Closer-to-Nature Forestry

Carbon Removals and Carbon Farming

White Paper

PLOCKHUGGET

Preface

Plockhugget commissioned this white paper to move beyond a narrow, product-only view of biogenic carbon and to connect product-level accounting with the full forest carbon cycle and the EU transition agenda. We anchor the analysis in EU ICOS observations from Swedish boreal sites and, for contrast, from Tharandt (continuous-cover management), and we pair these data with a transparent, conservative model parameterized from Nordic literature to compare clear-cut rotations with Closer-to-Nature forestry. Because Tharandt is the only closer-to-nature forestry ICOS site—and it is in Germany—we treat its signal as indicative rather than definitive for Sweden, underscoring the need for Swedish closer-to-nature forestry ICOS stations to calibrate models and resolve carbon fluxes in forests whose ecosystems remain largely intact.

In this report, carbon farming denotes long-term storage in the forest system (living biomass, litter, soils), while carbon removals denote durable storage in long-lived wood products. Under Closer-to-Nature management we find stronger in-forest stocks and a higher share of long-lived wood products than under clear-cut rotations. Finally, we clarify which biogenic number an EPD reports and how it can be used within SGBC's NollCO2, and we explain why separating management certification from product certificates, and retiring product certificates at the building level, prevents double counting and safeguards carbon farming benefits upstream.

Guide to Readers

This white paper takes you from a short primer on the biogenic carbon cycle and on-the-ground flux observations (EU ICOS) to what they mean for forest management and product accounting and closes with practical guidance and conclusions.

If you're skimming, read the Preface and the Conclusion for the headline message; the figures show the clear-cut emission pulse versus steadier uptake under continuous cover.

To truly understand the carbon cycle, start with "The biogenic carbon cycle of growing forests" and "The impact of forestry on carbon pools", which explain photosynthesis and respiration, litter and humus formation, and how harvesting shifts carbon among pools. Then read "Carbon Removals and Carbon Farming" for how we distinguish in-forest storage from durable storage in long-lived wood products and why Closer-to-Nature management tends to strengthen both.

For practice and reporting, use "Reporting of biogenic carbon removal in EPDs" and "The NollCO2 certification system for buildings" to apply the correct biogenic number.

As you read, use the unit notes in the text ($tC\ ha^{-1}\ yr^{-1}$; $NEE < 0$ = sink; $tCO_2 = 44/12 \cdot tC$) to interpret results consistently.

The biogenic carbon cycle of growing forests

Carbon sequestration in Swedish forests begins in spring as day length-and thus photosynthetic activity-increases. At this time, rising temperatures melt snow and thaw frozen soils, giving roots access to liquid water. Photosynthesis, together with adequate water and nutrient availability, drives new biomass growth. Carbon sequestration peaks during the summer months and then gradually declines in autumn as day length shortens and air temperatures fall.

Meanwhile, forests also return carbon to the atmosphere via both **autotrophic** (**R_a**) and **heterotrophic respiration (R_h)**[1]. Autotrophic respiration occurs when living biomass uses carbohydrates and oxygen to fuel its maintenance and growth processes. When litter (dead plant material on the forest floor - leaves, needles, small branches), below-ground fine root litter and logging residues are decomposed by soil microbes, a large part of that carbon is released back as CO_2 in heterotrophic respiration, while the remaining carbon and microbial debris become incorporated into humus. Humus is the dark, stable organic fraction of the soil that enhances its nutrient- and water-holding capacity. Microbial decomposition of humus is highly sensitive to temperature and the availability of water and nitrogen and approaches zero as soils freeze.

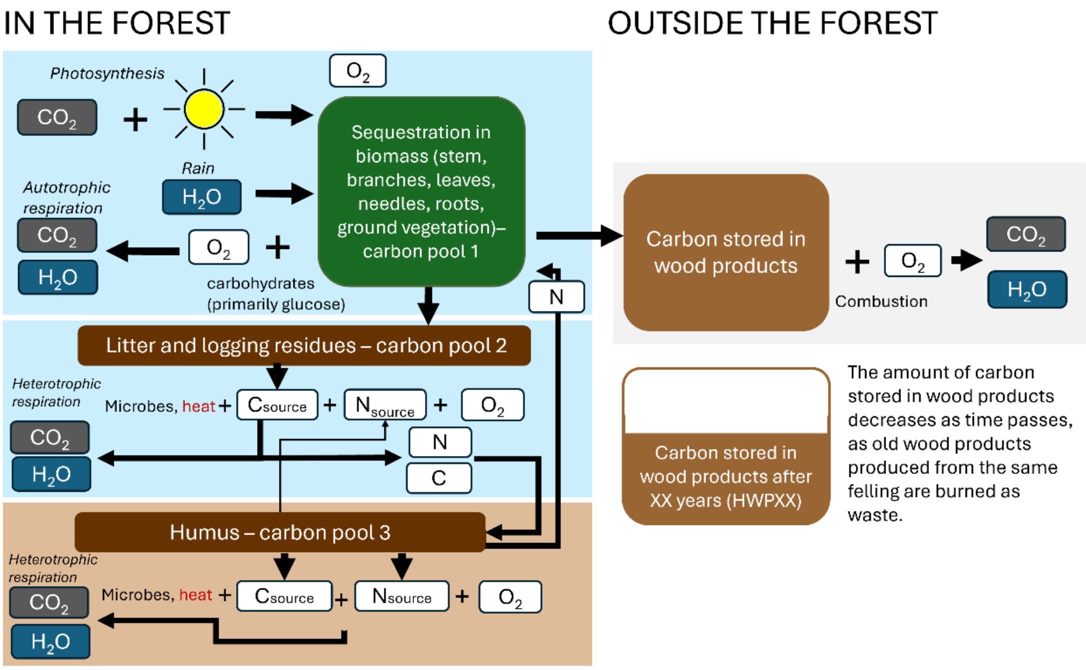

Figure 1 The life cycle of the wood product from a biogenic carbon perspective.

