-life stage of HWP during 2030–2035. The biogenic HWP sink is 6.5 MtCO₂/a lower. The decline in global harvests enhances the forest sink on average by 23.7 MtCO₂/a. Thus, the total net climate benefit obtained with a 9.5 MtCO₂/a increase in fossil emissions and a 17.2 MtCO₂/a decline in biogenic emissions is on average 7.7 MtCO₂/a during 2030–2035.

When valuing the economic costs of the foregone production in the EU (€10.7×10⁹/a) and the net global climate gain achieved by that (7.7 MtCO₂/a), the mitigation costs are circa 1400 €/t CO₂ at the EU level (Table 3). Due to smaller climate gain than what was achieved

with respect to scenario BASE in Section 3.1., the unit cost for emission reduction becomes higher. There is 10 Mm³ leakage of roundwood harvests within EU, as not all MSs (e.g., Romania, Spain, Lithuania, and Hungary) are forced to decrease their harvests from their BASEstagna levels. This reduces the costs at the EU level. The MSs that harvest less, cut their harvests together by 69 Mm³. Several of them face mitigation costs of well over 1000 €/t CO₂.

4. DISCUSSION

The costs of emission savings achieved by enhancing forest sinks through harvest constraints appear to be high. There are less costly methods to enhance forest carbon sinks, such as afforestation. However, these take longer to have an effect. Investments in less costly long-term measures should be undertaken simultaneously with harvest reduction, which increases the cost burden.

Several means exist for reducing GHG emissions from the atmosphere at lower costs. Under the EU Emission Trading Scheme, allowances for producing emissions from burning fossil fuels have been traded at a carbon price of EUR 75/tCO₂ in recent years [29]. In addition, the LULUCF policy affects the economic sector whose production is based on renewable resources contributing to bioeconomy development [30], and many investments have been made in forestry that produces the present sinks. Without past investments, such as planting with genetically superior material, the current sinks would likely have been lower [31].

The costs of harvest restrictions or harvest decline due to EU environmental policies have received surprisingly little attention in the literature. In Finland, the economic impacts of reducing roundwood harvests have been examined in two recent studies. A harvest decline of 7–11 Mm³ (o.b.) was assigned a cost of 1100–1150 M€/a in [32]. This includes direct and indirect economic effects during 2030–2040. A decline of 9 Mm³ in industrial roundwood harvests and 2 Mm³ of energy wood harvest from a baseline harvest of 73 Mm³ (o.b.) was assigned an economic effect of 1400 M€/a in [33]. The setting in [33] is best comparable to the effects of implying harvest constraints in the BASEstagna setting in this study with the Finnish industrial roundwood harvest decline of 12.5 Mm³ over bark. The cost estimates are of similar magnitudes. A circa 1.3 Mt/a decline in CO₂ emissions globally was attributed to the Finnish harvest decline of 12.5 Mm³.

For Sweden, an industrial source [34] estimates that meeting the Swedish LULUCF target by 2030 would require a 14 Mm³/a reduction in roundwood availability and result in a loss of € 2.2 × 10⁹ in added value (thus excluding induced economic effects). Their cost estimate is aligned with the results for the BASE scenario in this study.

Some argue that reducing harvests in managed forests is an almost costless way to mitigate climate change. From the perspective of a forest owner, and at typical discount rates applied in forestry, the cost of sequestering additional CO₂ at the stand level by delaying harvests can be low. However, for this to have a genuinely positive effect on biogenic emissions, even at the national level, postponed harvests must not be displaced to other forests within the country. Avoiding such leakage would require adequate compensation for many forest owners (or legislative mechanisms for allocating harvests). To have an impact, this should ultimately lead to a net reduction in the total harvests. In addition, the industrial use of wood would need to be scaled down, and a substantial part of the harvest reduction would likely leak outside the national borders. Therefore, this issue should be analysed from a systems perspective rather than at the stand level.

