Past and future climate effects of the Norwegian and Swedish forest-based sector

Peter Holmgren

Tittel: Past and future climate effects of the Norwegian and Swedish forest-based sector

Forfatter: Peter Holmgren.

Om forfatteren: Peter Holmgren er ansatt i FutureVistas. Holmgren har lang erfaring fra internasjonalt arbeid med skog, miljø og klima. Han har blant mye annet ledet det internasjonale skogforskningsorganet CIFOR og vært leder for FAOs skogressursutviklingsprogram, og videre stått for koordinering av hele FAOs arbeid relatert til klimaendringer. Holmgren har tidligere laget tilsvarende beregninger for den svenske skog- og trebaserte verdikjeden.

Dato: 06.2024

Sider: 28
Språk: English/engelsk, med norsk oversettelse av sammendraget.
Foto forside: Fotoknoff, Rune Hedegart/WoodWorks! Kollasj: Øyvind Malum, WOW Medialab
Layout: WOW Medialab

Kommentar fra oppdragsgiver

Skogen og brukandet av trävirke har stor klimateffekt i Norge och Sverige. Hittils har man inte haft en tillräckligt bra översikt av den totala effekten i Norge, medan Skogsindustrierna tidigare har tagit fram en översikt för Sverige.

Forumet Nordic Green Business Forum har sett behovet för att dokumentera och synliggöra den samlade klimateffekten av skogsbruket och användandet av trä i samhällets tjänst. Rapporten är beställd från Dr Peter Holmgren i FutureVistas, som vi menar har de bästa förutsättningarna för att ta en fram en sådan sammanställning. Vi tackar för ett gott genomfört arbete.

Denna rapporten visar med all tydlighet att ett aktivt skogbruk är det sätt vi kan bruka skogen på för att uppnå största möjliga klimatnytta i dagens situation. Skogens största klimatbidrag är att leverera förnybara resurser till samhället, som ersättning till fossilbaserade produkter, och därmed förhindra CO_2-utsläpp. Detta kräver att vi avverkar träd, timmer, och gör allt vi kan för att producera samhällsnyttiga varor av dessa.

Man kan räkna sig fram till att skogen kan ta upp CO_2 genom att reducera uttaget av skog eller bara låta den stå orörd. Men detta leder till en kortvarig effekt, som relativt snabbt kommer att avta. Risken för skador i de gamla skogarna är dessutom stor, och ökar med klimatförändringarna, i form av torka och påföljande insekts- och svampangrepp samt ökande fara för skogsbränder. En sådan strategi är kontraproduktiv, genom att man då inte utnyttjar skogens resurser till att ersätta produkter från fossila källor.

När man tittar på den totala skog- och träbaserade värdekedjans klimatnyttan, är det helt avgörande att se på hela värdekedjans totala klimatnytta. Idag skiljer rapporteringen på det som sker i skogen och effekten av att bruka skogsresurserna. Det medför att det är andra sektorer som får tillgodoräkna sig den positiva klimateffekten av att använda skogsråvara, medan skogsbruket belastas med att skogsavverkning räknas som utsläpp. Vi hoppas att rapporten kommer att bidra till en enhetlig och bra värdering av hur vi bäst använder vår skog och våra skogsprodukter i klimatsammanhang för att hindra CO_2-utsläpp.

Gunnar Olofsson
Styreleder i Statskog og leder i styret for Nordic Green Business Forum

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Contents

Summary

- Current structures in climate policy and reporting limit the role of forests to storing carbon. This means that harvesting of wood is always considered a loss, without accounting for gains when renewable wood-based products substitute alternatives in other economic sectors;

- This report provides an analysis of past and future climate performance of the forest-based sector in Norway and Sweden. It takes into account storage of carbon in forests and products, value chain emissions, and prevented emissions from alternative products with higher greenhouse gas emissions.

- Official statistics reveal a picture of rapidly increasing climate performance over past decades, together with major shifts in the product mix, where some paper products have declined and energy products increased. In 2022, Norway's forest-based sector had a positive contribution of 30 $MtCO_2e$ per year, while Sweden's contribution was 110 $MtCO_2e$.

- Future scenarios until 2100 for low and high harvesting illustrate major differences over the long term for Sweden and a slow increase for Norway (see figure below). Low harvest scenarios store more carbon in the short term, but net growth drops over time, and then delivers lower product volumes that displace alternatives.

- The risks of storing additional large quantities of carbon in living biomass are insufficiently understood. It is likely that the scenarios underestimate the potential as vulnerability to damages from climate, insects and wind may become considerably higher than anticipated.

- Even considering the anticipated additional forest carbon storage, the accumulated performances reveal a lose-lose situation for low-harvest scenarios with large economic sacrifices and no or negative climate gains.

Sammendrag

- Dagens strukturer i klimapolitikk og rapportering begrenser skogens rolle til å lagre karbon. Dette betyr at hogst av tre alltid regnes som et tap, uten å ta hensyn til gevinsten når fornybare trebaserte produkter erstatter alternativer i andre økonomiske sektorer;

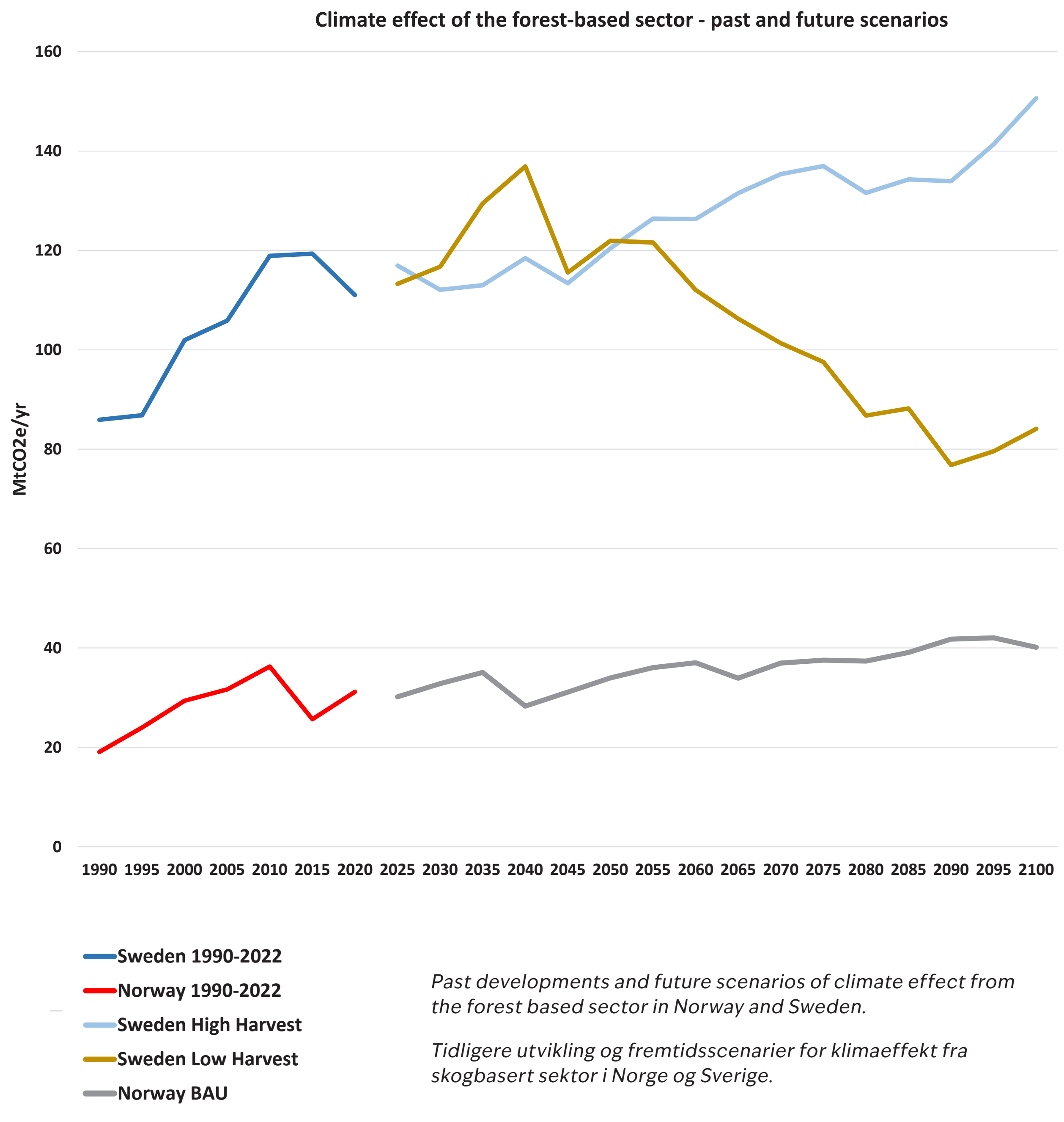
- Denne rapporten gir en analyse av tidligere og fremtidige klimaeffekter av den skog-baserte sektoren i Norge og Sverige. Den tar hensyn til lagring av karbon i skog og produkter, verdikjedeutslipp, og forhindret utslipp fra alternative produkter med høyere klimagassutslipp.

- Offisiell statistikk viser et bilde av raskt økende klimabidrag de siste tiårene, sammen med store endringer i produktmiksen, der noen papirprodukter har gått ned og energiprodukter økt. I 2022 hadde Norges skogbaserte sektor et positivt bidrag på 30 $MtCO_2e$ per år, mens Sveriges bidrag var 110 $MtCO_2e$.

- Fremtidige scenarier frem til 2100 for lav og høy hogst viser store forskjeller på lang sikt for Sverige og en langsom økning for Norge (se figur under). Scenarier med lav høsting lagrer mer karbon på kort sikt, men nettoveksten synker over tid, og gir deretter lavere produktvolum til å fortrenge alternativer.

- Risikoen ved å lagre ytterligere store mengder karbon i levende biomasse er utilstrekkelig forstått. Det er sannsynlig at scenariene undervurderer potensialet, fordi sårbarheten for skader fra klima, insekter og vind kan bli betydelig høyere enn antatt.

- Selv med tanke på den forventede ekstra karbonlagringen i skogen, viser de akkumulerte ytelsene en tap-tap-situasjon for scenarier med lav høsting, med store økonomiske ofre og ingen eller negative klimagevinster.



Past developments and future scenarios of climate effect from the forest based sector in Norway and Sweden.

Tidligere utvikling og fremtidsscenarier for klimaeffekt fra skogbasert sektor i Norge og Sverige.