If the soil is exposed by clear-felling, soil microbes will begin decomposing the remaining logging residues, dead fine roots and litter, initially by "borrowing" nitrogen from the existing humus pool, but over time their activity will also release nitrogen back into the humus. Because microbes no longer have to compete with plants for nitrogen, and because site preparation increases oxygen availability, microbial decomposition of carbon accelerates, but how much is

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[1] Högberg, P., Bhupinder, P.S., Ottosson-Löfvenius, M., & Nordgren, A. (2009), *Partitioning of soil respiration into its autotrophic and heterotrophic components by means of tree-girdling in old boreal spruce forest*, Forest Ecology and Management 257.

debated[2]. Emissions from coarse harvest residuals represent the greatest C source after clear-cutting, followed by fine roots and then foliage according to the work by Menichetti et al (2025)[3]. To some extent the increased heterotrophic respiration is offset by the sharp reduction of autotrophic respiration after tree removal. Root respiration ceases and, with little remaining green biomass, the autotrophic respiration drops markedly (near zero in the first year) until ground vegetation re-establishes. Once ground vegetation and new seedlings re-establish and begin competing with soil microbes for available nitrogen, while shading and cooler soils reduce aeration, the elevated heterotrophic respiration of the humus layer subsides, and decomposition rates return toward baseline.

In Figure 1, the carbon pool in growing biomass transfers carbon to the pool of litter and logging residues, which in turn transfers carbon to the humus pool during decomposition. When trees are harvested and processed into wood products, carbon moves into the harvested wood products (HWP) pool. If biomass from a harvest is sent directly to combustion, its entire stored carbon is treated as an immediate CO_2 emission.

Wood products include paper and cardboard, bioenergy, and longer-lived products such as timber cladding and sawn timber. Eventually, these wood products are combusted to produce electricity and heat in combined heat and power plants in Sweden. During combustion, the carbon stored in these products is released as CO_2. The amount of carbon remaining in wood products from a given harvest after a certain number of years is calculated as the **HWP** value.

Carbon dioxide is referred to as **biogenic** when it is part of the natural biological cycle involving living organisms, in contrast to **fossil** carbon, which originates from ancient, deeply buried biomass that has been transformed into coal, oil, or natural gas, which humans use as energy sources, resulting in fossil CO_2 emissions. Although the CO_2 molecules themselves are identical, the distinction between biogenic and fossil carbon is used to differentiate their sources and the roles each carbon type plays in the carbon cycle, with biogenic carbon participating in the continuous exchange between the atmosphere, living organisms, and the soil.

The impact of forestry on carbon pools

The EU has established a large number of ICOS measurement stations in its member states to monitor various ecosystem carbon fluxes[4]. In coniferous forests, ICOS researchers measure, among other variables, Net Ecosystem Exchange (NEE), Gross Primary Productivity (GPP), and ecosystem respiration (Reco) which comprises both heterotrophic and autotrophic respiration and are related as follows:

$$NEE = Reco - GPP = Reco - (NPP + R_a)$$

where

[2] Shahbaz, M., *et al.* (2022), *Spatial heterogeneity of soil carbon exchanges and their drivers in a boreal forest*, Science of the Total Environment 831.
[3] Menichetti, L., *et al.* (2025) *Soil Carbon Dynamics During Stand Rotation in Boreal Forests,* European Journal of Soil Science 76.
[4] ICOS Sweden (2025), https://www.icos-cp.eu/observations/national-networks/sweden

- **NEE is the net exchange** of carbon between the forest and the atmosphere. A negative NEE indicates a carbon sink, and a positive NEE indicates a carbon source.
- **GPP (Gross Primary Productivity)** is the total amount of carbon fixed by photosynthesis in plants within an ecosystem per unit area and time, before any portion is deducted for autotrophic respiration.
- **NPP (Net Primary Productivity)** is the amount of carbon remaining as new biomass after subtracting the plants' own respiration (R_a), i.e. NPP = GPP – R_a. NPP can be estimated using growth models.
- **Reco** stands for ecosystem respiration, i.e., the total respiration of the ecosystem. It is the sum of autotrophic respiration (R_a) and heterotrophic respiration (R_h).

Figure 2 presents data from the EU ICOS station in the Norunda forest, which is part of the Swedish boreal forests just north of the city of Uppsala[5]. In late summer 2022, a 30-hectare area with a 300 m radius around the main flux tower was clear-felled. The entire stand of 100-year-old Scots pine and Norway spruce, along with a smaller proportion of deciduous trees and the understorey vegetation, was harvested. The site is a drained peatland, and logging residues were left in place.

