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Feeling the “Pinch”? On the Cost of Relying on the Forest Sink to fulfill EU LULUCF and Climate Targets

David Ellison

ellisondl@gmail.com

Swedish University of Agricultural Sciences https://orcid.org/0000-0002-3755-6024

Torgny Lind

Swedish University of Agricultural Sciences

Per-Erik Wikberg

Swedish University of Agricultural Sciences

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Feeling the "*Pinch*"? On the Cost of Relying on the Forest Sink to fulfill EU LULUCF and Climate Targets

Torgny Lind [1], David Ellison [1], Per-Erik Wikberg [1]

[1] Department of Forest Resource Management, Swedish University of Agricultural Sciences (SLU), Umeå, SE

* Correspondence: EllisonDL@gmail.com

Abstract

Several EU Member states have recently been rocked by revelations that their LULUCF-based net forest carbon removal targets are becoming more and more difficult to achieve. Though blame for this phenomenon has frequently been leveled at governments and the forestry sector, much of the difficulty in achieving these targets derives from the global inability to better respond to and manage the climate challenge. Tree growth is highly dependent upon the climate and our inability to adequately reduce energy and industrial sector emissions is increasingly challenging the climatic conditions under which trees grow. Depending on how important a role the LULUCF sector plays in meeting individual Member state climate commitments, as well as on how the policy itself is structured, shortfalls in emission reductions will have variable impacts on national level climate change mitigation objectives. Countries with more sizable LULUCF sector commitments are likewise frequently both more heavily invested in, and constrained by, forest growth, harvest practice and their bioeconomy ambitions. Declining growth potentially means reduced availability of renewable, material, and circular bioeconomy resources: i.e., declining carbon sequestration in the harvested wood product carbon pool, and the declining availability of biomass-based, renewable, material and energetic resources. Moreover, where declining growth and LULUCF sector targets progressively impinge upon the availability of the renewable, material forest biomass resource, one can increasingly expect significant and increasingly acute social, ecological and political conflict. As the current road to Paris grows increasingly rough and rocky, we ask what the alternative routes might be?

Keywords: LULUCF, carbon sequestration, carbon sink, forest growth, targets, forest policy, decision support systems

1. Introduction

Forests store a large amount of carbon in vegetation and soil. In 2020, the carbon stock in the world's forests was around 870 $GtCO_2$ (Pan et al., 2024). Living biomass (43%) and soils (45%) represent the two largest carbon pools. For the period 1990-2019, the total annual global forest carbon sink was approximately 3.56 $GtCO_2$ (13 $GtCO_2e$). However, tropical deforestation reduced the *net* global sink to around 1,33 $GtCO_2$ (4,9 $GtCO_2e$) (Pan et al., 2024). By comparison, total annual fossil-fuel emissions were around 7.8 gigatons C (29 $GtCO_2e$) over the same period.

The climate change mitigation commitments made to the UNFCCC's 2015 Paris Agreement impose significant challenges for all Parties. In order to meet these challenges, many Parties have included commitments from the forestry sector. In the European Union (EU) Member states, land covered by forest holds the largest carbon pools and, due to its potential to sequester carbon, is considered important for mitigating climate change. The EU, in particular, has resolved to ratchet up carbon sequestration in standing forests by committing to raise its LULUCF targets over the near and far term (from 2030 to 2050). Within the land use, land-use change and forestry sector (LULUCF) the EU target is expected to contribute a net annual removal of -310 $MtCO_2e$ by the year 2030 (EU, 2023), and this target will progressively be increased for 2040 and 2050.

The ability of the EU Member states to fulfil these LULUCF targets, however, is increasingly mired in controversy. Many Member states have experienced significant difficulty with what is presumably a climate-driven decline in carbon uptake (Curran and Curran, 2025; Knutzen et al., 2025; Korosuo et al., 2023; Laudon et al., 2024; Migliavacca et al., 2025; Ritter et al., 2026), and increasing natural disturbances and rising mortality, especially in species less adapted to warming temperatures and declining rainfall (Patacca et al., 2023). Especially for spruce, mortality has been rising in northern Europe since approximately 1995 (for the Swedish mortality data by tree type, see Figure S1 in the Supplement/Appendix).

Declining forest-based biomass production potential challenges the Swedish (and more broadly European) goal of promoting the bioeconomy. Relative to the reported baseline for 2016 – 2018 of -46,5 $MtCO_2e$, the most recent commitment made in the context of the new EU LULUCF regulation (2023/839) imposes an *additional LULUCF target* on Sweden which requires an additional increase in net removals of -4 $MtCO_2e$ by the year 2030, and thus a total of -50.5 $MtCO_2e$ (or, with HWP included, -55.9 $MtCO_2e$). Proportional additional targets apply to all other EU Member states. Further, there are explicit indications that the EU and Swedish LULUCF target will continue to increase for 2040 and 2050.

Sweden has a very high share of land covered with forest (69%) and, among EU countries, the largest total forest area (28 million ha) ("Forests, forestry and logging," n.d.). For the year 2024, Sweden reported a net uptake for the LULUCF sector of -54,2 $MtCO_2e$. However, earlier declines (2018-2022) raised concerns about meeting the 2030 LULUCF target. The reported uptake in 2024 was about -8 $MtCO_2e$ more than reported during the baseline period 2016–2018 (figure 1). This represented an increase of -14 $MtCO_2e$ compared to uptake for the previous period 2020-2021 ("Emissions and removals of greenhouse gases from land use, land use change and forestry by type of greenhouse gas and subsector. Year 1990 - 2024," n.d.).

The EU LULUCF policy framework essentially ignores material and energetic substitution benefits (Jonsson and Sotirov, 2025; Petersson et al., 2022). In combination with rising LULUCF targets, declining biomass production will further constrain the forestry sector. This "pinch" is primarily policy and climate driven, and thus anthropogenically determined. Though many previously assumed climate change impacts would be positive for Nordic forests (see in particular (Bergh et al., 2003; Kellomäki et al., 2008)), recent large and regional variation in forest growth and mortality may indicate such predictions were premature. Due in particular to climate change-related phenomena, the level of growth may increase in some parts of the country, while declining in others (see Figure S3, Supplement). As it turns out, Nordic environs and the forests inhabiting them are more susceptible than previously believed to global warming pressures, changing temperature and rainfall patterns, and potential drought phenomena.

Just as importantly, the mismatch between the goal of increased carbon sequestration in standing forests, on the one hand, and the goal of maximizing the forest resource-based bioeconomy, on the other, is the direct outcome of a poorly structured policy design. Even if countries make significant efforts to improve the substitution potential of the existing biomass resource, LULUCF sector accounting targets seem increasingly more likely to limit forest resource availability and thus to undermine bioeconomy objectives, in particular in conjunction with negative climate-based forest growth impacts. In this regard, EU level strategies aimed at reduced harvest use intensity (Grassi et al., 2021; Korosuo et al., 2023; Migliavacca et al., 2025), lie in direct opposition to forestry sector resource maximization objectives and fail to integrate policy orientations and objectives that could potentially balance these interests and goals.

1. Background & objectives

The objective of this study is to highlight the consequences of projected variation in future net gross growth and harvest intensity on carbon sequestration on forest land within the LULUCF commitment framework. We simulate forest development under various assumptions about growth and harvest levels with a Swedish forest simulator (Heureka) designed for national simulations of the forest. Fulfilment of the LULUCF commitment is associated with many uncertainties due to variability in forest growth and mortality as well as to variation in the consumption of wood products and related harvest levels.

Carbon in the LULUCF framework is reported for different land-use classes (forest land, cropland, grassland, wetlands, settlements, other land) and carbon pools (living biomass, litter, deadwood, dead organic matter, mineral soils, organic soils). Harvested wood products (HWP) are also reported. For Sweden (as for the EU as a whole), the principal removal of carbon occurs within the land-use class forest (living biomass) and the HWP carbon pool. Except for grazing lands, all remaining land-use classes are a *source* (not a sink).