Introduction

The purpose of this report is to assess past and future overall climate effects of the Norwegian and Swedish forest-based sectors. Understanding historic developments and illustrating alternative long-term scenarios can support complex policy decisions and strategic investments regarding forest management, industry development and product innovation.

Particularities of the climate change discourse and reporting structure misdirect the forest-climate policy discourse. These include:

- Climate benefits of wood-based products occur in other sectors, at the consumption stage and are inherently difficult to account for;
- Current structures in climate reporting isolate the role of forests for storing carbon. This means that harvesting of wood is always considered a loss, without accounting for the gains when renewable wood-based products are used;
- EU and national policies that follow these structures may be suboptimal, or even counterproductive, including the LULUCF regulation of the European Union,
    - Partly as the role of forests is narrowed down to carbon storage, ignoring cross-sectoral effects when wood-based products are replacing alternatives;
    - Partly as the current high rate of net carbon storage in European forests is assumed to continue for decades, downplaying increasing risks of damages;
    - Partly as the level of net storage primarily is set to balance remaining greenhouse gas emissions in 2050 to achieve "net-zero" emissions, which means that a cross-sectoral effect is taken into account, but only for the carbon storage.
- As one consequence, innovation for new climate-effective products and solutions based on wood may be hampered as the use phase is downplayed or invisible in policy.
- To improve the situation, a methodology for calculating the overall climate effect of wood and wood-based products has been developed in Sweden. It is here applied to the forest-based sectors of Norway and Sweden to provide a better perspective of future options and pathways.

Foto: FotoKnoff/WoodWorks!

Assessment Model

Climate effects of the forest-based sector depend on both developments in the forest and the performance of wood-based products. Conventional reporting to the UNFCCC separates these effects (IPCC, 2006; UNFCCC, 2024):

- storage of carbon in forests and wood-based products is reported in the LULUCF sector, whereas:
- greenhouse gas emissions from the wood-based value chain as well as prevented emissions due to the use of wood-based products are reported in other sectors.

This separation build on the distinction of two separate climate change mitigation goals in article 4 of the climate change convention (United Nations, 1992):

1. "[...] control, reduce or prevent anthropogenic emissions and of greenhouse gases in all relevant sectors [...]"; and
2. "[...] conservation and enhancement, as appropriate, of sinks and reservoirs of all greenhouse gases including biomass, forests and oceans as well as other terrestrial, coastal and marine ecosystems".

In recent years, developments of reporting methodology for the forest-based sector has aimed at straddling this separation and provide a more complete assessment of contributions from the forest-based sector (Figure 1)

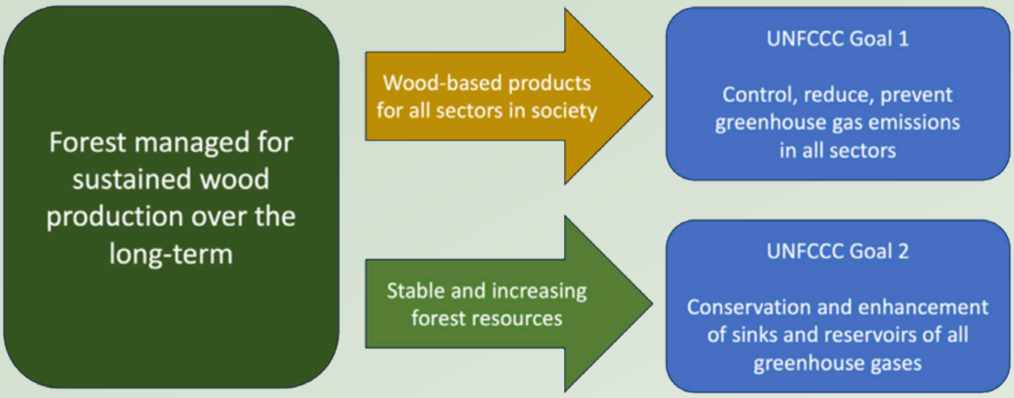


Figure 1 The forest-based sector contributes to both UNFCCC climate change mitigation goals.

Methodology has been developed (Forest Research Institute of Sweden, 2024; International Organization for Standardization, 2023) for an assessment using four components (Figures 2,3):

(a) Related to UNFCCC goal to control, reduce or prevent emissions:

1. value chain emissions for producing and placing wood-based products on the market including recycling and final use; and

2. prevented emissions from counterfactual non-wood products, through the use of wood-based products, including final use.

(b) Related to UNFCCC goal to conserve and enhance of sinks and reservoirs:

3. changes of carbon stored in forests where wood/material is sourced; and

4. changes of carbon stored in wood-based products.

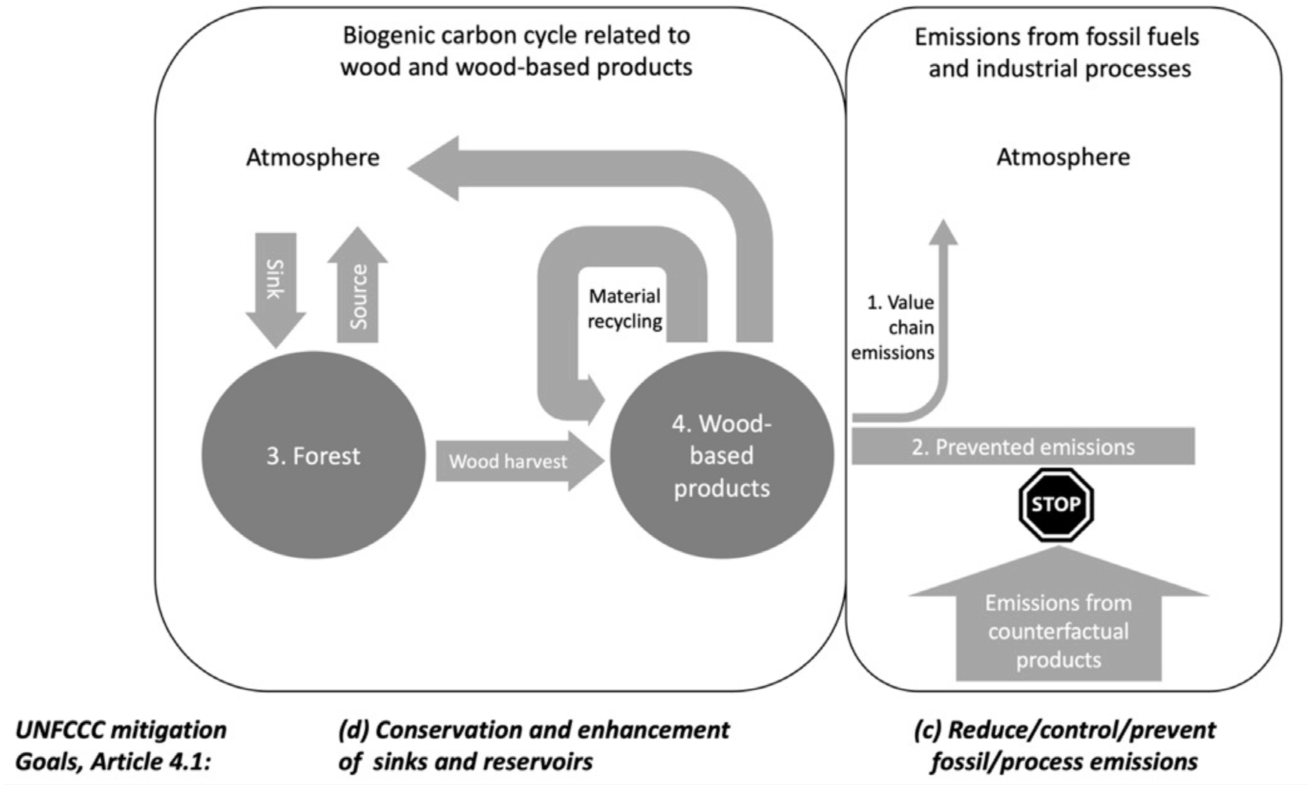


Figure 2 Illustration of relationships and flows between the four components (1-4) used to assess the climate effect of forests and wood-based products.

Foto: FotoKnoff/WoodWorks!

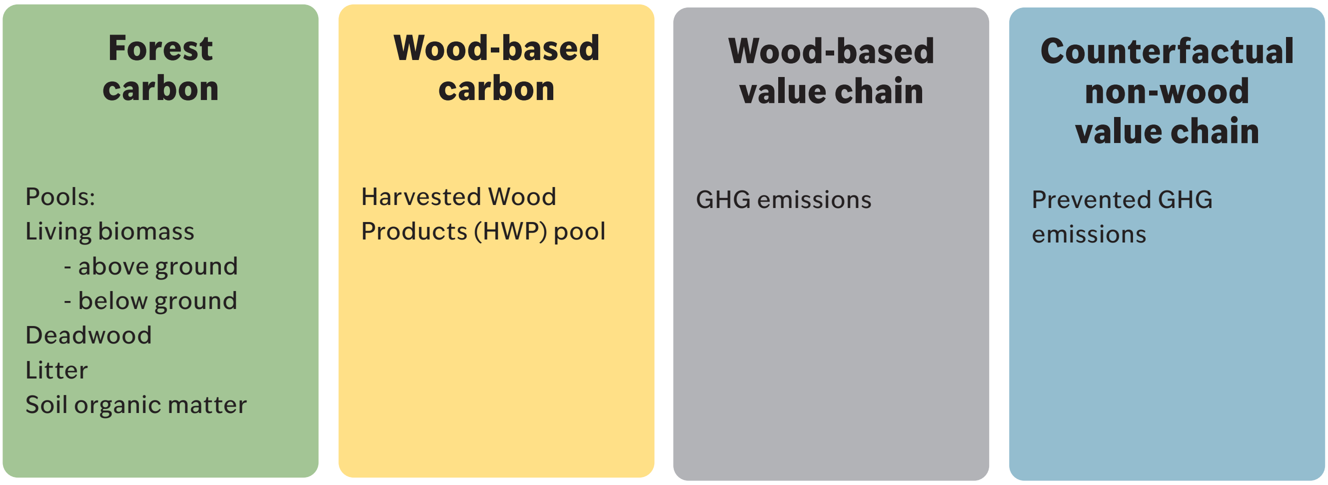


Figure 3 The four components used in the assessment.

Past and future - approach

Data sources

This report sets out to describe the past development in Norway and Sweden, and to present scenarios for the future. The basic data for these analyses are all available in official statistics and public reports.