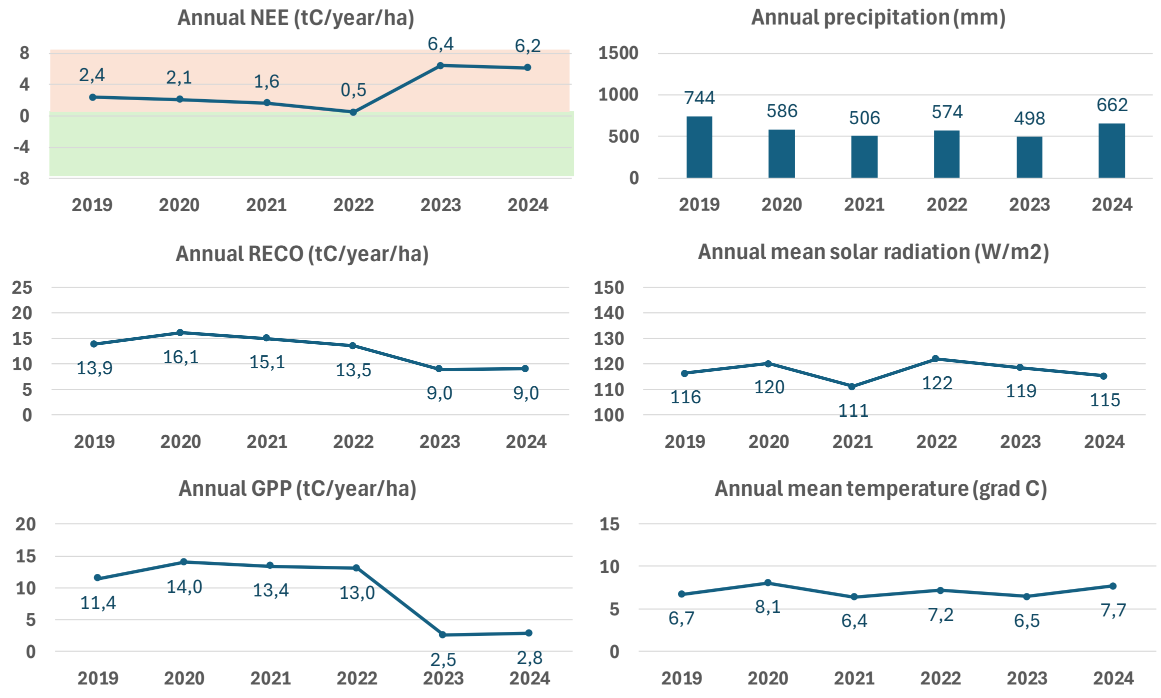

Figure 2 Norunda ICOS Flux station data compilation. NEE < 0 denotes net uptake (sink).

Figure 2 illustrates that, after clear-felling, GPP virtually stops due to a stop in photosynthetic carbon uptake while the large residue pulse after the clear-cut harvest causes an elevated Reco in the first years, resulting in a total annual emission of 6.2–6.4 tC $ha^{-1}yr^{-1}$ for the first two years, equivalent to 23 tCO_2 ha^{-1} yr^{-1}. These measurements are in good agreement with those reported

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[5] ICOS Sweden (2025), Norunda station, Kljun, N., Mölder, M., Lehner, I., Bergström, G., Båth, A., Holst, J., Linderson, M. (2025). ETC L2 Fluxnet (half-hourly) from Norunda, 2017-12-31–2024-12-31, ICOS RI, https://hdl.handle.net/11676/epwZ7_H-gvTQ5kb83RnDf6bz

by Tikkasalo et al. (2025)[6] in their study of carbon fluxes following clear-felling on drained peatland. With logging residues left on site, Tikkasalo et al. documented a CO_2 emission of approximately 23 tCO_2 ha^{-1} yr^{-1} during the first year after harvesting. At an illustrative EU ETS carbon price of SEK 800 per tCO_2 (as of April 2025), an emission of 23 tCO_2 ha^{-1} yr^{-1} would incur a cost of SEK 18 400 ha^{-1} yr^{-1} if forestry emissions were included in the ETS[7].

The Tharandt Forest in northeastern Germany is a 140-year-old spruce stand growing on podzolized brown earth. Around 1800, the original forest had been heavily logged, but it was replanted by Johann Heinrich Cotta. Beginning in 1811, Cotta applied “scientific principles” here, creating one of Europe’s first models of Closer-to-Nature forestry. Today, the stand is about 81% spruce, 7% pine, 9% larch, and 3% birch[8]. Figure 3 shows a compilation of data from the ICOS Germany Tharandt station[9]. It illustrates how the Tharandt Forest continues to store large amounts of carbon each year. No clear-felling disrupts this pattern, instead, harvesting is done through selective thinnings and small-scale removals, maintaining continuous canopy cover, structural diversity, and ongoing natural regeneration.

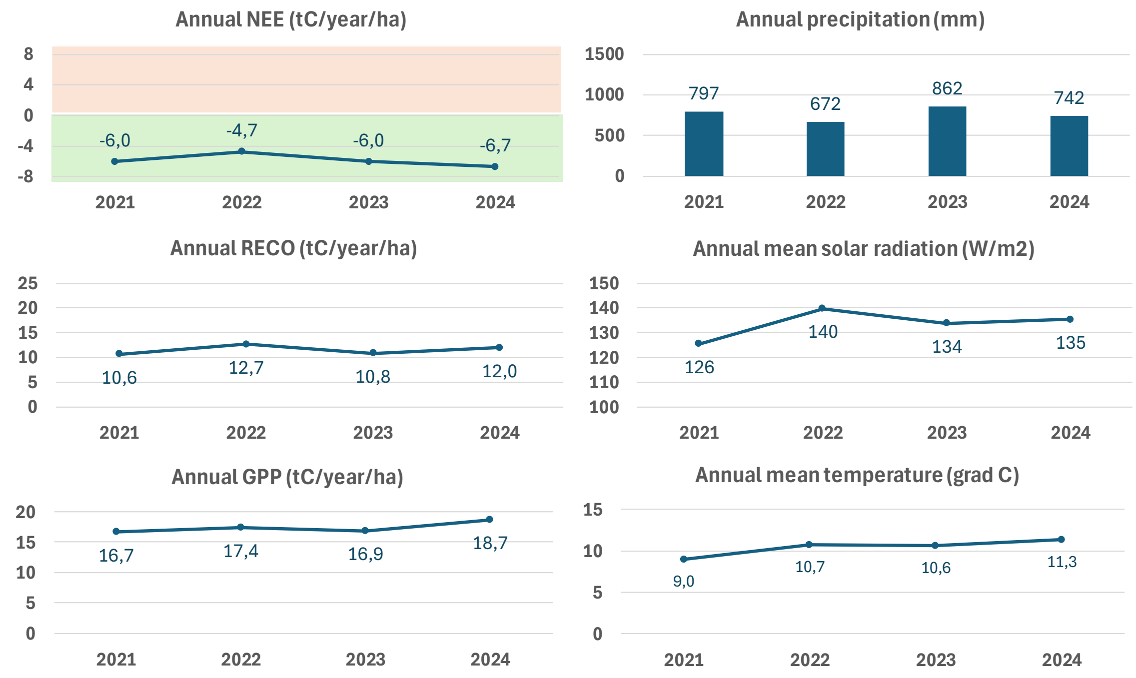

Figure 3 Tharandt ICOS Flux station data compilation. NEE < 0 denotes net uptake (sink).