Forest land represents the most important carbon sink in Sweden. Between 2016 and 2018, forest land and HWP sequestered 51,9 $MtCO_2e$, while all other land-use classes were net sources (5.4 $MtCO_2e$) (SCB 2025). Net annual carbon sequestration on forest land depends heavily on the total annual change in (uptake of) carbon in living trees, forest soils and the HWP carbon pool (Figure 1). HWP and dead organic matter exhibit significant interannual variation in carbon sequestration, while living biomass exhibits the largest interannual variation. Net annual sequestration in living biomass (trees) exhibits the greatest variation (see Figure 2: -5.4 to -40.2 $MtCO_2e$ between 1990 to 2024). HWP ranges between -3,6 and -11,8 $MtCO_2e$. Soils and other pools exhibit low absolute variation. Between 1990 and 2024, the combination of mineral and organic soils, reported total *net* annual carbon sequestration ranging between -11,1 and -15,7 $MtCO_2e$. Dead organic matter represents a large sink and varies more, from -6 to -19,0 $MtCO_2e$ with lower variation since 2016 (-11 to –16 $MtCO_2e$).

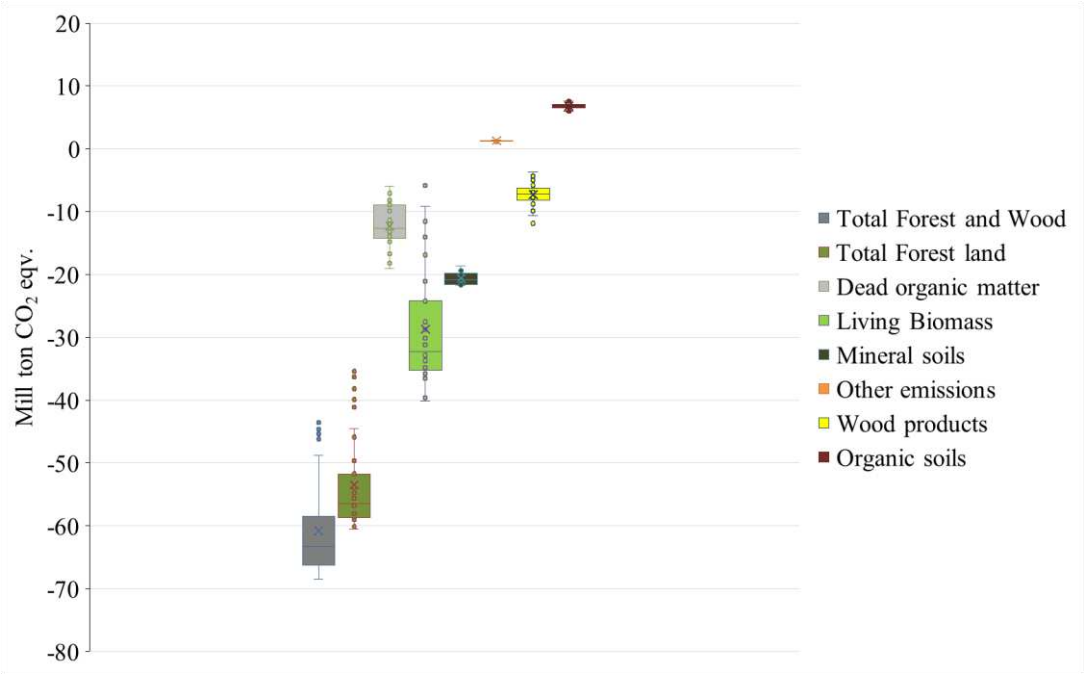


Figure 1. Total annual carbon sequestration by carbon pool reported for Sweden between 1990 – 2024, ($MtCO_2e$).

As highlighted in Figures 2 and 3, the years from about 2018 to 2022 exhibit a significant decline in forest growth, leading to ever smaller shares of net carbon removals in standing forests. These “pinch” years illustrate the difficulty imposed by an inflexible LULUCF regulation that fails to recognize all the benefits of material and energetic substitution, or to provide adjustment mechanisms that modify targets based on wood resource use and benefits linked to other segments of the climate policy framework (in particular the ETS and the Effort Sharing components of the system).

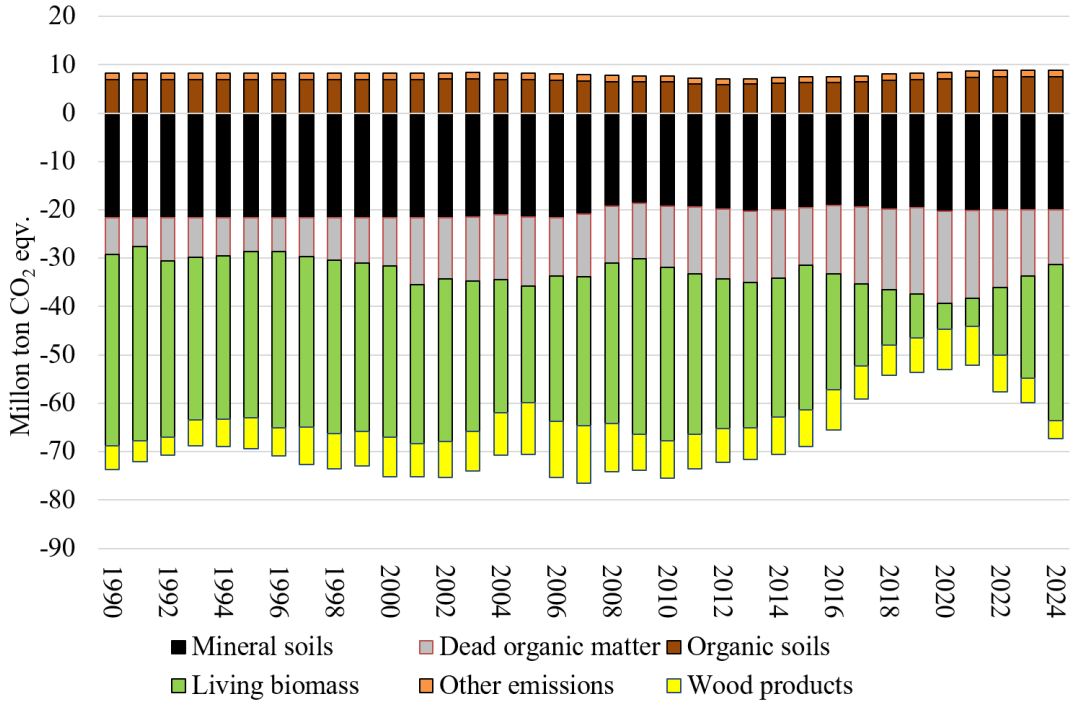


Figure 2. Annual carbon sequestration in Sweden, by land use class and carbon pool ($MtCO_2e$).

Source: SCB Statistical database Emissions and removals of greenhouse gases from land use, land use change and forestry by type of greenhouse gas and subsector. Year 1990 – 2024 ("Emissions and removals of greenhouse gases from land use, land use change and forestry by type of greenhouse gas and subsector. Year 1990 - 2024," n.d.).

The large interannual variation in the sequestration in living trees is explained by growth, mortality and harvest. In Sweden, all three exhibit considerable interannual variation (Figure 3). Of these three factors, growth and mortality are highly sensitive to weather conditions and the occurrence of larger forest damages caused by storms and bark beetle infestations.

Forest growth ranged from a peak of 131 mill m^3 in 2012 and started out as low as 96 mill m^3 in 1991. Between 1990 and 2024, annual harvest levels varied from 64 to 96 mill m^3, and between 2016 and 2024, they varied between 87 and 96 million m^3 (Skogsstyrelsen 2024). This generally represents a much lower rate of variation than for interannual measures of net carbon sequestration in living trees. The principal reason for the low carbon sequestration in living trees from 2017 to 2023 was the lower net growth on forest land, in combination with unusually high harvest levels in 2021 and 2022.

As highlighted in Figure 3, change in net removals in standing forests is largely explained by change in growth patterns and less so by change in harvest activity or variation in mortality rates. But, because it is difficult to influence either growth or mortality, the principal strategy for bringing about change in net carbon sequestration will ultimately be to influence change in harvest. The projected trendlines for gross forest growth represent scenarios with and without the significant decline in forest growth as of about 2012. The divergence in the high, medium and low forest growth scenario projections highlights the relative uncertainty inherent in knowing what the future holds and raises important questions about how such scenarios should be constructed. Does the growth period from 2012 to about 2020 represent some kind of tipping point? And if 2012 is not a tipping point, per se, has it set forest growth on a new trajectory? This period raises many important long-term questions not easily answered based upon comparatively short-term prognoses.