TABLE 3. AVERAGE CHANGE IN ECONOMIC CONTRIBUTION OF THE EU27 FOREST SECTOR, CONTRIBUTION TO THE GLOBAL LOSS OR GAIN OF GREENHOUSE GAS EMISSIONS, AND AVERAGE COST OF EMISSION SAVINGS PER UNIT, 2030–2035. LULUCF SCENARIO – BASESTAGNA SCENARIO

Country	Forestry	Forest Industries	Forest sector, total	Induced effects	Total gain or loss	Share of harvest decline	Mitigation Cost
	Mill. €/a	Mill. €/a	Mill. €/a	Mill. €/a	Mill. €/a	%	€/tCO ₂
Austria	–99	–336	–436	–92	–528	1.7 %	4081
Belgium	–43	30	–12	2	–10	1.0 %	136
Bulgaria	–35	–5	–40	–3	–43	0.3 %	1857
Croatia	81	76	158	42	200		0
Czech Republic	–522	55	–467	–30	–497	7.2 %	888
Denmark	18	43	62	23	85		0
Estonia	–391	82	–309	–31	–340	6.3 %	703
Finland	–1045	–302	–1346	–194	–1540	16.3 %	1222
France	–1133	–1629	–2762	–843	–3605	17.8 %	2620
Germany	–1486	–1360	–2846	–732	–3578	23.4 %	1979
Greece	17	8	26	2	28		0
Hungary	132	106	238	22	260		0
Ireland	–122	–93	–215	–23	–238	1.9 %	1614
Italy	–118	93	–25	10	–15	1.7 %	117
Latvia	–110	–68	–178	–33	–211	1.7 %	1642
Lithuania	107	42	149	31	180		0
Luxembourg	7	15	21	2	23		0
Netherlands	8	–5	4	0	4		0
Poland	–313	8	–306	–42	–348	4.7 %	955
Portugal	–561	17	–544	–88	–632	9.0 %	908
Romania	542	76	618	68	686		0
Slovakia	88	42	129	13	142		0
Slovenia	186	44	230	22	252		0
Spain	93	–36	57	–1	56		0
Sweden	–396	–463	–859	–219	–1078	7.1 %	1957
EU	–5095	–3560	–8653	–2094	–10 747		1391

It is possible that the policy decision to close the remaining gap to the EU's 2030 target, after reductions in fossil-based emissions, through forest sinks has been influenced by the assumption that forestry can deliver substantial emission reductions at near-zero cost. An EC report ([4], Fig. 86, p. 185) suggests that changes in rotation lengths, the ratio of thinning to final felling, harvest intensity, and harvest locations could achieve close to 50 MtCO₂/year of carbon savings at a cost of 0–50 €/tCO₂ in the EU by 2050 (measured in 2017 or earlier nominal values). The timeframe of the analysis renders some of these measures infeasible for delivering results by 2030. Because the methodology used to calculate these costs is not

documented in detail, it is not possible to say whether they reflect the cost burden, particularly for the EU MSs financing the policy. Due to leakage, the costs and benefits are distributed internationally when a carbon price is applied in one region in the global forest sector model used. Benefits accrued to US citizens, for example, may have been included, thereby lowering carbon costs. The potential decline in forest sink in RoW and impact on HWP substitution benefits are not reported in [4] focusing on the sinks in the EU.

Unlike emissions savings achieved by the energy sector, biogenic carbon sinks are non-permanent and subject to many risks, such as insect outbreaks and forest fires [35]. Such hazardous events appear to be becoming increasingly frequent in Europe. These risks were not incorporated into the costs calculated in this study.

In this study, proxies derived from forest sector output value changes combined with induced economic effect multipliers from earlier studies [23], [26] were used to assess the economic costs of contributing to the EU's LULUCF sink target by roundwood harvest reductions. A comparison with economic data from EUROSTAT [24] suggested that the method used provides conservative economic (indirect + direct) effects for forestry. However, such a static approach is a limitation, and it would be beneficial to verify the results with a general equilibrium model at the EU or country level, like e.g., in [33]. The model used should include a sufficiently detailed description of the forest sector.

While this study focuses on the costs associated with enhancing forest sinks under LULUCF regulation, it should be emphasized that reducing roundwood harvests in the EU may also provide valuable benefits through other ecosystem services. In some cases, these benefits can be directly measured as economic gains, for instance, when reduced harvesting leads to improved water quality, a higher supply of wild berries or mushrooms, or increased attractiveness of forests for recreation and tourism-related activities [36]. In other cases, these benefits are less tangible but are no less important. Reduced harvesting could be beneficial and align with biodiversity conservation [6], [7], given that the risk of biodiversity degradation in RoW following harvest leakage can be avoided [37], [9].