The Tharandt forest’s carbon uptake averages about 24 tCO_2 ha^{-1} yr^{-1}, dropping to around 17 tCO_2 ha^{-1} yr^{-1} in particularly dry years. Between 2021 and 2024, Tharandt stored an average of

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[6] Tikkasalo, A, *et al*. (2025), *Eddy-covariance fluxes of CO2, CH4 and N2O in a drained peatland forest after clear-cutting*, Biogeosciences 22.
[7] EU (2003), *Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community*, Official Journal of the European Union.
[8] Grünwald, T., *et al.* (2025), *Carbon fluxes controlled by land management and disturbances at a cluster of long-term ecosystem monitoring sites in Central Europe*, Agricultural and Forest Meteorology 369.
[9] ICOS Germany (2025), Tharandt station, Bernhofer, C., Eichelmann, U., Grünwald, T., Hehn, M., Mauder, M., Moderow, U., Prasse, H. (2025). ETC L2 Fluxnet (half-hourly) from Tharandt, 2019-12-31–2024-12-31, ICOS RI, https://hdl.handle.net/11676/mnCNEn9_x9ZvpacEOT-GtGb9

22 tCO_2 ha^{-1} yr^{-1}. At the same illustrative EU ETS carbon price as in previous example of SEK 800 per tCO_2, that sequestration is worth SEK 17 600 ha^{-1} yr^{-1}. Over 70 years, it would amount to roughly SEK 1 200 000 per hectare, if forestry carbon uptake had been included in the ETS.

To illustrate how carbon uptake varies between different conifer forests, consider Hyltemossa in southern Sweden, just outside Perstorp. This 43-year-old Norway spruce stand grows on sandy moraine over brown earth. Figure 4 illustrates a compilation of data from the ICOS Sweden Hyltemossa station[10]. Hyltemossa's annual carbon balance has swung from a net uptake of -2.8 tC ha^{-1} yr^{-1} to a net release of 1.5 tC ha^{-1} yr^{-1} over the past four years. Growth in the Hyltemossa forest dipped in 2023 but recovered in 2024, yet Reco rose over the same period, turning its NEE into a net carbon release. The underlying cause is still under investigation.

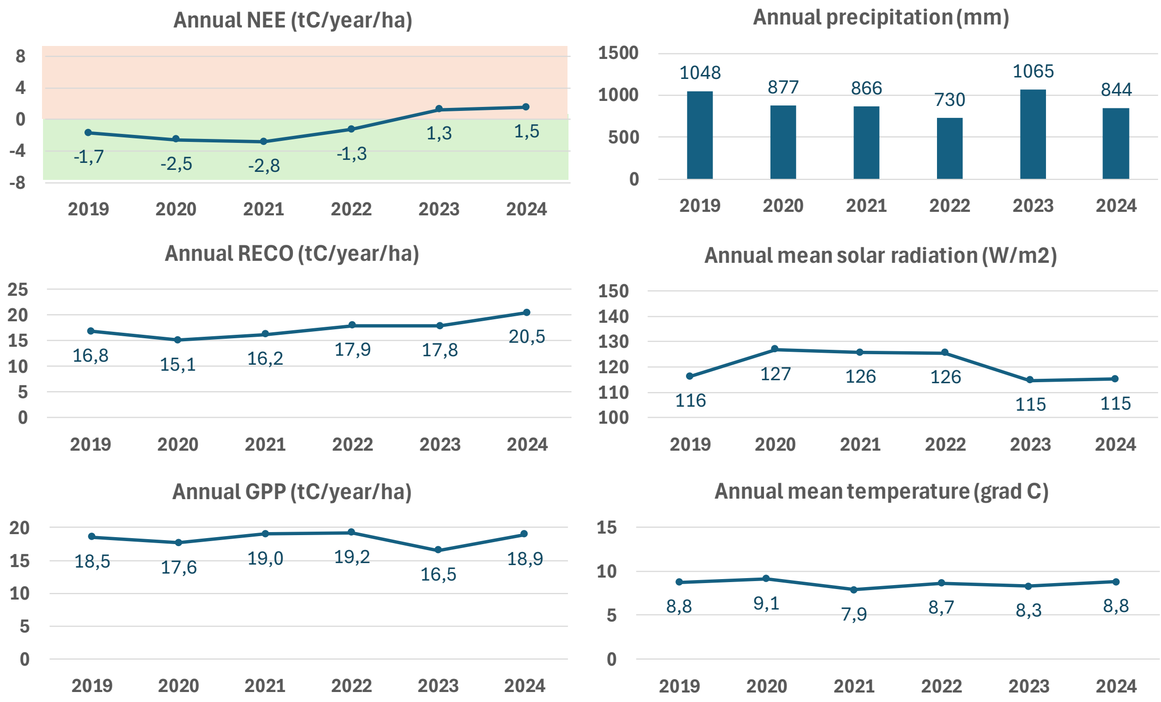

Figure 4 Hyltemossa ICOS Flux station data compilation. NEE < 0 denotes net uptake (sink).

A more northerly spruce–pine mix is the 100-year-old stand at Svartberget (60% pine, 40% spruce) outside the town of Umeå in northern Sweden. The dominating soil type is moraine.

The experimental forest covers 1076 ha of boreal forest land and governs a manifold of research activities since 1923. Figure 5 illustrates a compilation of data from the ICOS Sweden Svartberget station[11]. Svartberget's carbon fluxes appear more stable than Hyltemossa's, but its annual carbon sequestration the last four years is lower, with a NEE around –0.5 t C ha^{-1} yr^{-1}.