Past production levels are well described in official statistics. For easy comparison between the countries, FAO's statistical database has been used to obtain production data for 1961-2022 (Food and Agriculture Organization, 2024)

The development of carbon stocks in forest and Harvested Wood Products (HWP) are well documented in National Inventory Reports to the climate change convention for the years 1990-2022 (UNFCCC, 2024).

Bioenergy production for district heating and electricity were taken from respective country's statistical offices, deriving the wood-based fraction in the production.

Value chain emissions were estimated based on previous analyses (Swedish Forest Industries, 2022).

Future scenarios have been made in both countries and provide basic assumptions and projections of harvest levels and forest/HWP storage under different forest management schemes (Mohr et al., 2022; NIBIO, 2022; Skogsstyrelsen, 2022). From these a low and high harvest scenario were chosen for Sweden and a business-as-usual scenario (BAU) for Norway to be included in the analysis.

Several additions and parameters had to be assumed as they are not part of official climate reporting. Some are described in the below sections. The most important and detailed concerns displacement factors for different product categories, as detailed in Table 1.

Displacement factors

Displacement factors express the quantity (potential) of prevented greenhouse gas emissions, per quantity of wood-based products fulfilling the same function. It is a unitless factor expressing the prevented emissions (tCO_2e), divided by the carbon contents in the corresponding wood-based product(s) (also tCO_2e).

For example, one ton of CO_2e in sawn wood (approximately equivalent to 1 m^3) will prevent 1.2 tons of CO_2e of greenhouse emissions (Table 1).

The concept is documented in Forest Research Institute of Sweden (2024). As described, the methodology prescribes that displacement factors are the sum of two components:

1. Prevented emissions at first use(s) of the product/material as it is delivered to the market. This includes recycled material used in the production, and thereby includes the overall use of recycling at the production unit. For export market situations, this is a conservative assumption that will not fully account for the effects of recycling as future benefits will materialize in other locations. For a country-level assessment it is reasonable, however, to not account for future recycled uses in other countries.

2. Prevented emissions at final use of the material as it is recovered for energy. Here it is important that the displacement factor reflects what is currently recovered for energy for the product category in question, and not the eventual future recovery of the specific products delivered today. This means that today's recovery rates should be used and set in relation to the delivered quantities today. This usually results in a smaller number as past market volumes were smaller, meaning that the pool for recovery is also smaller.

Displacement Factors are based on science literature and comparative Life Cycle Assessments. Many studies exist for each product category, using different contexts and assumptions. Median values across the set of relevant sources have been used for each product category in Table 1. Some of the relevant references include (Cowie et al., 2019; Hurmekoski et al., 2021; Leskinen et al., 2018; Rüter et al., 2016; Sathre and Gustavsson, 2011; Sathre and O'Connor, 2010).

Foto: Rune Hedegart/WoodWorks!

Table 1. Displacement factors (DFs) used in the study, see Forest Research Institute of Sweden (2024) for further details.

Product category	DF first use(s), including recycled material tCO_2e / tCO_2e	DF final use from recovered material for energy tCO_2e / tCO_2e
Sawn wood	1.2	0.31
Panels	1	0.31
Wood pulp	0.3	0.61
Newsprint and printing paper	0	0.61
Packaging paper and paper board	1.5	0.61
Wood fuel	0.61	
Pellets, District heat and electricity	0.81	

1) *For past developments, the DF for energy purposes was set to increase linearly from 0 in 1961 (when little recovered material went into energy production that displaced fossil fuels) to the table value in 2022.*

The past

Carbon storage in Forests and Harvested Wood Products

The development of carbon storage in the forest and in Harvested Wood Products (HWP), including in solid wood and paper-based products, have been reported by both Norway and Sweden to the UNFCCC since 1990 and the statistics are publicly available (UNFCCC, 2024). These reports are based on each country's National Forest Inventory, which since the 1920s are world leading institutions for monitoring national developments of the forest resources.

Both countries have a long history of active forest regeneration and management so as to restore the forest landscape from a depleted stage at the beginning of the 1900s after a long era of extractive logging. The results have been very successful, with about a doubling of growth and standing volume over the past century. In Sweden, the harvest has also doubled, along with the growth of the forest industry capacity. In Norway, the harvesting has been more modest, leading to a rapid increase of forest carbon, which is now slowing down REF as more forest stands are getting older, growing more slowly and are vulnerable to damages. Over the period 1990-2022, Norways forests have increased their carbon storage by 700 $MtCO_2e$ (1.9 tCO_2e/ha/yr) and Sweden by 1 600 $MtCO_2e$ (1.8 tCO_2e/ha/yr).

Also, the storage of carbon in HWP has increased in both countries. In Sweden, the growing forest industry has gradually increased its output, a process that also increases the carbon stored in HWP, currently at a rate of 8 $MtCO_2e$ per year. Norway has not seen the same expansion of the forest industry, and therefore accounts for a much smaller increase of HWP storage

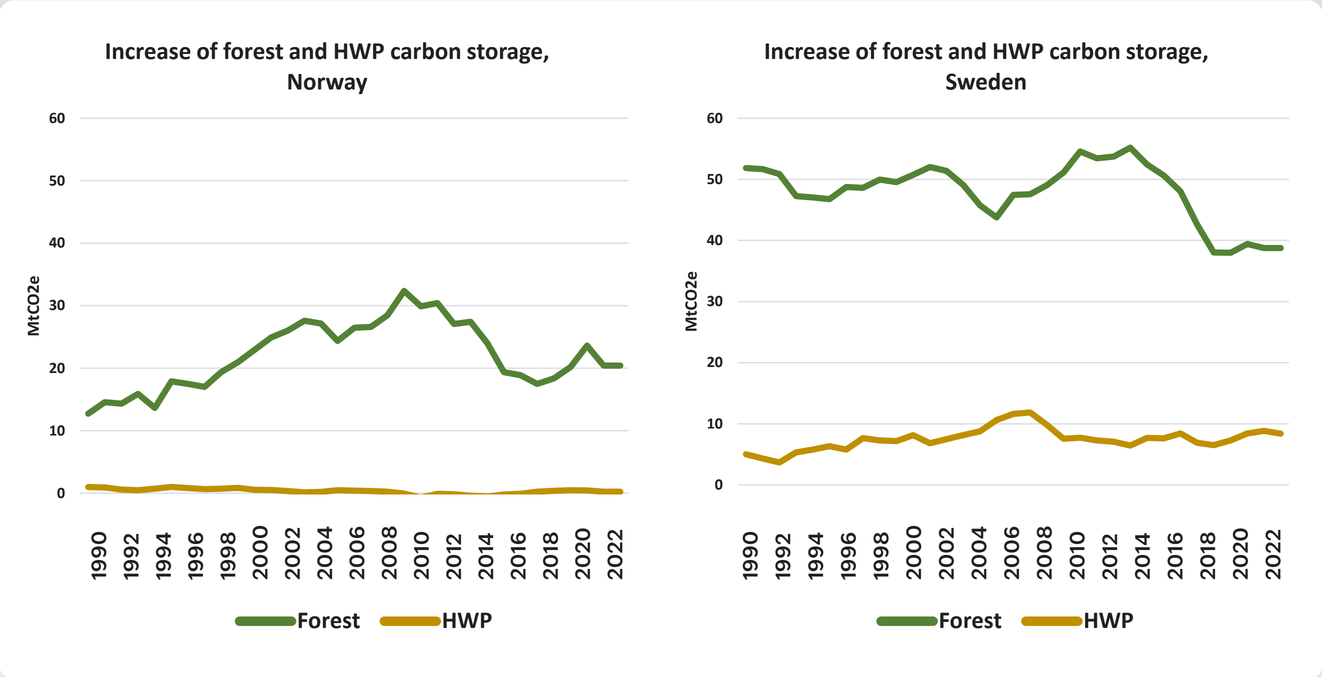


Figure 4 Increase of forest and HWP storage in Norway and Sweden 1990-2022 according to national reports to the UNFCCC. By comparison, the territorial greenhouse gas emissions in 2022 were 59 $MtCO_2e$ in Norway and 45 $MtCO_2e$ in Sweden.

Value chain emissions

Most industrial sectors have made efficiency gains in recent decades, particularly by using less fossil energy per produced unit. This is very much the case in Nordic forest industries where the industry units are near fossil-free as most of the energy is now derived from side streams of the processed wood.

The phase-out of fossil energy over past decades has drastically decreased the carbon footprint of the industry units as such. As a result, the largest emission component remaining in the wood-based value chain (cradle-to-gate, that is from the forest to the forest industry customers gate) is transport. This includes forest operations (transporting wood to roadside), road or rail transport to forest industry, and transport of products to customers.

Overall, the greenhouse gas emissions per produced unit (m3 of roundwood) is just over 1/3 in 2022 compared with 1990. As volumes have increased, the total emissions have not been reduced at the same rate (Figure 5).

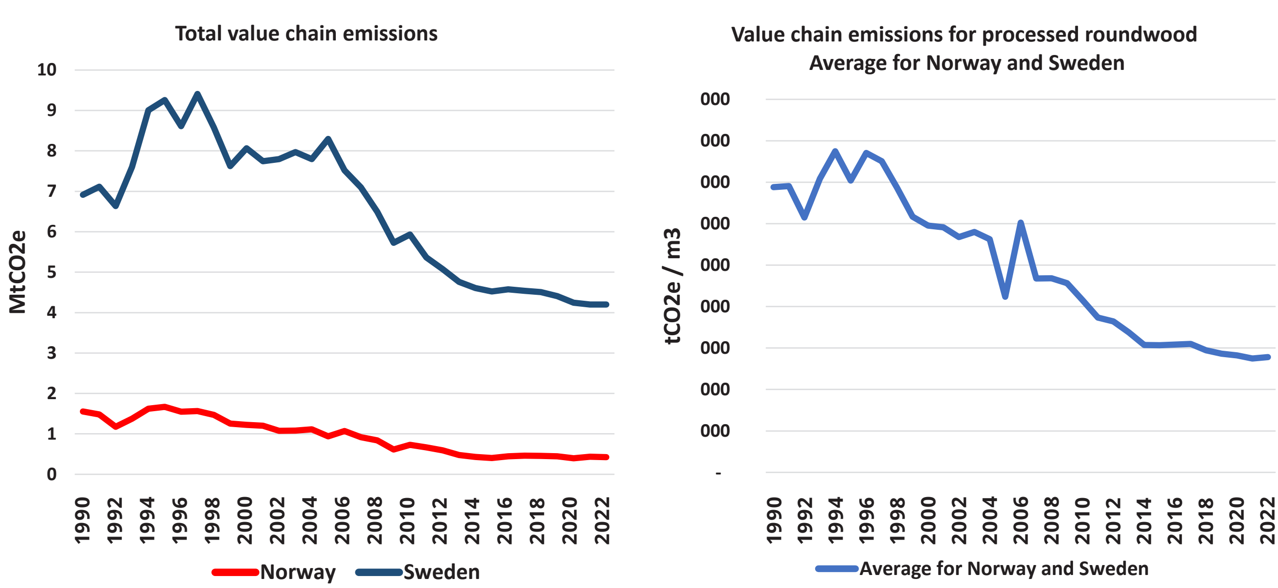


Figure 5 Value chain emissions for the forest-based sector 1990-2022, cradle-to-gate. Estimates based on various official statistics.