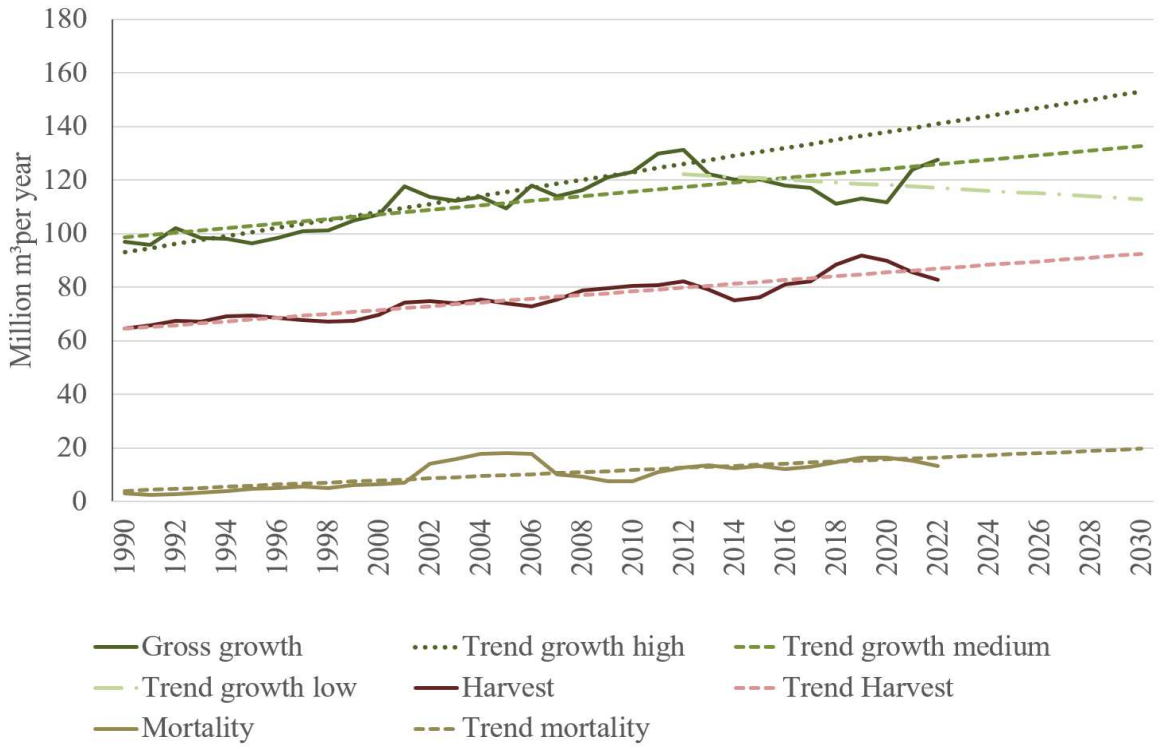


Figure 3. Growth, harvest and mortality on all land, excl. formally protected areas.

Source: Swedish NFI.

Further, we note that variation from the historical trends is most significant for growth. Even over the longer term, variation in harvest practice and mortality rates has been comparatively minor.

2. Material and methods

2.1 Forest data

We use data from Swedish National Forest Inventory (NFI) permanent plots (Fridman et al., 2014) inventoried between 2018-2022 to analyze carbon storage and the carbon sink. These permanent sample plots also form the basis for annual climate reporting to the EU and the UNFCCC. The NFI records data from 38,583 sample plots, of which 20,772 are on productive forest land, and 3,120 on non-productive forest land. These plots represent a total area of 27.8 mill ha for forest land (based on the FAO definition of "forest"), of which 23,1 mill ha are on productive forest land and 4.7 mill ha are on non-productive forest land. Productive forest land is land that is: suitable for forestry, can potentially produce >1 m³sk/ha per year, and is not primarily used for other purposes.

2.2 Decision support system

We use the decision support system Heureka RegWise (version 2.23.0.2), designed for simulating the consequences of forest management on forest outcomes and their development at regional and national level, and over time, up to 100 years. RegWise uses a ruled-based simulation framework with mainly empirical tree- and plot-level growth and yield models which simulate the development of the forest over time based on the forest management strategy (Elfving, 2019; Fahlvik et al., 2014). Individual NFI sample plots make up the treatment units in this study on which management actions

(such as thinning, final felling or no active measures) are applied. The effect of different silvicultural actions and forest management strategies on outcomes for a range of indicators representing various ecosystem services and biodiversity can likewise be modelled in Heureka (Lämås et al., 2023).

2.3 Scenario assumptions

Six scenarios were simulated over a period of 100 years, with varied assumptions regarding growth and harvest levels. These were distributed across management classes and linked to their availability for wood production. The area distribution of forest management classes and management was similar to the scenarios used in the Forest Impact Analyses (Skogsstyrelsen, 2022). Of Sweden's 27.8 million ha of forest, 18.6 mill ha are available for wood supply (FAWS) and 33% (9.1 mill ha) are unavailable due to protection or low productivity (Table 2). These consist of formally set aside areas (2.7 mill ha), non-productive forest land (4.7 mill ha), and land subject to *nature considerations* during final felling (1.8 mill ha). The forest area in the simulations was distributed across 3 different management classes (no forest management, continuous forest management (CCF), forest management). The simulations were made on 5 different regions with some variation in forest management as in *Forest Impact Analyses* (Figure 4) (Skogsstyrelsen, 2022). In total, forest management is practiced on 18.6 mill ha. Forested areas with no forest management covered 7.3 mill ha, of which continuous cover forestry (CCF) was applied to 0,36 mill ha.

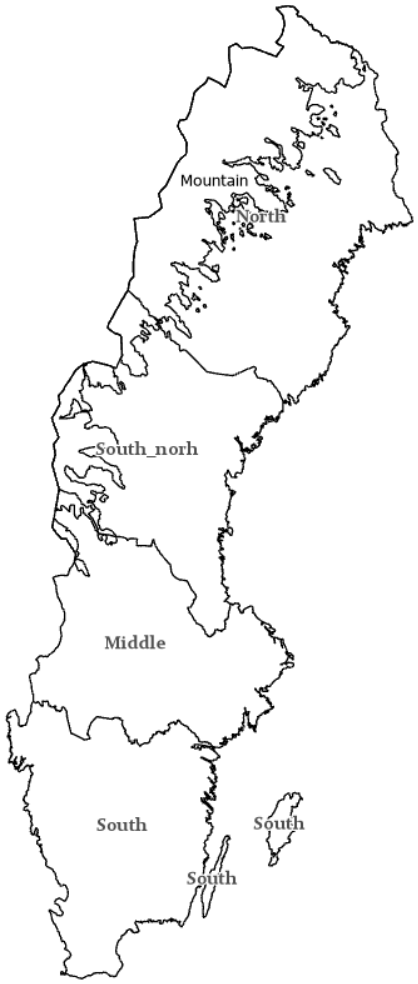


Figure 4. Regions for simulations

Table 2. Areas of forest distributed on management classes within regions based on NFI data, 1000 ha

	No management			CCF*	Forest Management	
Region	Formal set aside	Voluntary	Low-Productive	Nature considerations	FAWS	Total
South	157	311	352	264	3971	5055
Middle	246	316	533	424	4369	5889
South-north	125	308	661	581	4522	6197
North	246	289	1108	471	5370	7485
Mountain	564	107	2008	68	417	3165

Total	1 338	1 332	4 662	1 809	18 650	27 790

Note (*): 80 % of the nature consideration area is without management, while 20 % is managed selectively (i.e., with no final felling).

2.4 Scenario assumptions on growth and harvest levels

Basic assumptions related to growth and harvest rates varied across the scenarios. The applied forest management was the same in all scenarios. The five-year period from 2015 to 2019 represents a period with lower growth compared to average growth for the years 1985–2019. The relative growth (annual gross growth/timber stock expressed as a percentage) was approximately 0.25% lower than the average during this period. To reduce relative growth by 0.25%, an 8% adjustment of absolute growth compared to model predicted growth using the standard growth models in Heureka was required (Elfving, 2019). The five-year period from 2009 to 2013 represents a period with high relative growth compared to average 1985-2019 In Heureka growth was adjusted upward to resemble this five-year period with an adjustment of absolute growth by 8%. Table 3 provides additional details about the 6 scenarios used in the study.