[10] ICOS Sweden (2025), Hyltemossa station, Heliasz, M., Kljun, N., Biermann, T., Holst, J., Holst, T., Kornacher, P., Linderson, M., Mölder, M., Rinne, J. (2025). ETC L2 Fluxnet (half-hourly) from Hyltemossa, 2017-12-31–2024-12-31, ICOS RI, https://hdl.handle.net/11676/rnCmH1Z5GgIDXIq4kJ6GdZOb

[11] ICOS Sweden, Svartberget station, Peichl, M., Nilsson, M., Larmanou, E., Smith, P., Marklund, P., De Simon, G., Lofvenius, P., Dignam, R., Holst, J., Mölder, M., Andersson, T., Boschetti, F., Kozii, N., Linderson, M., Ottosson-Löfvenius, M. (2025). ETC L2 Fluxnet (half-hourly) from Svartberget, 2018-12-31–2024-12-31, ICOS RI, https://hdl.handle.net/11676/N2bJqUpBn5_YfjmxWf6KOvsi

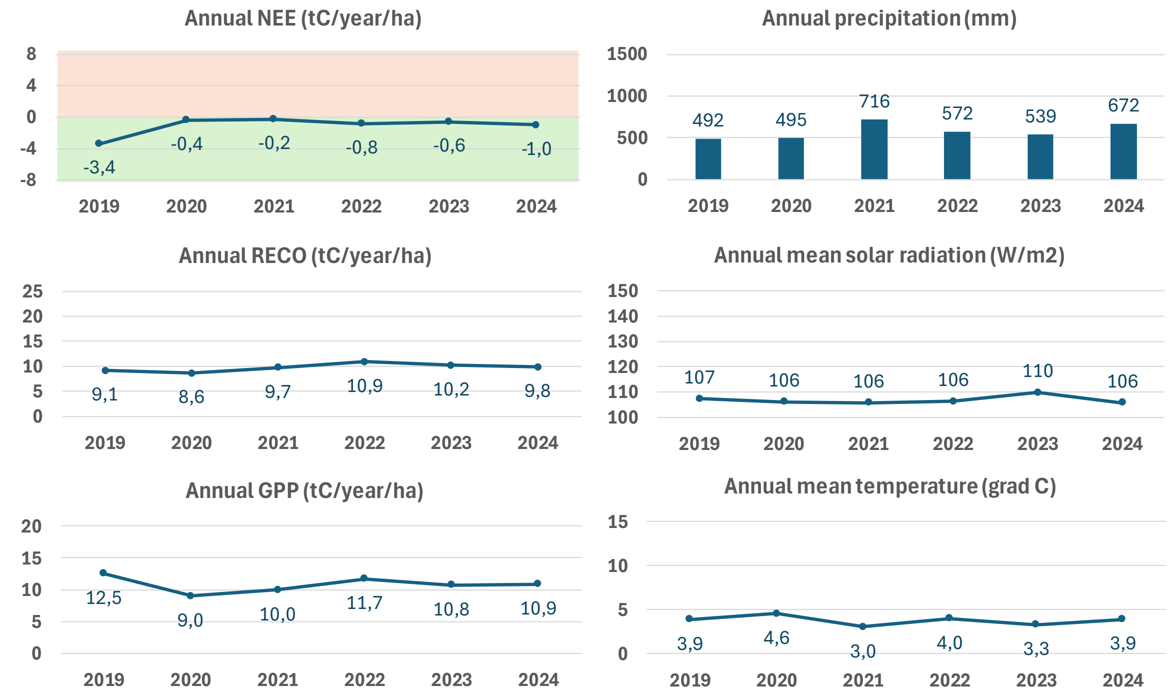

Figure 5 Svartberget ICOS Flux station data compilation. NEE < 0 denotes net uptake (sink).

Carbon Removals and Carbon Farming

Under the EU's Carbon Removals and Carbon Farming certification (CRCF)[12] regulation, "carbon farming" encompasses land-based practices that enhance the farming of CO_2 in soils and vegetation and "Carbon removals" include CO_2 to be stored as carbon in long-lived wood products. By quantifying changes in carbon pools such as living biomass, litter, and soil organic matter, carbon farming projects can generate certified "carbon removal units" for climate mitigation. These activities must demonstrate additionality relative to a defined reference scenario and include robust monitoring, reporting, and third-party verification.

To illustrate the scale of carbon-pool changes for the carbon farming activity "Converting to Closer-to-Nature forestry" from the Swedish baseline scenario "Clear-cut rotation forestry", we ran a simple simulation using published data from peer-reviewed scientific papers and carbon-flux measurements from the Swedish EU ICOS stations for evergreen needleleaf forests. Since we assume that the total machinery input required for a full harvest every 90 years is equivalent to that for periodic 15-year thinnings over the 45-year (or 90-year) period, we have excluded machinery-related fossil CO_2 emissions from our analysis and fully focused on biogenic CO_2.

We assumed a clear-cut age of 90 years for the baseline scenario. The growth curve, a series of discrete 15-year growth increments, for pine and spruce is based on a growth model reported in the Finnish study by Parkatti et al (2019)[13], with slight adjustments to harmonize with Plockhugget's "Forester" simulation program results for a 90-year rotation forestry. According to

[12] https://climate.ec.europa.eu/eu-action/carbon-removals-and-carbon-farming_en
[13] Parkatti, V.-P., *et al.* (2019), *Economics of boreal conifer species in continuous cover and rotation forestry*. *Forest Policy and Economics 100: 55-67.*

"Forester," the forest in the baseline scenario, after 90 years, has the basal area distribution of 44% spruce, 42% pine, and 14% birch. The self-sown birch is thinned by 50% twice, allowing it to self-sow again and reach a basal area proportion of 14% by age 90. In this Closer-to-Nature forestry, the harvest is 25–30% of the stand every 15 years. We assumed that sawlog yield under Closer-to-Nature forestry is 50%, more than double the 21% yield under clear-cutting forestry. We modelled the 90-year period beginning with clear-cutting in the baseline scenario and beginning with the conversion to Closer-to-Nature forestry in the carbon farming activity "conversion to Closer-to-Nature forestry ". All carbon flux inputs (NEE, litter and humus formation, and NPP in wood, leaves, needles, roots, and branches relative to stem growth) were sourced from peer-reviewed studies of Swedish and Finnish boreal needleleaf forests [14, 15, 16, 17, 18, 19]. The time to carbon balance (CB), i.e. the year when carbon emissions are equal to carbon uptake again after the clear-cut, was set to 10 years based on the discussion by Lindroth (2023)[20].

Figure 6 contrasts simulated carbon-flux trajectories under clear-cut rotation (left) versus conversion to Closer-to-Nature forestry (right). After clear-cutting, autotrophic respiration ceases and heterotrophic respiration exceeds GPP, yielding positive NEE (net emissions) for ~10 years. In line with Menichetti et al. (2025) [3], the early-year emissions are dominated by decomposing coarse logging residues, with decomposing of below-ground dead fine roots the second-largest source and decomposing of litter the third largest. The modelled NEE curve, after the baseline scenario's first 10 years, oscillates around zero, mainly due to our digital growth curve with 15 years intervals.