Prevented emissions

Statistics from 1961-2022 illustrate the growth and development of marketed wood-based products in Norway and Sweden (Figure 6). Solid wood products have a steady increase in both countries. Included pulp and paper volumes have declined sharply in Norway and slightly in Sweden. Bioenergy products show a dramatic increase, related mainly to investments in district heating and electricity production. In 2022, the primary use of wood biomass for broad product categories were similar between Norway and Sweden with about half the volumes used for energy, a quarter for solid wood products and a quarter resulting in fibre-based products (Figure 7).

Using displacement factors (see previous section), the product volumes can be converted to illustrate the potentially prevented emissions from alternative products that depend more on fossil fuels and/or cement production. Both Norway and Sweden show increasing levels of prevented emissions for the period 1961-2022. The combined increase has been around 1 $MtCO_2e$ per year or more than 60 $MtCO_2e$ over the entire period (Figures 8,9), taking into account a gradually increasing displacement factors for bioenergy. By comparison, the reported territorial greenhouse gas emissions in 2022 were 59 $MtCO_2e$ in Norway and 45 $MtCO_2e$ in Sweden.

A further development over time is that the prevented emissions per cubic meter of roundwood has increased considerably in both Norway and Sweden. This may reflect several factors including a more effective use of raw material in processing, gradually increasing displacement factors for bioenergy, less bioenergy used in processing - leaving more for the market, development of markets for industrial bioenergy which also opened for the use of branches and tops, growth of packaging material, and higher use of recycled material in fibre-based products (Figure 9).

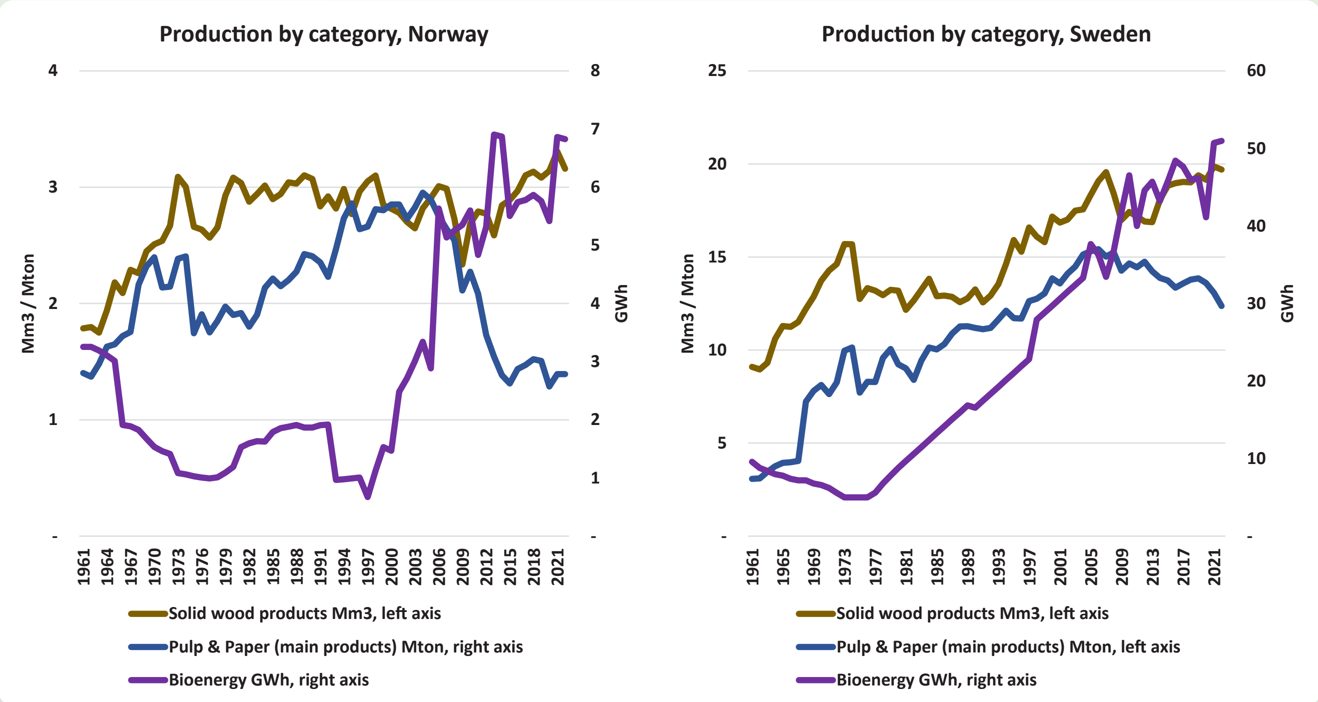


Figure 6 Growth and development of wood-based products production in Norway and Sweden. Solid wood products include sawn wood and panels. Pulp & paper includes packaging/board, newsprint/print and pulp export. Bioenergy includes woodfuel, pellets and district heat/electricity and excludes internal energy use in forest industries. Source FAOSTAT.

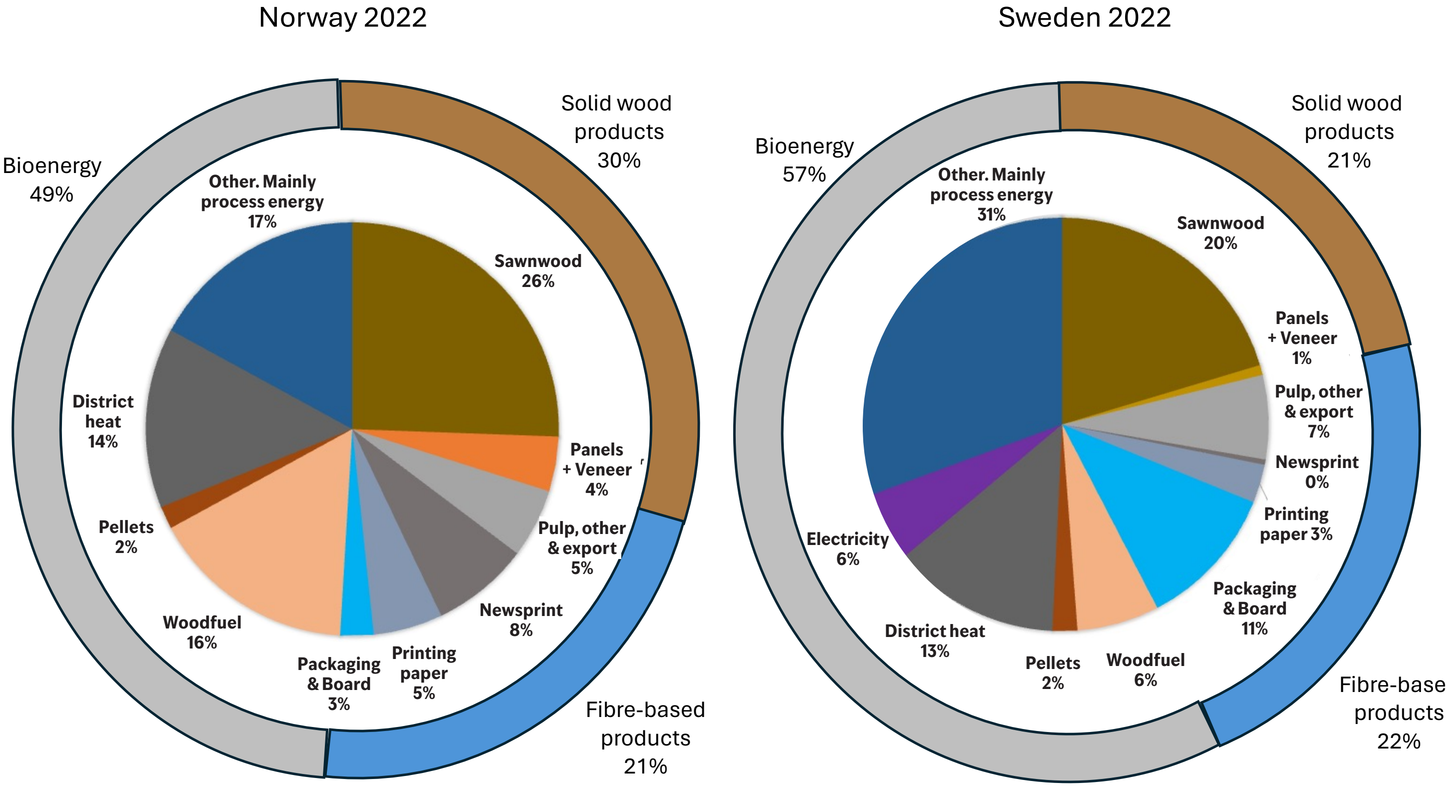


Figure 7 *Approximate primary use of wood biomass (harvested + imported – exported volumes) in 2022, distributed across major product categories. Sources: FAOSTAT and official national statistics on energy production.*