The harvest levels were assumed to vary between 100 and 90% of the net growth on FAWS forest land (Table 3). This was done to simulate harvest level intensity impacts on carbon sequestration. For the scenarios with medium growth labeled “100_100” and “100_90”, no adjustments of growth were made in Heureka. These scenarios thus represent a development where growth is simulated using Heureka’s default growth models. For all other scenarios, similar to Forest Impact Analyses, growth was adjusted for the expected impacts of climate change on forest growth (Skogsstyrelsen, 2022). This was accomplished by adjusting the empirical growth functions using the BIOMASS process-based vegetation model (McMurtrie et al., 1990) and the RCP4.5 radiative forcing scenario (Thomson et al., 2011), as modelled using MPIESM (Giorgetta et al., 2013).

Table 3. Assumptions on growth and harvest levels, growth correction, proportion of harvest in relation to growth in FAWS

Scenario[1]	Growth correction	Proportion harvest of net growth on FAWS, %
108_100	1,08	100
108_90	1,08	90
100_100	1	100
100_90	1	90
92_100	0,92	100
92_90	0,92	90

3. Results

The principal explanation for the total amount of carbon sequestration in land-use class forests derives from the basic relationship between levels of growth, mortality and harvest. Gross growth for 2030-2035 varies from 116 to 138 mill m³, net growth from 101 to 121 mill m³ per year (Figure 5). (Note: in Sweden, since data that includes 5 observation years is the most accurate, we use the annual average data for 2030-2035 as a reference since. This number best represents a realistic estimate of the respective indicator in 2030). Over the same period, mortality only varies between 15-17 mill m³.

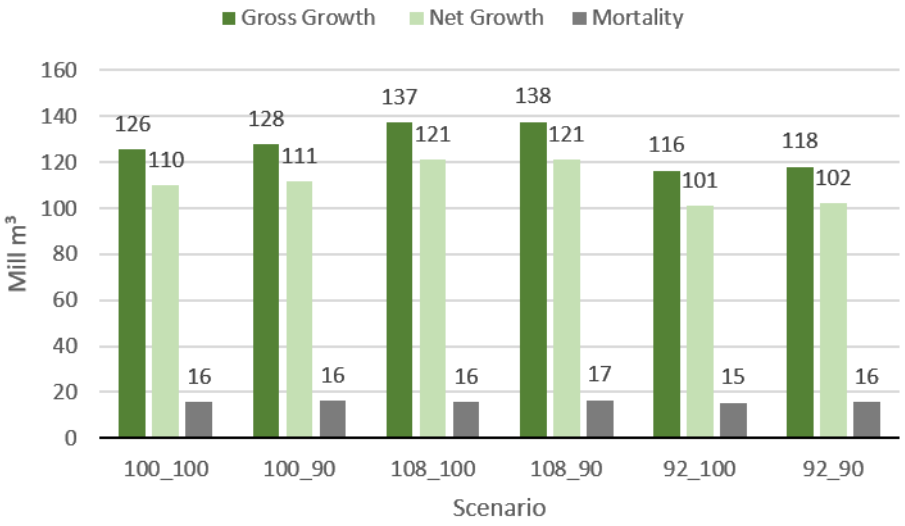


Figure 5. Growth (gross and net) and mortality, 2030-2035, mill m³

[1] Climate change according to RCP 4.5

The harvest level in the first period (from 2020-2025) was the same for all scenarios, 91 mill m³ independent of growth levels. The harvest level was based on the current level of harvest in Sweden for the years 2020-2024 according to statistics from Skogsstyrelsen (2026). Depending on the scenario, harvest levels for 2030-2035 ranged between 81 and 106 mill m³ (Figure 6). This can be compared with historic harvest levels in Figure 3. Based on historical harvest data from 1990-2022, the projected harvest trend for 2030-2035 is about 94 mill m³.

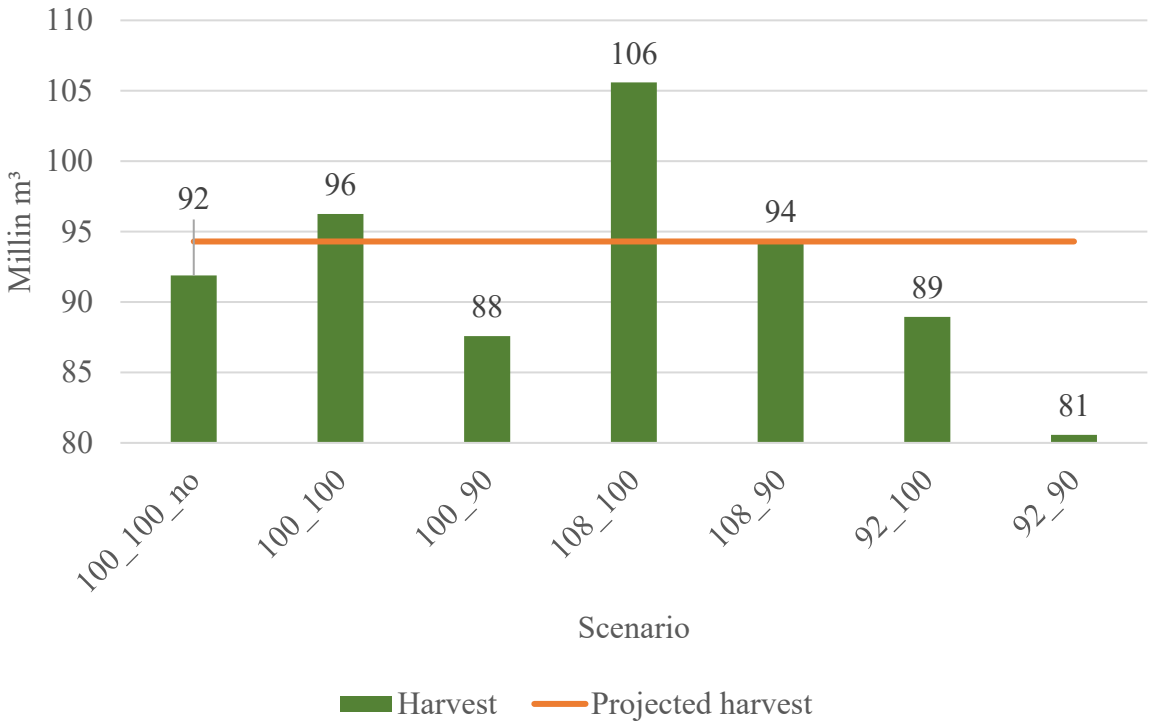


Figure 6. Total harvest level, incl. pre-commercial thinning, 2030-2035, mill m³. Note: the projected harvest for 2030-2035 is based on the trendline in Figure 3.

According to Statistics Sweden ("Utsläpp och upptag av växthusgaser," n.d.), carbon sequestration for the period 2016-2018 was -17.4 $MtCO_2e$ for living biomass. Depending on the harvest level assumptions for the period 2030-2035, the scenario analyses resulted in higher or lower net carbon sequestration in living trees, ranging between – 15 to – 32 $MtCO_2e$ (Figure 7). The difference in HWP varies between – 4 to – 8 $MtCO_2e$ (Figure 7).