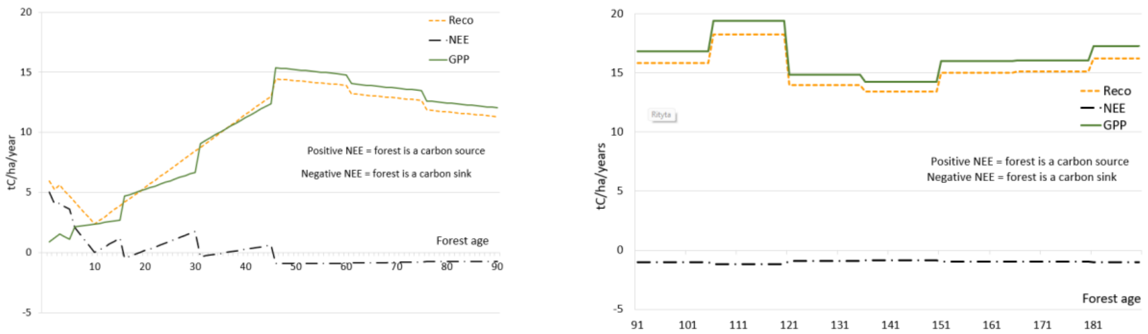

Figure 6 Simulated NEE, GPP, and Reco curves for the baseline scenario "Clear-cut rotation forestry" following clear-cut harvest (left), versus the carbon farming "Conversion to Closer-to-Nature forestry" (right). NEE < 0 denotes net uptake (sink).

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[14] Vestin P., *et al.* (2020), *Impacts of Clear-Cutting of a Boreal Forest on Carbon Dioxide, Methane and Nitrous Oxide Fluxes,* Forests 11.
[15] Ilvesniemi, H., *et al*. (2009), *Long-term measurements of the carbon balance of a boreal Scots pine dominated forest ecosystem*, Boreal environment research 14.
[16] Berg, B. (2018), *Decomposing litter; limit values; humus accumulation, locally and regionally*, Applied Soil Ecology 123.
[17] Berg, B., *et al.* (2007), *Carbon Sequestration Rates in Swedish Forest Soils – a Comparison of Three Approaches*, Silva Fennica 41(3).
[18] Persson, H.Å., Stadenberg, I. (2010) *Fine root dynamics in a Norway spruce forest (Picea abies (L.) Karst) in eastern Sweden*. Plant Soil 330.
[19] Svensson, M. (2009), *Carbon dynamics in spruce forest ecosystems - modelling pools and trends for Swedish conditions*, PhD Thesis, KTH Architecture and the Built Environment.
[20] Lindroth, A. (2023). Clarifying the carbon balance recovery time after clear-cutting. *Global Change Biology*, *29*(15).

Under Closer-to-Nature management, GPP stays steadier, dipping only briefly around each 15-year selective harvest, after which growth rebounds in the regenerating cohort and surrounding trees. The periodic, modest residue inputs from these selective cuts have only a limited, short-lived effect on respiration, far smaller than after a clear-cut, consistent with Menichetti et al. (2025)[3], whose model found thinning effects on respiration to be minor.

Table 1 presents how each carbon pool changes over a 45-year period under the baseline scenario and the carbon farming scenario. Under the baseline scenario, the living biomass carbon pool loses 74 tC ha^{-1} because the entire stand is harvested and the regrowth of replanted trees cannot recapture that carbon within four decades. The litter pool initially experiences a drop in input from needles, leaves, and twigs, but the loss is offset by the large addition of logging residues. The humus pool initially loses carbon due to decomposition of fine roots material and, in our model, only returns to net zero after about 30 years. This is optimistic relative to Menichetti et al., where the soil-carbon pool returns to net zero only after ~69 years (Scots pine) and ~37 years (Norway spruce). Finally, HWP45 shows only a modest increase in sequestered carbon, since just 21 % of the harvested timber is directed into long-lived products, with the remainder going to bioenergy or short-lived paper and cardboard products.

For the conversion to Closer-to-Nature forestry, the change in the living biomass pool over 45 years is modest because only small harvests are taken every 15 years and gaps are naturally restocked by seedlings. Since the stand remains almost intact, the litter pool is larger than for the baseline scenario, and there is no major rise in heterotrophic respiration due to large amounts of coarse logging residues. More carbon flows into the humus carbon pool and the HWP45 value is higher because Closer-to-Nature forestry yields a much greater share of long-lived wood products.

Table 1 Carbon Farming and Carbon Removals over the 45-year calculation period

Change in forest carbon pools	Baseline scenario clear-cut + 45 years.	Carbon farming conversion + 45 years.
Δ Living biomass	release: 74 tC ha^{-1}	release: 2 tC ha^{-1}
Δ Litter & residues	sequestration: -9 tC ha^{-1}	sequestration: -13 tC ha^{-1}
Δ Humus	sequestration: -2 tC ha^{-1}	sequestration: -10 tC ha^{-1}
Δ Total	release: 63 tC ha^{-1}	sequestration: -21 tC ha^{-1}
Change in wood products carbon pool	Baseline scenario clear-cut + 45 years.	Carbon farming conversion + 45 years.
HWP45 sawn wood	sequestration: -5.1 tC ha^{-1}	sequestration: -17 tC ha^{-1}
HWP45 wood panels	sequestration: -0.1 tC ha^{-1}	sequestration: -0.5 tC ha^{-1}
HWP45 paper & cardboard	sequestration: 0.0 tC ha^{-1}	sequestration: 0.0 tC ha^{-1}
HWP45 total	sequestration: -5.2 tC ha^{-1}	sequestration: -18 tC ha^{-1}

Carbon Farming value after 45 years compared to baseline = -21 - 63 = - 84 tC ha^{-1}
Carbon Removals value after 45 years compared to baseline = -18 - -5 = - 13 tC ha^{-1}