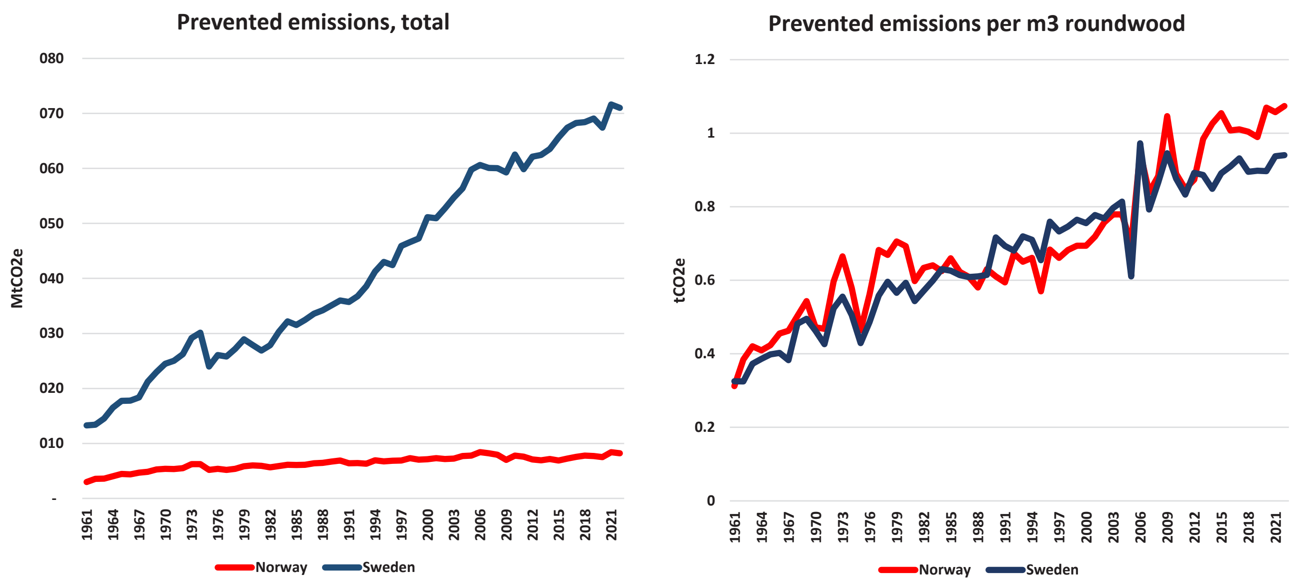


Figure 8 *Total prevented emissions by wood-based products (left) and prevented emission by cubic meter of roundwood processed (right)*

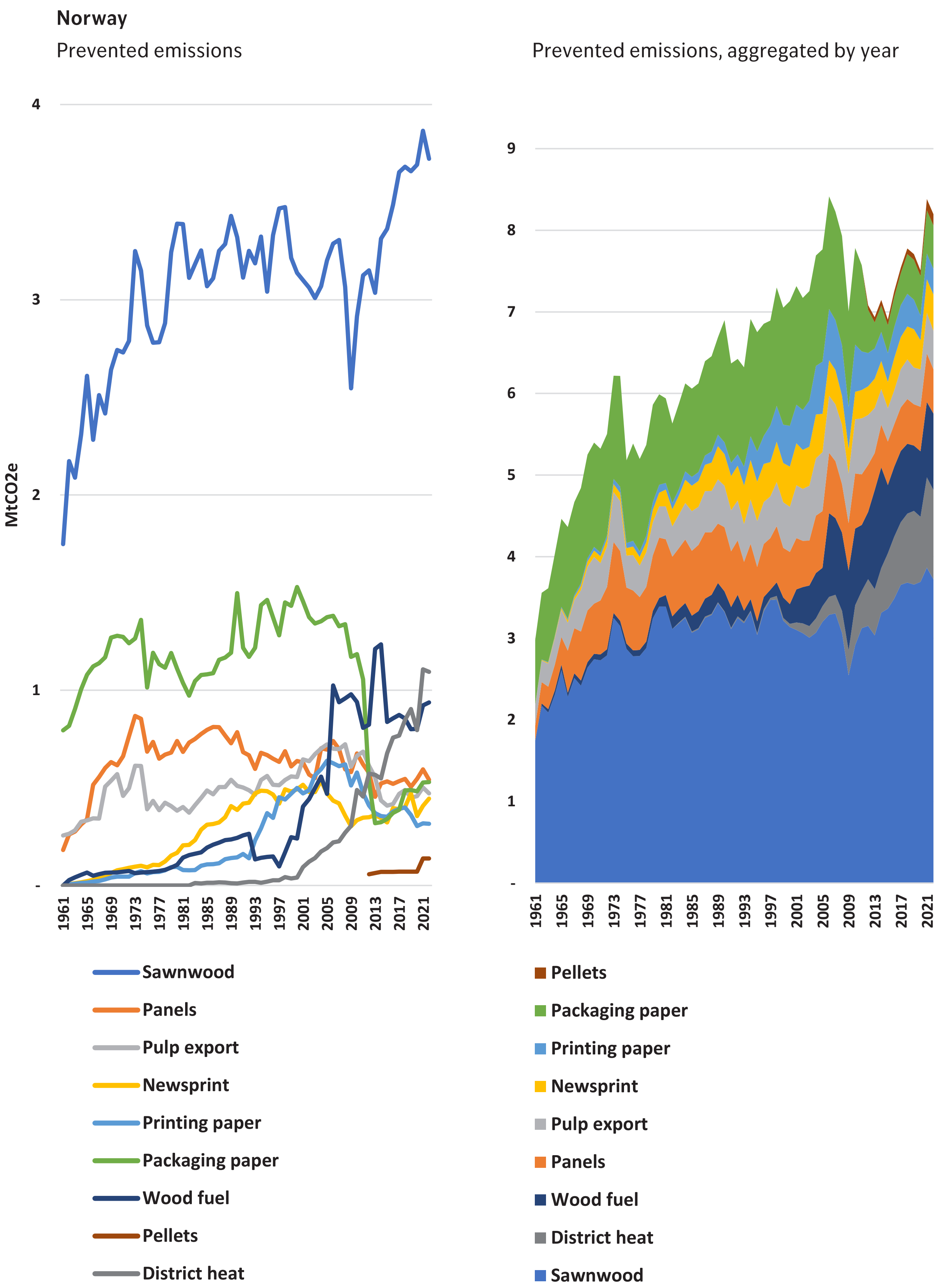
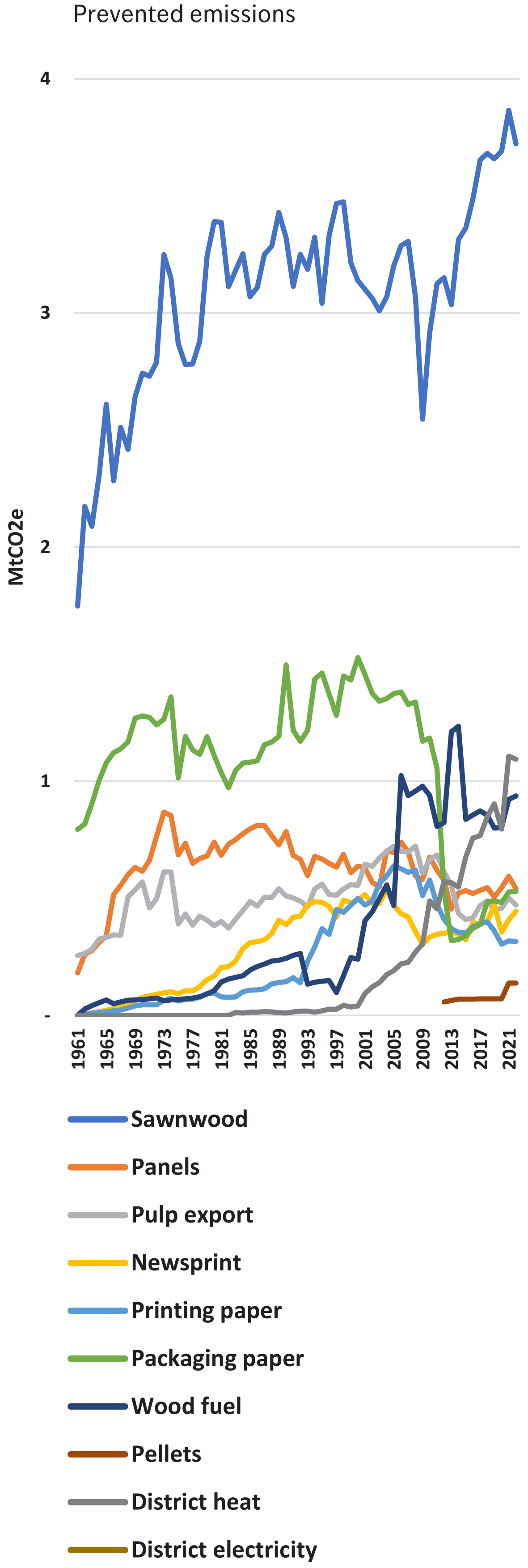
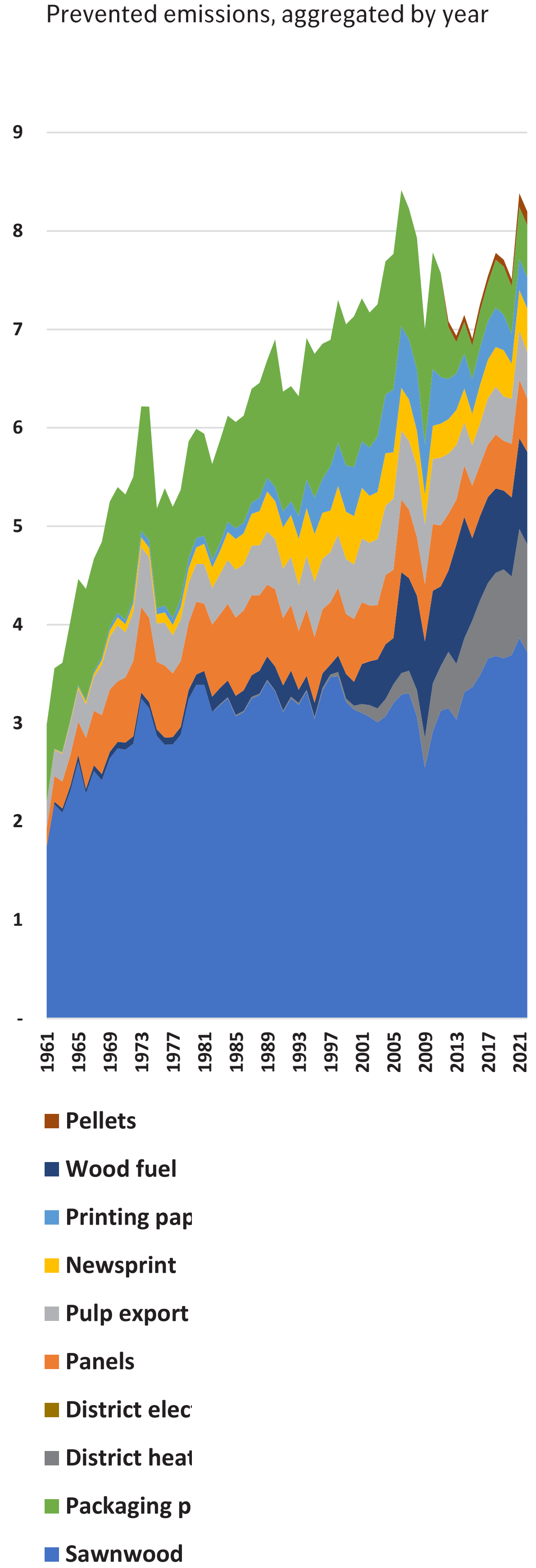


Figure 9 Prevented emissions 1961-2022 by wood-based products in Norway and Sweden 1961-2022. Likely, the alternative products are more efficiently produced today, with less fossil/process emissions. Taking this into account would mean a higher level of displacement in earlier years. (Note that the corresponding values chain emissions for wood-based products have also been reduced, which is reported separately in this document).