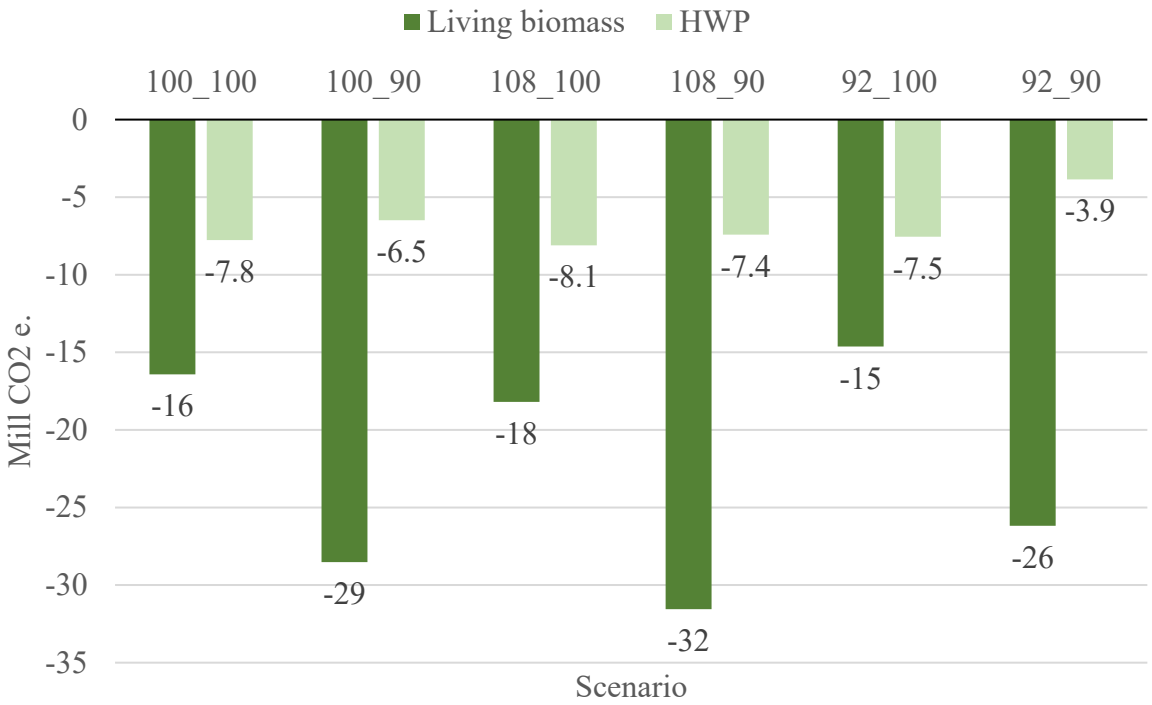


Figure 7. Average Annual Carbon sequestration in living biomass and HWP, year 2030-2035, $MtCO_2e$.

For pools in mineral soils, dead organic matter and organic soils, we leveled the outcome of the Heureka simulations of carbon sequestration with the official LULUCF reporting and used the differences between scenarios. For the years prior to the initiation of the simulations (2015-2019) the average net carbon sequestration was -27 $MtCO_2e$ in total, with -19 $MtCO_2e$ for mineral soils, -15 $MtCO_2e$ for dead organic matter, 1 $MtCO_2e$ for other emissions, and 7 $MtCO_2e$ for organic soils. Higher growth and higher harvest levels lead to an increase in carbon inputs from litter fall and stumps, resulting in higher net carbon sequestration in soils and dead organic matter (Figure 8). Based on historically small inter-annual change and the fact that large portions of organic soils are located on unmanaged forest land, organic soils and other emissions have little impact on the total carbon balance.

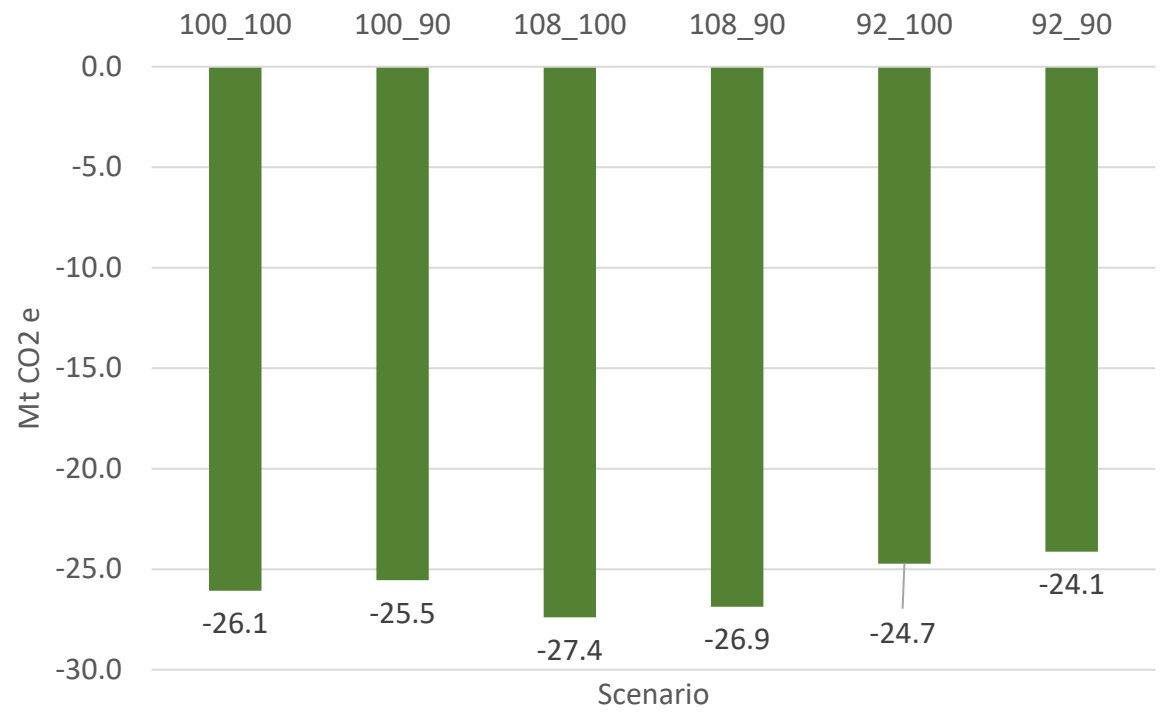


Figure 8. Net sequestration for mineral soils, dead organic matter and organic soils, year 2030-2035, $MtCO_2e$.

Assuming all other pools remain unchanged, meeting the 2030 forest land target generally requires harvest limited to 90% of growth under average or high growth scenarios (Figure 9).

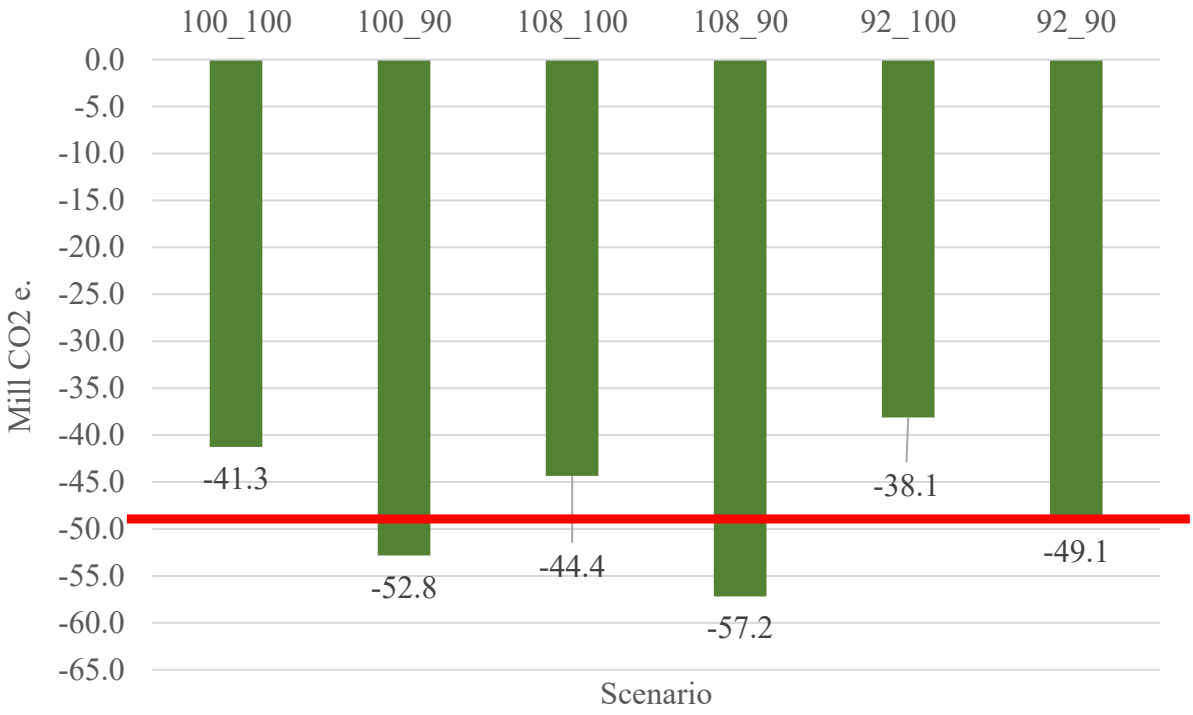


Figure 9. Total carbon sequestration on Forest land, $MtCO_2e$. The red line designates the total target for Forest land (-48.7 $MtCO_2e$). This target does not include either the total LULUCF (-50.5 $MtCO_2e$), or the Forest land + HWP target (-55.9 $MtCO_2e$).