Carbon Farming value for 383 m^3sk/ha harvested timber after 45 years	-805 $kgCO_2/m^3$sk	-1.6 $kgCO_2$/kg
Carbon Removals value for 383 m3sk/ha harvested timber after 45 years	-120 $kgCO_2/m^3$sk	-0.2 $kgCO_2$/kg
Total Carbon Removals and Farming value for 383 m^3sk/ha harvested timber after 45 years	-925 $kgCO_2/m^3$sk	-1.9 $kgCO_2$/kg

**Absolute numbers from our simplified model, but they should be interpreted as indicative. 1m^3sk ~ 491 kg*

Table 2 presents how each carbon pool changes over a 90-year period under the baseline scenario and the carbon farming “Converting to Closer-to-Nature forestry”. The living biomass carbon pool in the baseline scenario is after 90 years fully regrown into the 90-year cycle’s starting value, hence no change. The litter and logging-residues carbon pool has decreased slightly as the logging residues have decomposed, while the humus carbon pool has increased. The carbon stock remaining in wood products after 90 years, HWP90, has decreased from its HWP45-year value.

For the carbon farming “Conversion to Closer-to-Nature forestry”, the living biomass carbon pool has increased slightly, the litter and logging residues carbon pool has also increased slightly while the humus carbon pool has increased drastically. Because we continuously replenish the HWP pool with new wood products every 15 years through selective logging, the carbon stock in harvested wood has grown. In other words, because we calculate the HWP carbon stock at a specific year, a stream of regular selective-harvest additions accumulates (and replaces what has decayed), so the cumulative removal by that year is larger than from a single large input from the year of the clear-cut.

Table 2 Changes in carbon pools over the 90-year simulation period*

Change in forest carbon pools	Baseline scenario clear-cut + 90 years.	Carbon farming conversion + 90 years.
Δ Living biomass	release: 0 tC ha^{-1}	sequestration: -4 tC ha^{-1}
Δ Litter & residues	sequestration: -8 tC ha^{-1}	sequestration: -12 tC ha^{-1}
Δ Humus	sequestration: -10 tC ha^{-1}	sequestration: -19 tC ha^{-1}
Δ Total	sequestration: -18 tC ha^{-1}	sequestration: -35 tC ha^{-1}
Change in wood products carbon pool	Baseline scenario clear-cut + 90 years.	Carbon farming conversion + 90 years.
HWP90 sawn wood	sequestration: -2.1 tC ha^{-1}	sequestration: -22 tC ha^{-1}
HWP90 wood panels	sequestration: 0.0 tC ha^{-1}	sequestration: -0.6 tC ha^{-1}
HWP90 paper & cardboard	sequestration: 0.0 tC ha^{-1}	sequestration: 0.0 tC ha^{-1}
HWP90 total	sequestration: -2.1 tC ha^{-1}	sequestration: -22.3 tC ha^{-1}
Carbon Farming value after 90 years compared to baseline = -35 - -18 = -17 tC ha^{-1}		
Carbon Removals value after 90 years compared to baseline = -22- -2 = - 20 tC ha^{-1}		
Carbon Farming value for 644 m^{3}sk/ha produced timber after 90 years	-97 kgCO_2/m^{3}sk	-0.2 kgCO_2/kg
Carbon Removals value for 644 m^{3}sk/ha produced timber after 90 years	-115 kgCO_2/m^{3}sk	-0.2 kgCO_2/kg
Total Carbon Removals and Farming value for 644 m^{3}sk/ha produced timber after 90 years	- 212 kgCO_2/m^{3}sk	- 0.4 kgCO_2/kg

**Absolute numbers from our simplified model, but they should be interpreted as indicative. 1m^{3}sk ~ 491 kg.*

In 2050 (in 25 years from this report’s publication)

Table 3 shows how each carbon pool changes by 2050 (25 years from this report’s publication) under the baseline and Closer-to-Nature scenarios. As in the 45-year comparison, the baseline loses a large share of living biomass at harvest; by year 25, regrowth has not recaptured this carbon. The humus (soil organic carbon) pool also remains net negative at year 25 in our model. The Closer-to-Nature scenario therefore delivers a much larger Carbon Farming value, –4.1 kg CO_2 per kg wood.

For a building certification targeting net zero in 2050, this means the project can account not only for Carbon Removals (typically the sum of EPD biogenic values for the wood products installed) but also add a Carbon Farming component, in our case **-4.1 kgCO_2 per kg wood product**, reflecting in-forest stock changes over the same 25-year window—provided the units are sourced from closer-to-nature–certified harvests.

In the near future, when CRCF methods are published, it's likely that simply summing EPD biogenic values will be replaced by an HWP-at-target-year calculation of a building's in-situ carbon. Whether that HWP approach will align exactly with the IPCC method remains to be seen.

Table 3 Carbon Farming and Carbon Removals over the 25-year calculation period

Change in forest carbon pools	Baseline scenario clear-cut + 25 years.	Carbon farming conversion + 25 years.
Δ Living biomass	release: 114 tC ha^{-1}	release: 15 tC ha^{-1}
Δ Litter & residues	sequestration: -7 tC ha^{-1}	sequestration: -18 tC ha^{-1}
Δ Humus	release: 1 tC ha^{-1}	sequestration: -5 tC ha^{-1}
Δ Total	release: 108 tC ha^{-1}	sequestration: -8 tC ha^{-1}
Change in wood products carbon pool	Baseline scenario clear-cut + 25 years.	Carbon farming conversion + 25 years.
HWP25 sawn wood	sequestration: -7.6 tC ha^{-1}	sequestration: -16 tC ha^{-1}
HWP25 wood panels	sequestration: -0.2 tC ha^{-1}	sequestration: -0.5 tC ha^{-1}
HWP25 paper & cardboard	sequestration: 0.0 tC ha^{-1}	sequestration: 0.0 tC ha^{-1}
HWP25 total	sequestration: -7.8 tC ha^{-1}	sequestration: -16 tC ha^{-1}
Carbon Farming value after 25 years compared to baseline = -8 - 108 = - 116 tC ha^{-1}		
Carbon Removals value after 25 years compared to baseline = -16 - -8 = - 8 tC ha^{-1}		