Sweden


Prevented emissions
MtCO2e
4
3
2
1
-
1961
1965
1969
1973
1977
1981
1985
1989
1993
1997
2001
2005
2009
2013
2017
2021
Sawnwood
Panels
Pulp export
Newsprint
Printing paper
Packaging paper
Wood fuel
Pellets
District heat
District electricity


Prevented emissions, aggregated by year
9
8
7
6
5
4
3
2
1
-
1961
1965
1969
1973
1977
1981
1985
1989
1993
1997
2001
2005
2009
2013
2017
2021
Pellets
Wood fuel
Printing pap
Newsprint
Pulp export
Panels
District elec
District heat
Packaging p
Sawnwood

Total climate effect

Adding together the components in previous sections provides a complete picture of the historical climate effect of the Norwegian and Swedish forest-based sector for the period 1990-2022 (Figure 10).

Sweden has about a factor 4 higher climate effect compared with Norway, almost double the effect for each hectare of forest. The combine positive effect in 2022 was about 140 $MtCO_2e$ per year, which can be compared with the combined territorial emissions of both countries in 2022 at 104 $MtCO_2e$.

For Sweden a clear shift is also visible. In 1990, about 2/3 of the climate effect came from increasing forest and product carbon stock and about 1/3 from prevented emissions. In 2022, the shares were the opposite, reflecting a growing importance of wood-based products for the overall climate effect.

The climate effect has steadily increased over time. However, in recent years the increase has stalled, mainly due to a slower rate of increase of forest carbon. The reasons are partly climatic – particularly an unusually dry year in 2018, followed by insect damages, partly due to continually increasing demand for renewable wood. Note, however, that the net sink in the forest of both countries is still at a very high level.

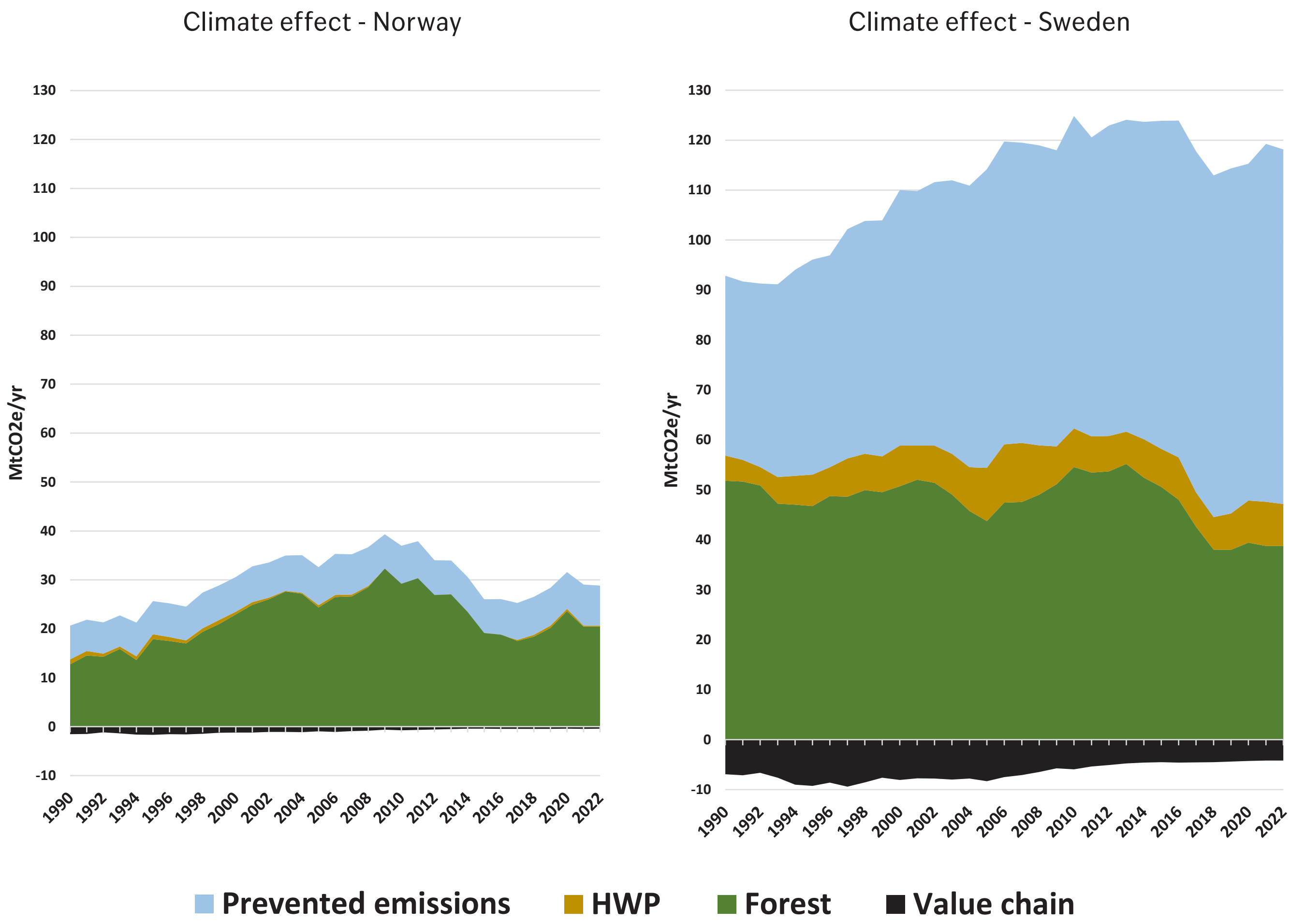


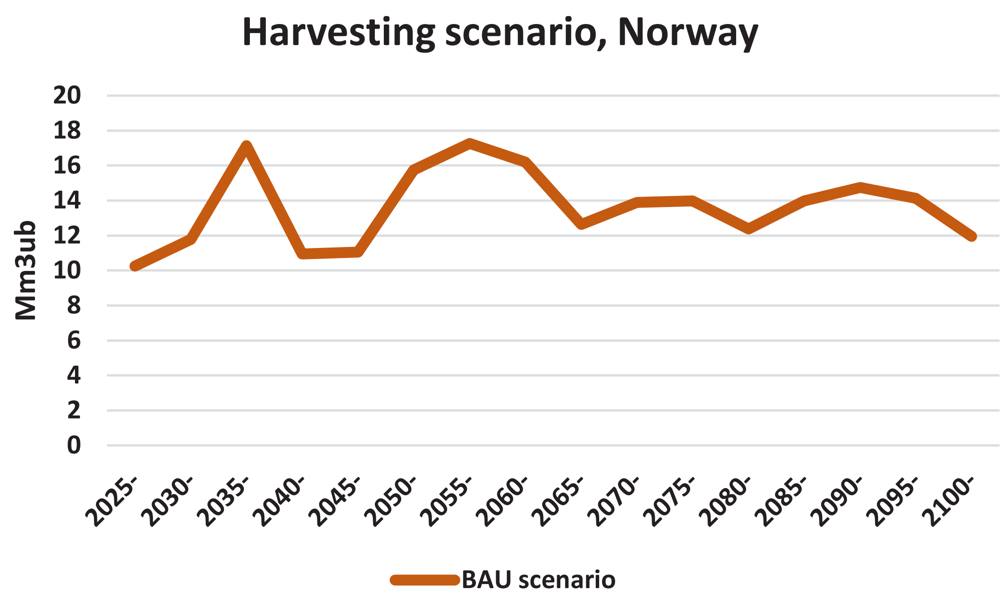
Figure 10 Combined climate effects 1990-2022 across the four components included in the assessment.

The future

Scenarios and indicative economic consequences

Future scenarios have been developed based on forest sector studies where variations of forest management schemes are applied in long term modeling (Mohr et al., 2022; NIBIO, 2022; Skogsstyrelsen, 2022). For Sweden a low and high harvest scenario were selected and for Norway a BAU scenario (Figure 11). For Sweden the scenarios “Fokus mångfald” (“Focus biodiversity”) and “Fokus tillväxt” (“Focus growth”) were used.

Aside of differences in climate effects, the scenarios also reflect dramatic differences in economic performance. Norwegian scenarios (NIBIO, 2022) differ by about 5 Mm^3/yr in harvested wood and the two selected Swedish scenarios differ by 20 Mm^3 in the initial periods, growing to over 40 Mm^3/yr. These differences represent considerable impacts on the economy, including sector employment in the countryside, survival of wood-based industries, capital values of forest property, and tax and export revenues. However, it is beyond this report to analyze these impacts.



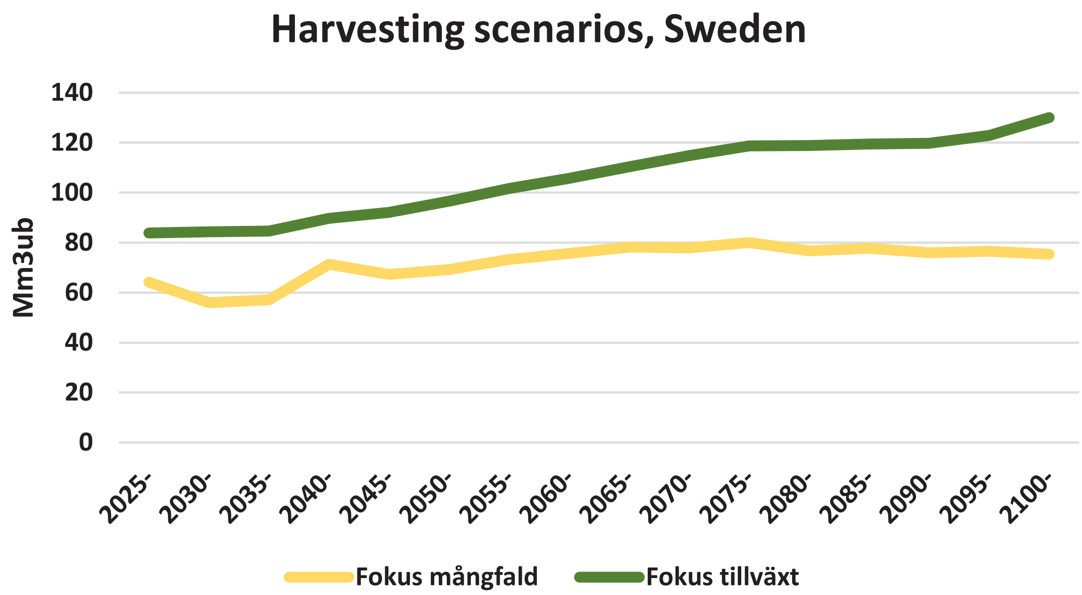


Figure 11 Harvesting scenarios used for Norway and Sweden (Mohr et al., 2022; Skogsstyrelsen, 2022)

Climate effect development in selected scenarios

The scenarios provide both forest carbon stock developments, and the level of wood harvesting over time.