5. CONCLUSIONS

Despite the many uncertainties in the parametric data used to evaluate the costs of LULUCF policy, the results indicate that mitigating climate change through harvest reductions in EU countries is considerably more costly than many other climate change mitigation measures are. Relating the estimated costs, aiming to accommodate direct, indirect, and induced economic effects, in the EU to the global net emission savings achieved with these costs suggests that the mitigation costs are 1000 €/tCO₂ or much higher, depending on the economic setting where the policy is implemented. However, this cost burden is not equally distributed among EU countries. In some countries, the economic burden on citizens and, thus, the price of emission savings is considerably higher. This cost estimate allows for a high error margin while not exceeding the social costs of carbon [38]. However, a thorough sensitivity analysis of the cost with respect to several uncertainties would be beneficial. This will be the subject of future research. In addition, the effects of employment should be examined.

It must be noted that production and trade flows at the country level are difficult to project with the model used, or with any other forest sector model, as they are affected by several assumptions, for example, those related to transport costs, exchange rates, and the strategies and investment behaviour of global forest industry companies. The market-driven baseline presented in this study is more sensitive to such factors, whereas the baseline with stagnating harvests is less dependent on them. The costs of the LULUCF policy for the EU are higher in

the latter scenario. This is because climate change mitigation benefits decrease with the difference in harvest between the baseline and policy scenarios. In both cases, the LULUCF policy benefits economically the countries outside Europe to which part of the EU harvest and forest industry production leak.

ACKNOWLEDGEMENT

This research was funded by the Finnish Forest Foundation under project 20250290 “Costs of meeting the EU’s LULUCF target through restrictions on forest management”.

REFERENCES

- [1] Regulation (EU) 2023/839 of the European Parliament and of the Council of 19 April 2023 amending Regulation (EU) 2018/841 as regards the scope, simplifying the reporting and compliance rules, and setting out the targets of the Member States for 2030, and Regulation (EU) 2018/1999 as regards improvement in monitoring, reporting, tracking of progress and review. *Official Journal of the European Union* 2023: L 107/1.
- [2] Korosuo A., Pilli R., Viñas R. A., Blujdea V. N. B., Colditz R.R., Fiorese G., Rossi S., Vizzarri M., Grassi G. The role of forests in the EU climate policy: are we on the right track? *Carbon Balance Manag.* 2023:18:15. <https://doi.org/10.1186/s13021-023-00234-0>
- [3] Kallio A. M. I., Garvik E. EU policy on forest carbon sinks revisited. *Environ. Sci. Policy* 2026:177:104332. <https://doi.org/10.1016/j.envsci.2026.104332>
- [4] European Commission. Indepth analysis in support of the Commission Communication COM(2018) 773. A Clean Planet for all. A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy. Brussels, 2018. climate.ec.europa.eu/system/files/2018-11/com_2018_733_analysis_in_support_en.pdf