If net sequestration in all other land-use classes remains unchanged over time, an increase in carbon sequestration of -4 $MtCO_2e$ is required for forest land and HWP to fulfil the LULUCF target by 2030. Meeting the total LULUCF target requires net carbon sequestration of -55.9 $MtCO_2e$. In Table 4, the yellow highlighted fields indicate this demand cannot be fulfilled, while green highlighted fields indicate potential to fulfil the target for 2030. Since the LULUCF targets may change in coming years, cells highlighted green are potentially not sufficient to meet amended targets in future LULUCF policy frameworks.

Table 4: Total sequestration forest land incl. HWP, $MtCO_2e$.

Period	_100_100	_100_90	_108_100	_108_90	_92_100	_92_90
2020-2025	-49,5	-48,3	-61,0	-60,7	-37,6	-36,8
2025-2030	-49,2	-60,6	-52,6	-64,9	-45,6	-52,5
2030-2035	-49,0	-59,3	-52,5	-64,6	-45,7	-52,9
2035-2040	-51,4	-62,6	-55,9	-67,1	-48,9	-55,4
2040-2045	-47,9	-59,1	-53,7	-65,1	-46,0	-53,7
2045-2050	-48,6	-59,3	-54,6	-65,3	-46,1	-52,7
2050-2055	-47,0	-58,3	-54,3	-65,0	-45,5	-52,6
2055-2060	-47,2	-58,0	-54,0	-63,6	-44,3	-51,0
2060-2065	-46,3	-57,5	-54,9	-63,6	-43,1	-50,7
2065-2070	-45,9	-57,8	-52,5	-63,8	-42,7	-50,6
2070-2075	-42,2	-56,1	-55,0	-62,3	-40,5	-50,2
2075-2080	-43,3	-55,0	-60,2	-61,4	-39,7	-49,6
2080-2085	-39,2	-52,2	-49,2	-56,7	-37,1	-47,4
2085-2090	-40,6	-50,9	-52,9	-55,9	-36,4	-45,5
2090-2095	-37,6	-48,6	-54,0	-54,0	-38,0	-42,8
2095-2100	-39,5	-50,1	-54,4	-53,3	-40,2	-44,2
2100-2105	-33,5	-49,0	-42,5	-52,1	-34,0	-43,7
2105-2110	-32,2	-45,5	-36,1	-49,3	-30,5	-40,1
2110-2115	-31,8	-47,7	-37,2	-51,1	-30,9	-42,8
2115-2120	-30,8	-46,9	-35,4	-49,6	-31,6	-41,4

Long term decline in sequestration reflects ageing forests in unmanaged areas (Figure 10). In Figure 10, though clearly impacted by low growth in the period between 2012 and 2022, the carbon sequestration for FAWS remains stable between –10 to –15 $MtCO_2e$ at 90 % harvest.

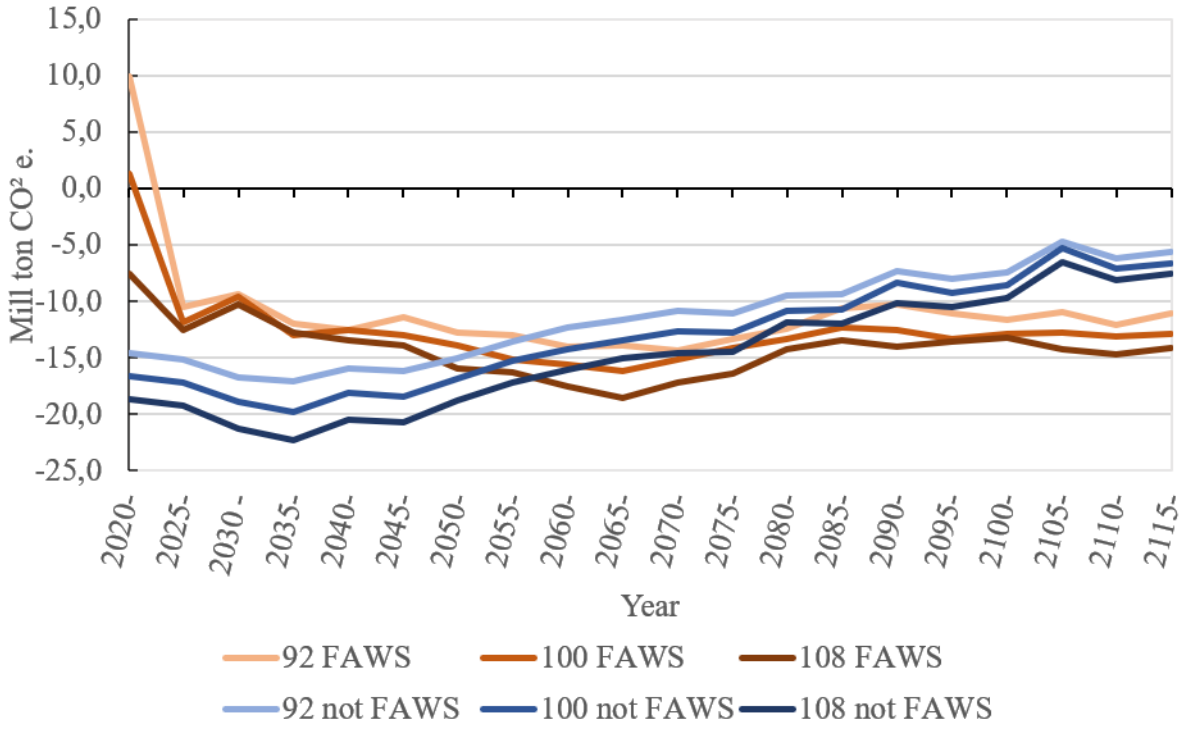


Figure 10. Carbon sequestration on land in and outside FAWS for 90% harvested of growth scenarios, $MtCO_2e$.

4. Discussion

Frequent concerns have been raised about the ability of the LULUCF sector to meet its targets for the upcoming period ending in 2030, not to mention 2050. One might ask how we have arrived at the current impasse. Previous assumptions about future forest growth were more encouraging. In this context, the original LULUCF target assumptions may have seemed more reasonable and potentially viable.

The results show that the forest sink is highly sensitive to growth fluctuations. The 2018–2020 "pinch" largely reflected declining growth, compounded by elevated harvest. As illustrated by the high and low gross forest growth trendlines (Figure 3), had forest growth not declined as dramatically during this period, or if it had instead continued to increase along the historical trend, this pinch might not have occurred at all, or could have been far less dramatic.

While many seem ready to blame harvest practices and the forestry sector more generally for the declining forest carbon sink, an important share of the problem, and thus blame, should instead be traced back to the extent to which shifting forest growth patterns are the direct result of climate change, i.e., and thus, of insufficient reductions in rising emissions in the energy and industrial sectors. In this regard, when assessing future forest carbon sink potential, forests and forestry are not necessarily the key explanatory factor. Much of the focus should ultimately be directed at the flipside of the emission/removal continuum, by which, of course, the LULUCF sector is intensely affected. As we are continuously reminded, the frequency of reduced rainfall, drought events and other extremes are highly likely to increase in intensity as the climate continues to warm (Grünig et al., 2026; Patacca et al., 2023).

In this regard, the "target" system introduced through UNFCCC and EU legislation is problematic. Predicting future growth potential is extraordinarily difficult, as future global and regional weather patterns resulting from climate change remain highly uncertain, as do future global emission trajectories. To highlight the degree of unpredictability, IPCC calculations of future emission reduction trajectories are divided into a broad range of alternative projections (as many as 7 official RCP ("representative concentration pathway") scenarios are mentioned in the Sixth Assessment Report published from 2021 to 2023), each reflecting variation in climate change impacts and the behavior of Parties to the UNFCCC agreements.