Displacement factors were applied at the roundwood level. A continued development of efficiency, innovation and market pressure towards more climate-smart consumption is considered. Past increasing trend of prevented emissions per m3 roundwood harvested (Figure 8) is assumed to continue, but at a lower rate compared with the past 60 years, arriving at a displacement factor for roundwood of 1.5 tCO_2e/tCO_2e in year 2100.

Value chain emissions per processed cubic meter of roundwood were assumed to continue to be reduced over time at the same rate as 1990-2022.

HWP storage for Sweden were taken from the official scenario results (Skogsstyrelsen, 2022). For Norway, the HWP rate has been fairly low and were assumed to be at 0.25 $MtCO_2e$/yr for the low harvest scenario and 0.40 $MtCO_2e$/yr for the high harvest scenario throughput the period.

The resulting scenarios show the differences in future climate effects (Figure 12). The difference at year 2100 is for Sweden very large – 65 $MtCO_2e$/yr. In Sweden, the effect of products is increasing over time for both scenarios. The Norway BAU scenario shows a small but steady increase of both annual forest carbon net sink (whereas HWP pool increase is negligible) and of displacement by products.

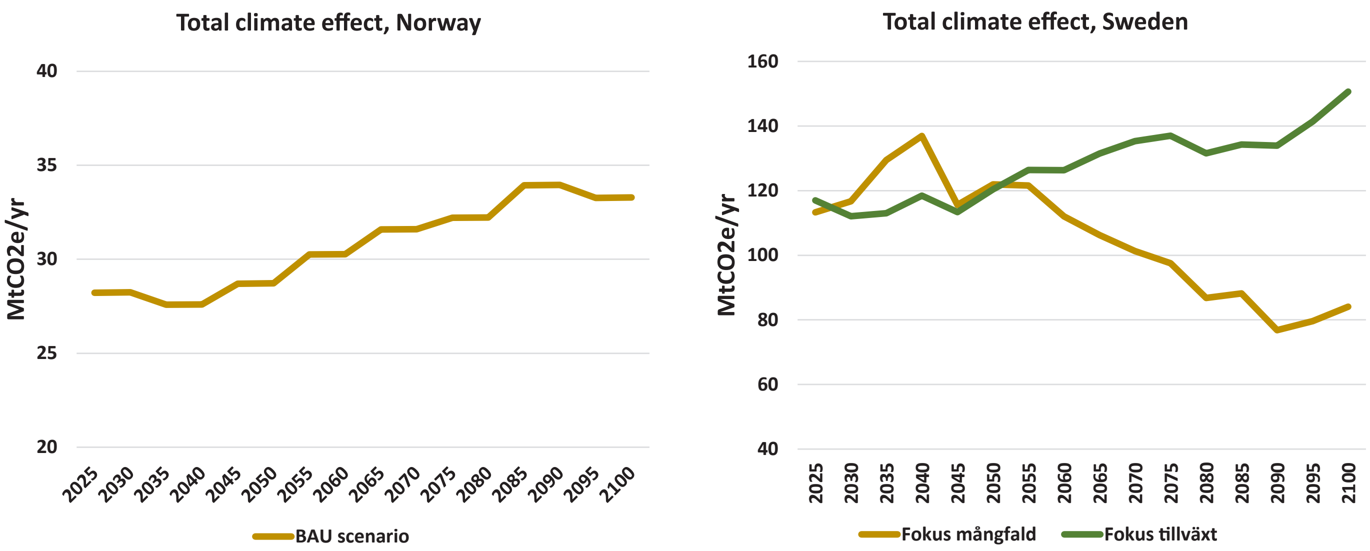
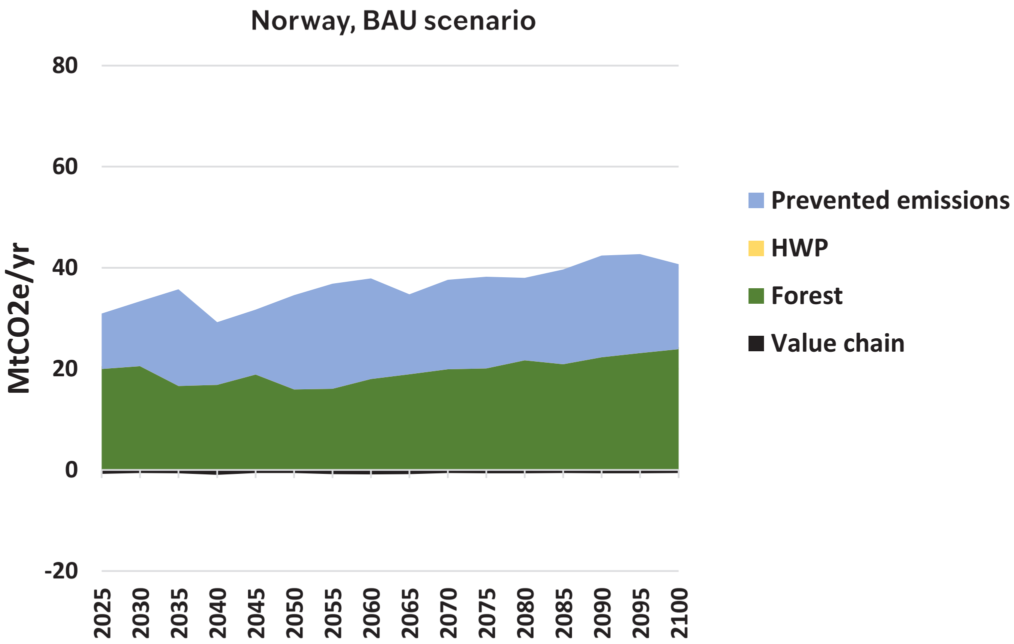


Figure 12 (page 20 and 21) Harvesting scenarios used for Norway and Sweden (Mohr et al., 2022; Skogsstyrelsen, 2022)


Norway, BAU scenario
80
60
40
20
0
-20
MtCO2e/yr
2025
2030
2035
2040
2045
2050
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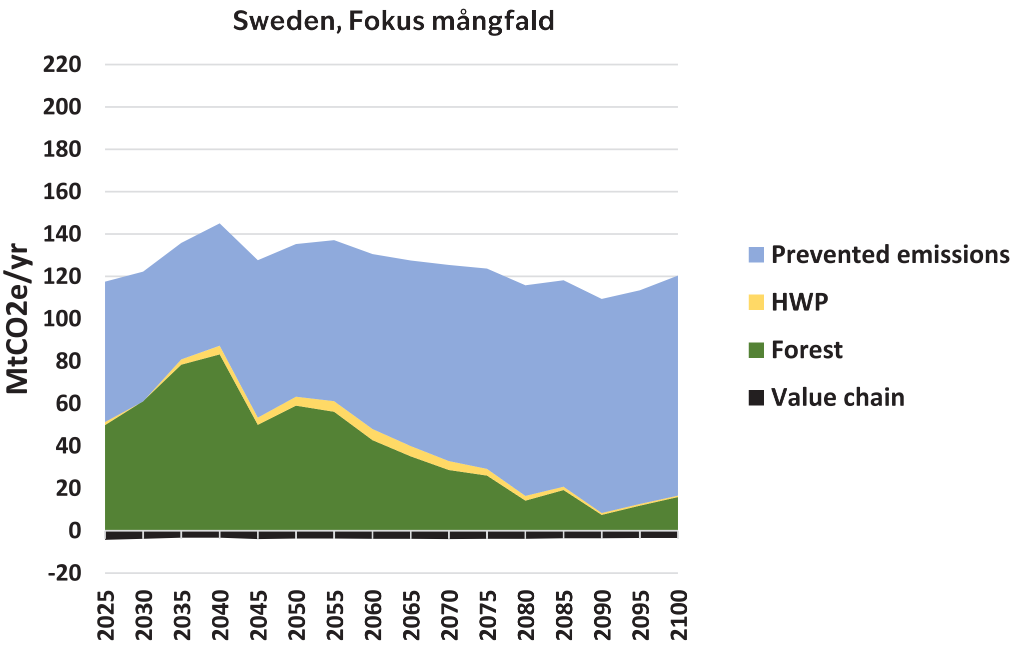
2060
2065
2070
2075
2080
2085
2090
2095
2100
Prevented emissions
HWP
Forest
Value chain


Sweden, Fokus mångfald
220
200
180
160
140
120
100
80
60
40
20
0
-20
MtCO2e/yr
2025
2030
2035
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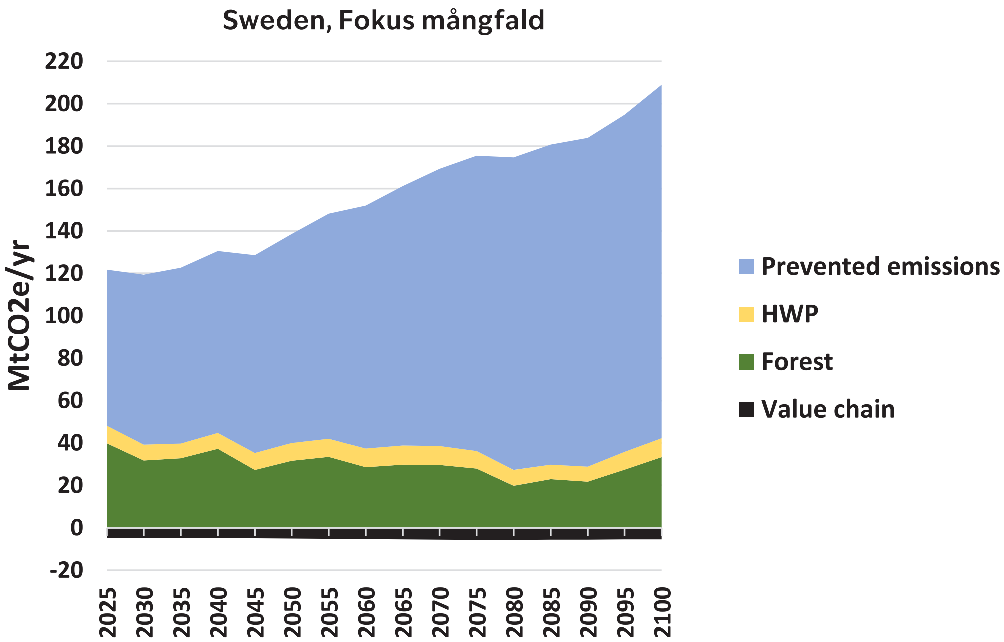
Value chain


Sweden, Fokus mångfald
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Prevented emissions
HWP
Forest
Value chain

Discussion and Observations

The past

The past shows an impressive growth of the forest-based industry and the related positive climate effect in both countries over the past decades. It is also clear that recent years have seen a still high, but lower, net sink in the forest. This appears to be caused by two main factors:

- Natural short-term climate variations with unusually dry years in 2018 and 2019, leading to reduced growth as well as increased insect damages in following years, reducing growth further;
- Increased harvest levels due to high demand for renewable material an in the most recent years due to closed borders with Russia and Belarus.