- [5] Päivinen R., Kallio A. M. I., Solberg B., Käär L. EU Forest reference levels: The compatible harvest volumes compiled and assessed in terms of forest sector market development. *Forest Policy and Economics* 2022:140:102748. <https://doi.org/10.1016/j.forpol.2022.102748>
- [6] Schier F., Iost S., Seintsch B., Weimar H., Dieter M. Assessment of Possible Production Leakage from Implementing the EU Biodiversity Strategy on Forest Product Markets. *Forests* 2022:13(8):1225. <https://doi.org/10.3390/f13081225>
- [7] di Fulvio F., Snäll T., Lauri P., Forsell N., Mönkkönen M., Burgas D., Blattert C., Eyvindson E., Toraño Caicoya A., Vergarechea M., Antón-Fernández C., Klein J., Astrup R., Lukkariinen J., Pitzén J., Primmer E. Impact of the EU biodiversity strategy for 2030 on the EU wood-based bioeconomy. *Glob. Environ. Change.* 2025:92:102986. <https://doi.org/10.1016/j.gloenvcha.2025.102986>
- [8] Schulte M., Lauri P., Di Fulvio F., Forsell F., Augustynczik A. L. D., Eggers J., Hahn T., Jonsson R. Global Forest carbon leakage and substitution effect potentials: The case of the Swedish forest sector. *J. Environ. Manag.* 2025:9:393:127193. <https://doi.org/10.1016/j.jenvman.2025.127193>
- [9] Kallio A. M. I., Rannestad M. Potential impacts of the EU’s biodiversity strategy on the EU and global forest sector and on the risk of biodiversity loss. *Environ. Syst. Decis.* 2025:45:58. <https://doi.org/10.1007/s10669-025-10050-1>
- [10] FAOSTAT. Forestry production and trade. [Online]. [Accessed 02.01.2026]. Available: www.fao.org/faostat/en/#data/FO
- [11] Kallio A. M. I. Wood-based textile fibre market as part of the global forest-based bioeconomy. *For. Policy Econ.* 2021:123:102364. <https://doi.org/10.1016/j.forpol.2020.102364>
- [12] Kallio A. M. I. European Forest sector in a turbulent world. *Journal of Forest Economics* 2024:38(4):375–396. <https://doi.org/10.1561/112.00000569>
- [13] IMF. 2026. Real GDP growth. Annual percent change. [Online]. [Accessed 01.03.2026]. Available: www.imf.org/external/datamapper/NGDP_RPCH@WEO/OEMDC/ADVEC/WEO_WORLD
- [14] IPCC (2006a) IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4: Agriculture, Forestry and Other Land Use, Annex 2: Summary of Equations.
- [15] Kallio A. M. I., Houtmeyers S., Aza A. On Carbon Substitution and Storage Factors for Harvested Wood Products in the Context of Climate Change Mitigation in the Norwegian Forest Sector. *Environ. Clim. Technol.* 2023:27(1):254–270. <https://doi.org/10.2478/rtruect-2023-0020>
- [16] Sathre R., O’Connor J. Meta-analysis of greenhouse gas displacement factors of wood product substitution. *Environ. Sci. Policy* 2010:13(2):104–114. <https://doi.org/10.1016/j.envsci.2009.12.005>
- [17] European Commission (2024) EDGAR (Emissions Database for Global Atmospheric Research) [Online]. [Accessed 15.1.2025]. Available: <https://edgar.jrc.ec.europa.eu/>
- [18] UNFCCC (The United Nations Framework Convention on Climate Change) Nationally Determined Contributions Registry. UNFCCC. [Online]. [Accessed 19.12.2024]. Available: <https://unfccc.int/NDCREG>