Four principal pathways are available by which EU Member states can improve their LULUCF target performance. In what follows, we focus specifically on Swedish potential to meet these new LULUCF targets.

If we could accurately predict future climate-related impacts on forest growth, **the first** and simplest strategy for resolving shortfalls in meeting EU LULUCF climate targets is potentially to reduce harvest (see e.g., (Grassi et al., 2021)). Harvest activity did experience a modest uptick during the more recent period from about 2018 to the present, and this occurred a few years after growth began to diverge from its historical trend (2012) and declined significantly over several years.

Public authorities in Sweden have little leverage with which to directly influence the choices made by land and forest owners and harvest volumes typically are not centrally determined. As in most European countries, harvest practices are highly decentralized in Sweden. In northern Europe, approximately 70% of forest land is privately owned (60% across Europe as a whole) (Mauser, 2021). Sweden has a somewhat smaller share of privately owned forests (48%), and some 320,000+ private

land and forest owners (Federation, 2024). However, the share of harvested timber from private land and forest owners amounts to approximately 60% of the total.

Harvest has generally increased over time. But, as illustrated in Figure 3, over the period 1990-2022 it has remained within the high trendline for gross forest growth, rarely diverging significantly from the mean. Following the pattern of increasing forest growth, over time, this has resulted in a steady increase in harvested volumes. Thus, in Sweden, relative variation in harvest practice around the mean is quite small (Figure 3, harvest trendline).

The principal driver of harvest activity remains fluctuations in demand and thus price, and the private decisions of individual land and forest owners. Thus, the first alternative for guaranteeing the integrity of forest-related commitments, reducing harvest intensity, is complicated, runs, historically, against the grain of Swedish (as well as other Member states') practice, and can be almost impossible to structure within the required framework of annual policy adjustments to annual variation in growth patterns.

Thus, policymakers only have a limited number of indirect mechanisms available to them. Legislative action requires longer response times. Fluctuations in growth, on the other hand, are possible on an interannual basis, requiring a comparatively short response-time horizon. Policymakers can, for example, impose a tax on harvest. On the other hand, one under-explored option may be the possibility of removing the VAT on wood products and re-imposing it when the need arises in order to create a more flexible lever for influencing short term harvest activity.

A ***second alternative*** might be to increase forest cover. However, planting additional new forest is difficult in the Swedish context because such a large share of the land surface is already covered by forest (almost 70%). Moreover, it takes several years before increased forest cover has a meaningful impact on carbon sequestration rates. Further, the EU LULUCF legislative framework will not recognize additional, unlimited benefits from carbon sequestration in standing forests beyond the amounts required by the forest reference level and permitted by the "cap" until the year 2030. Thus, for the immediate future, this alternative is not likely to enjoy widespread support and depends crucially on the size of the "cap" for which individual countries are eligible. For Sweden, the permitted cap is exceptionally small and thus exceedingly difficult to target in a meaningful way.

In future, it is possible that the EU's new carbon farming initiative (CRFC) will supply additional forest growth and carbon sequestration potential. This policy orientation provides an additional space for promoting marginal increases in carbon sequestration and forest growth. The range of strategies open to Member states is quite broad, encompassing "afforestation, species selection, changes in rotation periods, reduced harvest intensity, continuous cover forestry, and peatland management" (Chiti et al., 2026). However, this policy framework as well will not likely be available to most land and forest owners prior to 2030. Moreover, while potentially valuable as a long-term strategy, the ability of the CFRC framework to respond to short-term (i.e., interannual) variation, is presumably limited. Actors can of course promote reforestation strategies or aim to shorten or prolong rotation cycles. But the capacity for such action to respond to sudden changes in forest growth seems limited.

Increasing forest productivity on existing forest land represents a ***third alternative***. Productivity gains can derive from improved forest management, increased use of genetically adapted species selection, fertilization and adjusted rotation periods. Based on current research, fertilization can potentially provide large gains in forest productivity (Bergh et al., 2005, 2003; Högberg et al., 2014; Jacobson and Pettersson, 2010; Petersson et al., 2022; Ryan, 2013; Wester et al., 2023), and potentially represents one of the more rapid-acting measures. Though not suited to fulfilling short-term interannual goals, strategies based on fertilization measures can improve climate benefits

within the context of greater time lags (from 5 to 10 years). Currently, it is primarily the forest industry that engages in fertilization and not private land and forest owners. This is true both because of the costs involved, as well as the fact that more fertilization is carried out in nutrient poor northern Sweden (where the forest industry dominates) and less in southern parts of Sweden (Wester et al., 2023).

Social resistance to increased fertilizer use has stood in the way of change in the forestry sector for several decades. Recent government reports, however, suggest that significantly more fertilization is possible and should perhaps be pursued (*En robust skogspolitik för aktivt skogsbruk. Slutbetänkande av 2024 års skogspolitiska utredning.*, 2025; Höijer et al., 2018). On the other hand, rising fertilizer prices due to unforeseen circumstances (e.g., Covid, war with Iran, the Ukraine war, and rising oil prices) represents a potential limiting factor.

A ***fourth alternative*** concerns increased HWP carbon storage and substitution potential. Significantly increasing *substitution effects* can have very large impacts on the mitigation potential of forest-based resources (Petersson et al., 2022). These goals can be achieved, for example, by encouraging the increased use of long-lived harvested wood products (e.g., via the increased substitution of steel and cement in construction), further increasing the efficient use of existing wood-based resources (Kallio and Rannestad, 2025; Petersson et al., 2022), and by promoting the development of bioenergy with carbon capture and storage (BECCS).

The goal of reducing forest use intensity does not appear to represent a viable alternative strategy. For one, reducing forest use intensity in one location is likely to increase forest use intensity in other regions. "*Leakage*" of this kind likely means that increased forest-based carbon removals in one location will be compensated by reduced removals and increased harvest intensity in other locations. Thus, reductions in Europe likely imply a significant impact on the leakage of forest use intensity to other parts of the world. Though *leakage* is neglected in most scenario analyses (see however (Di Fulvio et al., 2024, 2019; Kallio et al., 2018; Kallio and Garvik, 2026; Kallio and Rannestad, 2025; Kallio and Solberg, 2018; Schier et al., 2022)), leakage potential both undermines the effort to reduce emissions by reducing harvest use intensity, and challenges potentially less stable, and therefore more vulnerable, governance frameworks.

Some of the more immediate leakage effects have already been felt quite prominently, in the reverse sense, in the European marketplace as a result of the Russian war against Ukraine and international sanctions on Russia and Belarussian exports. The resulting shifts in trade provide some evidence for the likelihood of such outcomes, pressuring European consumers to rely more strongly on the local marketplace, boosting prices and increasing harvest intensity (Lööf and Stephan, 2022)(see also: ("Utrikeshandel med skogs- och skogsindustriprodukter," n.d.).

Sweden is not alone in facing challenges related to declining forest growth and rising disturbances (Patacca et al., 2023). Several other EU Member states are likewise experiencing significant and rapidly rising difficulties in meeting European LULUCF sector targets (Ritter et al., 2026). Finland, Estonia, Latvia, Germany, France and others have all witnessed a shift in net growth and a continuously increasing carbon sink to, in some cases at least, becoming a net source of emissions. Finland, for example, announced with some alarm in early 2025 that the forestry sector had become a net source of emissions in 2023, with only the HWP segment retaining a net sink ("Preliminary greenhouse gas inventory results for 2023," n.d.). Germany likewise published a report in October 2024 suggesting that Germany's forests had shifted from a net sink to a net source ("Ergebnisse der vierten Bundeswaldinventur," 2024; "Germany's forests no longer a carbon sink, now net emitters – report | Clean Energy Wire," 2024). In 2026, Ciais and colleagues published a report on the declining

rates of forest growth in France (Ciais et al., 2026). All of these countries report problems with their ability to meet LULUCF targets. For the forest rich countries focus on further development and expansion of the renewable material resource-based circular bioeconomy, forest growth potential has become a significant problem.