Carbon Farming value for 211 m^3sk/ha produced timber after 25 years	-2020kgCO_2/m^3sk	-4.1 kgCO_2/kg
Carbon Removals value for 211 m^3sk/ha produced timber after 25 years	-146 kgCO_2/m^3sk	-0.3 kgCO_2/kg
Total Carbon Removals and Farming value for 211 m^3sk/ha produced timber after 25 years	- 2167 kgCO_2/m^3sk	-4.4 kgCO_2/kg

**Absolute numbers from our simplified model, but they should be interpreted as indicative. 1m^3sk ~ 491 kg*

Conclusion

Converting from clear-cut rotation to Closer-to-Nature forestry strengthens the forest's role as a carbon sink by keeping continuous canopy cover, sustaining litter inputs, and moderating post-harvest respiration. In our simulations, Closer-to-Nature maintains standing biomass and channels a larger share of harvested carbon into long-lived wood products (HWP), whereas the baseline clear-cut creates a prolonged biomass deficit, an early-year decomposition pulse from coarse residues and dead fine roots, and a delayed recovery of soil organic carbon (humus).

Across multi-decadal horizons (45/90 years), the direction of change is consistent: Closer-to-Nature reduces post-harvest emissions, stabilizes net ecosystem exchange, and increases the portion of harvested carbon that remains stored in durable products. The baseline's clear-cutting and replanting fail to recapture the lost biomass within the shorter horizon and only partially close the gap over longer periods.

Our treatment of soils reflects current evidence. Early emissions after clear-cut are driven primarily by residue decomposition; humus recovers slowly and, in our model, returns to net zero only after ~30 years (longer in some published studies). Thinnings/selection harvests have far smaller soil-carbon effects than clear-cuts, which supports the case for Closer-to-Nature's steadier profiles of both GPP and respiration.

To align with net-zero targets in 2050, we also evaluate stocks at year 25 from this report's publication. By 2050, the baseline still carries a substantial biomass deficit, and the humus pool remains net negative, while Closer-to-Nature forestry keeps the stand largely intact and sustains soil inputs. As a result, *Closer-to-Nature forestry delivers a much larger Carbon Farming value at 25 years——**4.1 kg CO_2 per kg wood relative to the baseline**—and a higher HWP 25 because a greater fraction of harvests becomes long-lived products*.

For building projects seeking net zero by 2050, we therefore recommend: calculating Carbon Removals with HWP (rather than summing EPD biogenic values), and add a separate, verified Carbon Farming component when timber is sourced from Closer-to-Nature-certified harvests. This links site-level forest outcomes to project-level accounting at the decision year.

Uncertainty remains intrinsic to long-range carbon accounting. Climate-change stressors (droughts, extreme rainfall, higher temperatures, shifting disturbance regimes) can alter both photosynthesis and respiration; species choice and site conditions matter; and product lifetimes/end-of-life pathways influence HWP stocks.

Reporting of biogenic carbon removal in EPDs

An Environmental Product Declaration (EPD) under the standard EN 15804 reports only the biogenic carbon removed and stored in the wood product itself, and the carbon emitted as CO_2 at the end of the wood product's life. The biogenic GWP value reported in an EPD is identical whether the wood comes from clear-cut forestry or Closer-to-Nature forestry. One (1) kg of wood of the same species and moisture content stores the same amount of carbon regardless of forest management method.

The NollCO2 certification system for buildings

NollCO2[21] is the Sweden Green Building Council's certification system for net-zero carbon buildings. It requires that a building's life-cycle carbon impact falls below a limit value set along the pathway to the IPCC's 2050 climate targets. Any remaining emissions, once the limit value has been reached, must be balanced by climate actions-one such action is purchasing Closer-to-Nature certificates from Plockhugget that correspond exactly to the volume of long-lived wood products for which the project intends to claim the biogenic GWP balancing value. This ensures that the wood products' carbon removal does not come at the expense of carbon farming in the forestry.

If an EPD is not available, the NollCO2 balance value can be calculated as follows:

On average, wood is composed of 50 % carbon by weight. Accordingly, the European standard SS-EN 16449 specifies the carbon fraction c_f in wood biomass as 0.5.

Moisture content has a significant effect on wood's dimensions and density: as moisture decreases, the wood shrinks and its density falls. The amount of biogenic carbon stored in a wood product is determined by its volume V_ω and density ρ_ω at a given moisture content ω, where $\omega = 0{,}12$ is the standard reference level.

When the carbon in the wood is released and binds with oxygen, carbon dioxide is formed, with one mole of carbon combining with two moles of oxygen. The atomic weight of carbon is 12 u and that of oxygen is 16 u, giving carbon dioxide a molecular weight of 44 u. The amount of biogenic carbon dioxide produced when the stored biogenic carbon in the tree stem is released and bound to oxygen is then:

$$\text{GWP biogenic } = \frac{44}{12} \times c_f \times \frac{\rho_\omega \times V_\omega}{1+\omega}\ (kgCO_2)$$

Using generic values:

$$\text{GWP biogenic } = 1{,}64 * \rho_{0,12\%} * V_{0,12\%}\ (kgCO_2) = 1{,}64 * m_{0,12\%} (kgCO_2)$$

For 1 kg wood where $\omega = 0{,}12$:

$$\mathbf{GWP\ biogenic\ = 1,64\ kgCO_2/kg}$$

For 1 m^3sk spruce wood where $\rho_{0,12\%} = 460\ kg/m^3$:

$$\text{GWP biogenic } = 1{,}64 * 460 = 754\ kgCO_2/m^3sk$$

For 1 m^3sk pine wood where $\rho_{0,12\%} = 520\ kg/m^3$:

$$\text{GWP biogenic } = 1{,}64 * 520 = 858\ kgCO_2/m^3sk$$

[21] https://www.sgbc.se/certifiering/nollco2/

Contact us

For more information on Closer-to-Nature forestry and Plockhugget's certification-or to explore how we can help you achieve your sustainability goals-please get in touch with us at:

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This white paper was prepared 2025 on behalf of Plockhugget by Pia Stoll Konsult AB (info@piastoll.se, https://piastoll.se) including all data analysis and modelling.

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