- [19] International Energy Agency. Coal information. [Online]. [Accessed 18.6.2024]. Available: www.iea.org/reports/coal-information-overview/consumption
- [20] IPCC. Chapter 12. Harvested wood products. In: IPCC Guidelines for national greenhouse gas inventories. In Pingoud *et al.* 2006. [Online]. [Accessed 18.06.2026]. Available: www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_12_Ch12_HWP.pdf
- [21] Penman J., Gytarsky M., Hiraishi T., Krug T., Kruger D., Pipatti R., Buendia L., Miwa K., Ngara T., Tanabe K., Wagner F. (Eds.). IPCC Good Practice Guidance for LULUCF. 2003. [Online]. [Accessed 18.06.2026]. Available: www.ipcc.ch/site/assets/uploads/2018/03/GPG_LULUCF_FULLEN.pdf
- [22] Soimakallio S., Böttcher H., Niemi J., Mosley F., Turunen S., Hennenberg K.J., Reise J., Fehrenbach H. Closing an open balance: the impact of increased tree harvest on forest carbon. *GCB Bioenergy* 2022;14(8):989–1000. <https://doi.org/10.1111/gcbb.12981>
- [23] Li Y., Mei B., Linhares-Juvenal T. The economic contribution of the world's forest sector. *For. Policy Econ.* 2019;100: 236–253. <https://doi.org/10.1016/j.forpol.2019.01.004>
- [24] Eurostat. Output of forestry by type. [Online]. [Accessed 15.1.2026]. Available: <https://ec.europa.eu/eurostat/web/forestry/database>
- [25] OECD. Input-Output tables. [Online]. [Accessed 15.1.2026]. Available: www.oecd.org/en/data/datasets/input-output-tables.html
- [26] Li Y., Mei B., Linhares-Juvenal T., Formenton Cardoso N., Tshering C. Forest sector contribution to national economies 2015 – The direct, indirect and induced effects on value added, employment and labour income. *Forestry Working Paper* 2022;33. Rome, FAO.
- [27] Econmove GmbH and Economica GmbH. The economic impact of the forestry and wood industry in Europe in terms of the bioeconomy. Report. 2023. www.forstholzpapier.at/images/2023_05_Report_Wood_Satellite_Account_final.pdf
- [28] Eurostat. Population on 1 January. [Online]. [Accessed 05.02.2026]. Available: ec.europa.eu/eurostat/databrowser/view/tps00001/default/table?lang=en&category=t_demo.t_demo_pop
- [29] European Commission. On the functioning of the European carbon market in 2024. COM(2025) 735 final. 2025. Available: climate.ec.europa.eu/document/download/dde1b1de-652b-49ed-8f15-d9fa8badd39f_en?filename=com_2025_735_en.pdf
- [30] Laganovska I., Feofilovs M., Blumberga D., Forestry Sector Resource Optimization with TIMES. *Environ. Clim. Technol* 2022;26(1):1279–1298. <https://doi.org/10.2478/rtuct-2022-0097>
- [31] Jansson G., Hansen J. K., Haapanen M., Kvaalen H., Arne Steffenrem A., The genetic and economic gains from forest tree breeding programmes in Scandinavia and Finland. *Scand. J. For. Res.* 2017;32:4. <https://doi.org/10.1080/02827581.2016.1242770>
- [32] Kniivilä M., Hirvelä H., Lintunen J., Mutanen A., Vatanen, E., Viitanen, J., Kurttila, M. Metsien tiukan lisäsuojelun hakkuumahdollisuus-, arvonlisäys- ja työllisyysvaikutusten arviointi: Skenaariotarkastelu EU:n biodiversiteettistrategiasta Suomessa. Luonnonvara- ja biotalouden tutkimus 64/2022. Luonnonvarakeskus. Helsinki. 2022 [Assessment of the impacts of strict additional forest protection on harvesting opportunities, value added, and employment: A scenario analysis of the EU Biodiversity Strategy in Finland]. [Online]. [Accessed 05.02.2026]. Available: urn.fi/URN:ISBN:978-952-380-480-7 (In Finnish).
- [33] Lintunen J., Pihlainen S., Assmuth, A. (Ed.) Katsaus toimiin ja ohjauskeinoin metsien kestävyystavoitteiden saavuttamiseksi. Luonnonvara- ja biotalouden tutkimus 3/2026. Luonnonvarakeskus. Helsinki. 2022 [Review of measures and policy instruments to achieve forest sustainability goals.] urn.fi/URN:ISBN:978-952-419-149-4
- [34] Swedish forest industries. Future climate policy: A new approach for the LULUCF regulation. Position Paper Swedish Forest Industries. June 2025. [Online]. [Accessed 05.02.2026]. Available: www.skogsindustrierna.se/siteassets/bilder-och-dokument/positionsapper/positionsapper_sfif_position_a_new_approach_to_the_lulucf_regulation.pdf
- [35] Bumbiere K., Diaz Sanchez F. A., Pubule J., Blumberga D. Development and Assessment of Carbon Farming Solutions. *Environ. Clim. Technol.* 2022;26(1):898–916. <https://doi.org/10.2478/rtuct-2022-0068>
- [36] Hu X., Hou Y., Li D., Hua T., Marchi M., Forero Urrego J.P., Huang B., Zhao W., Cherubini F. Changes in multiple ecosystem services and their influencing factors in Nordic countries. *Ecol. Indic.* 2023;(146):109847. <https://doi.org/10.1016/j.ecolind.2022.109847>
- [37] Fischer R., Zhunusova E., Gunter S., Iost S., Schier F., Schweinlie J., Weimar H., Dieter M. Leakage of biodiversity risks under the European Union Biodiversity Strategy 2030. *Conserv. Biol.* 2023;38:e14235. <https://doi.org/10.1111/cobi.14235>
- [38] Rennert K., Errickson F., Prest B.C. *et al.* Comprehensive evidence implies a higher social cost of CO₂. *Nature* 2022;610:687–692. <https://doi.org/10.1038/s41586-022-05224-9>