Together, all of these factors suggest the imposition of "targets" upon the LULUCF pillar itself represents a problematic and potentially disastrous framework for promoting and achieving climate change mitigation goals. The number one challenge to the integrity of the EU LULUCF commitment strategy appears to be the rapid and occasionally abrupt climate change-related impacts on forest growth wrought by global warming and climate change. The data do not support the frequent observation that harvest practice is out of control. If anything, they suggest that, all other things equal, and assuming that growth had proceeded uninhibited by climate impacts, net removals in standing forests would have likely remained stable or even continued to increase. Though, as highlighted above, harvest practice is buffeted by shifting geopolitical relationships and internal and international demand pressures, the larger problems with the LULUCF framework concern the impacts rising industrial and energy sector emissions have had on global and local weather patterns.

Beyond awareness of increasingly extreme climate-related phenomena (the drying of the landscape, the increased likelihood, frequency and duration of drought, the increased frequency of more violent windstorms, rainfall events, pest outbreaks and wildfires; (Grünig et al., 2026; Patacca et al., 2023)), our inability to fully predict with pinpoint precision when and where such events will occur means such changes, over time, will cause increasingly significant damage. More importantly, perhaps, for our purposes, while most of the alternatives proposed in the literature for adapting to rapid climate change phenomena may improve forest resilience vis-à-vis shifting ecological zones (Hanewinkel et al., 2013; Kremer et al., 2012), significantly less evidence suggests these strategies will likely be effective in the face of many of the more extreme events (excessive drying of the landscape, drought phenomena, wind storms and wildfire).

In addition, without a parallel mechanism that permits adjustments for the wood resource-based benefits that derive from material and energetic substitution, the direct imposition of targets on the LULUCF pillar has the effect of driving a wedge between countries that support the advancement of the renewable, material resource based circular bioeconomy, and those shifting their focus to a biodiversity-oriented forestry model favoring elements such as reduced forest use intensity, mixed forest stands, continuous cover forestry and integrated forest management. For the one group, targets represent a serious and perhaps unacceptable imposition of EU-centered rulemaking, while, for the others, steadily rising LULUCF targets play into the hands of stakeholders who strongly favor reduced forest use intensity and stronger protections for the preservation (and potential increase) of more natural forest cover.

Despite the detrimental effects that derive from imposing targets directly on the LULUCF sector, EU policy efforts thus far have not wavered. Quite simple solutions to this dilemma, however, are available. We highlight two possible alternative strategies. One such strategy is to even the playing field for achieving climate change mitigation goals across the individual segments of the EU climate policy framework. This can be achieved by allowing fully fungible credits/allowances across each of the segments, making it possible to achieve commitment-based climate change mitigation goals in any and all segments. Currently, trading across each segment is regulated by clauses which restrict the total amount of trading. The removal of these barriers would solve this problem and improve the overall efficiency and effectiveness of the system.

A second alternative, however, may be preferable. In this alternative, the LULUCF target would be imposed on the economy-at-large, added as a *floating component* to an individual country's overall emission reduction commitment. By removing the target from the more explicit LULUCF pillar and applying it to the economy-at-large, individual Member states would then have the option to fulfill this component of their commitment through whichever means available to them is most efficient and effective. Thus, for example, when material and energetic substitution have an equal or potentially greater impact than carbon sequestration in standing forests on reducing emissions, Member states and subnational level actors can meaningfully choose between these alternatives without paying the price of *debits*. In the long run, this second option is preferable to the first option, because the explicit and direct imposition of targets on the LULUCF sector is frequently seen both as a commitment, and as a moral obligation, to achieve a fixed amount of carbon sequestration in standing forest.

Overall, the practice of forestry and comparatively intensive forest resource use in the more forest rich countries has resulted in a growth cycle which exceeds that of natural forest cover, and which provides an accelerated rate of carbon sequestration in standing forest. In the long term, reducing forest use intensity has the unfortunate side effect of reducing the total annual amount of net forest growth. Thus, continuously raising LULUCF targets will have a significant impact on future forest growth, biomass availability, and thus the renewable, circular bioeconomy.

5. Conclusions

If the current turnaround in forest growth persists, it may not be necessary to do anything at all in order to be able to fulfill Swedish targets. However, forests, as a carbon sink, are especially difficult to rely upon and guide effectively, especially via short-term political decision making. The forest sink depends on many different factors beyond the control of political authorities, such as growth, mortality, market demand, timber prices, forest owner harvest preferences, etc. The results from the scenario analyses in this study show the large variation in carbon sequestration within the LULUCF framework that can arise because of future growth and harvesting levels. Manipulating these and other factors in the near term is exceedingly difficult and perhaps impossible. Reduction of harvest intensity may be necessary to fulfil the Swedish LULUCF goals by 2030. LULUCF target setting thus represents a significant imposition on national level strategies and goals. Depending on how forest growth evolves in Sweden in the coming years and depending crucially on how the LULUCF framework itself evolves, it may become necessary to institutionalize a methodology for strictly controlling harvest behavior in order to fulfil the proposed LULUCF targets for 2030 and beyond.

The current LULUCF target strategy shifts future climate change mitigation potential into the present by constraining harvest use intensity, but this comes at the cost of limiting future carbon drawdown potential through productive forest resources. As suggested by (Petersson et al., 2022), increasing land use set asides results in significant future long-term loss of total forest-based climate change mitigation potential. This, in fact, has been a persistent finding across a significant number of studies. Reductions in current harvest intensity have negative impacts on future forest growth and climate change mitigation potential. Moreover, the future loss in climate change mitigation potential is greater than the immediate short-term gain. In the worst-case scenario, if substitution effects are high, and if the need to drawdown atmospheric carbon is great in the coming decades, the EU's LULUCF target strategy could have disastrously negative effects, in particular for countries eyeing ways to achieve higher rates of material and energetic substitution. The increasingly integrated structure of the wood product and bioenergy production-based value

chain in some EU Member states will likely be compromised and significantly diminished by strategies geared toward the promotion of carbon removals in standing forests which come at the expense of wood resource production.

Even more concerning, perhaps, is the likelihood that; 1) the leakage of wood-based production to other parts of the world, as well as 2) consumer shifts to complementary but more carbon intensive products, would presumably minimize any potential gains from reduced European harvest intensity. One can imagine a perfect storm of events in which rising targets, declining growth, the recurrence of droughts, pest infestations, windstorms and other extreme events, the resulting leakage pressures and a consumer shift to more fossil fuel intensive complementary products, along with declining future biomass production potential, all conspire to shift global emission reductions in the wrong direction.

Current, LULUCF modeling and target-setting seems contorted, overly complex, and ultimately unsuited to promoting more appropriate forest-based climate change mitigation goals. The failure to recognize the central, climate-relevant contributions of the wood-based sector and thus the failure to adequately incentivize more responsive, energetic and innovative forest sector outcomes seems to be a policy feature (direct outcome) rather than a policy bug (intervening factor) in the EU LULUCF-based climate policy framework. Mobilizing positive, forest-related behavior ultimately requires a strategy that does not progressively undermine future forest investment interests of land and forest owners.

Comparatively simple alternatives for modifying LULUCF policy structure exist which do not challenge the goals of the natural, material resource-based, renewable, circular bioeconomy, and which further provide meaningful incentives for more efficient and effective climate change mitigation strategies. Moreover, the political value in pursuing alternative methodologies lies in their potential to both depoliticize decision-making regarding forest-related add-ons to national emission reduction commitments and to favor increased climate change mitigation ambition. Since target-setting can be structured to harness the benefits of the circular bioeconomy without constraining its objectives, under these conditions, forest industry objectives would likely to shift from resisting LULUCF targets, to favoring their implementation. Likewise, since forest-related add-ons to national emission reduction commitments represent cumulative, additional contributions, this strategy could also potentially go a long way to appeasing stakeholder groups who fear tradeoffs between forest sector removals, and energy and industrial sector emission reductions (offsetting).

For these reasons we respectfully submit; as currently constituted, the EU-based LULUCF target strategy seems designed to fail. Moreover, the costs of imposing such a scenario on the European marketplace in terms of lost income and the reduced availability of a viable, renewable, material resource, seem ill-aligned with national, EU-level and ultimately global climate change mitigation objectives.

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