Results from the past also show how product categories have shifted over time. Sawn wood has grown in both countries. In Sweden paper products are increasingly about packaging, which also leads to higher climate benefits. For both countries, industrial bioenergy has grown considerably in recent decades, making bioenergy the largest component in the overall energy system in Sweden.

Foto: Rune Hedegart/WoodWorks!

Scenarios

For each country, scenarios for future harvest levels were chosen from official studies. The lower harvest level for Sweden can be seen to represent restrictions imposed by EU regulations and other national policy that restrict harvests. The higher harvest level represents active forest management with long-term investment for an increasing flow of raw material. Both cases are realistic from a forest management perspective and are mainly distinguishes by political choices.

Several assumptions are included in the future scenarios. Some notes concerning these:

- Innovation and changed consumption patterns are included as the displacement factor per m3 of harvested roundwood is assumed to continue to increase. However, this effect is conservatively set and may be grossly underestimated;
- Continued build-up of carbon in forests is the result of all scenarios. However, the models used for future predictions are likely not sufficiently including risks of large-scale damages to older forests, especially in a changing climate. The higher build-up of carbon, the higher risk that it will be lost. Canada and USA provide important examples of this from extensive forest fires in recent years.
- The extent of future damages on forests from wind, drought, insects or fire are inherently difficult to predict. It is possible that these risks have been underestimated in the published future scenarios for both countries. As risks are generally higher with older stands and larger standing stocks, such underestimations would lead to an overappreciation of the performance of low-harvest scenarios. Some recent data point to increasing levels of damages over time (Breidenbach et al., 2024; Riksskogstaxeringen, 2023). No further analysis has been made as part of this study.

The future

Results show dramatic differences for Sweden. Initially the low harvest scenario builds up carbon stock in the forest, at the expense of harvested volumes and downstream economic activity. In the longer term, however, the high harvest (Focus growth) scenario is superior. The difference between the scenarios grows to become larger than today's total territorial emissions in Sweden. For both scenarios, the long-term development is that wood-based products generate a larger share of climate benefits compared with carbon storage in the forest.

The future scenario for Norway shows a positive climate effect development. However, the BAU scenario leads to a large build-up of forest carbon, which may be unrealistic. Further studies of the climate-related risks in forests are needed to determine whether the scenario represents a realistic development, or if the net sink in the forest will become dramatically lower over time as indicated by (Breidenbach et al., 2024).

Putting together the past and the future reveals important policy choices (Figure 13)

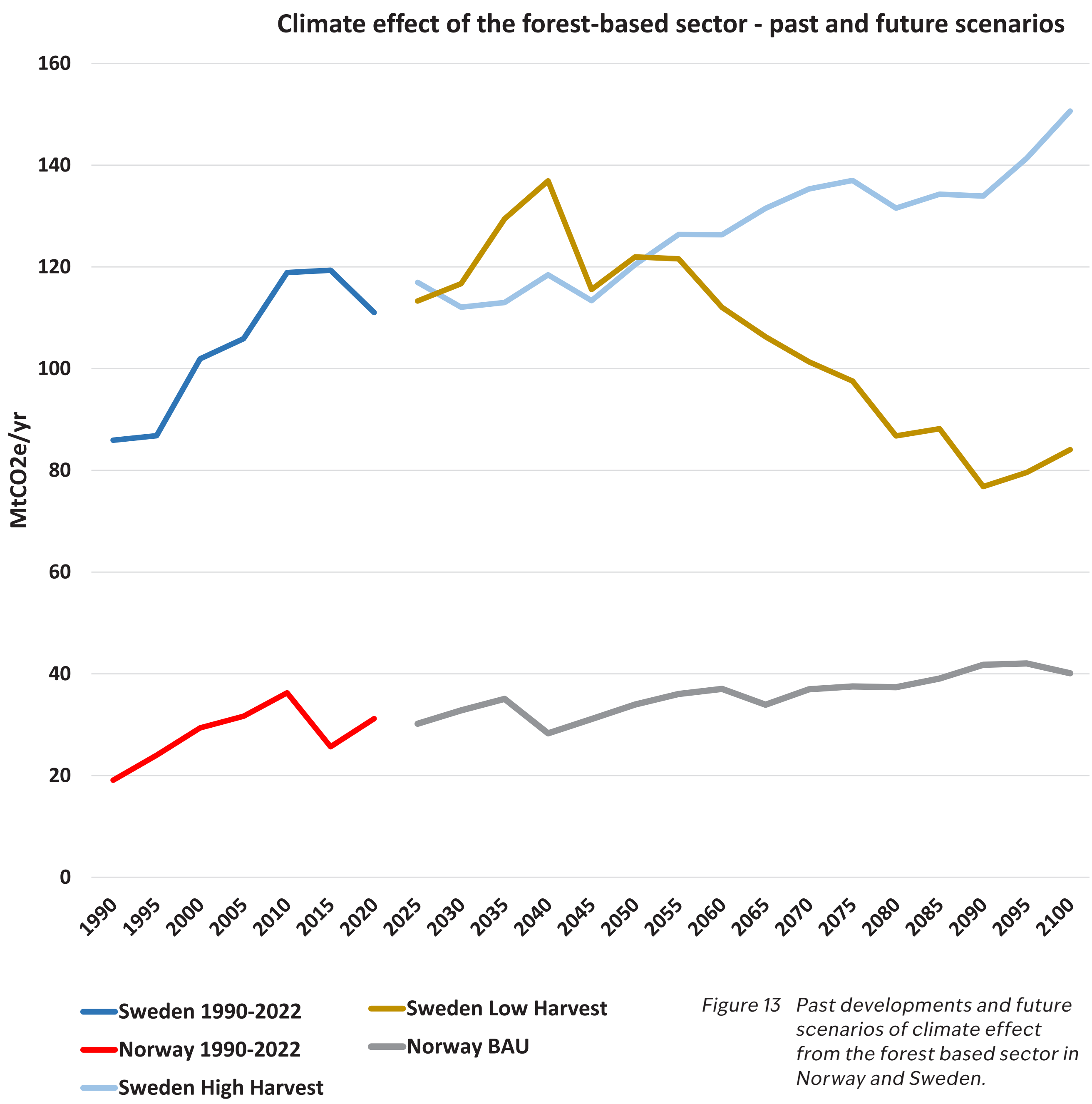


Figure 13 Past developments and future scenarios of climate effect from the forest based sector in Norway and Sweden.

Comparing scenarios through accumulated performance over time indicates how effective the scenarios are in relation to economic sacrifices (Figure 13, Table 2). Large reductions of harvesting volumes do not lead to much climate effect, and very large negative results over the long term in Sweden. When comparing from a LULUCF perspective, the Low harvest scenarios store more carbon, except after 2060 in Sweden where the roles are reversed.

Table 2 illustrates the accumulated situation at two points in time, as well as the effectiveness of reducing harvest for the isolated LULUCF perspective.

For example, by year 2060:

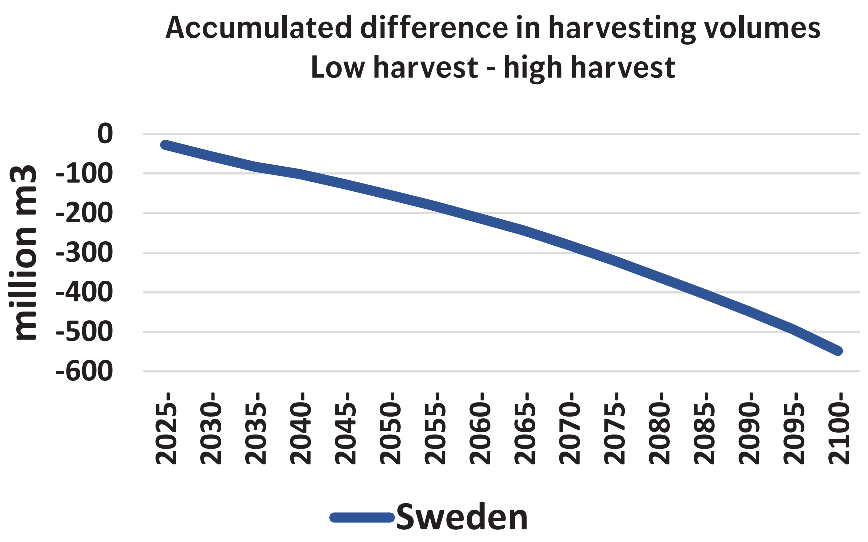
- Sweden has abstained from 210 million cubic meters of harvest in the low harvest scenario.
- At this point the accumulated overall climate performance is negligible (20 $MtCO_2e$) as the LULUCF pools have swelled by 150 $MtCO_2e$.
- This means that 1.6 m^3 of reduced harvest has led to 1 tCO_2e storage in LULUCF.
- Assuming a market value after industry of ca SEK 2 500 per processed m^3 of roundwood, this means that until 2060, a ton of CO_2e storage in LULUCF will cost 2 500 * 1.6 = 4 000 SEK in lost revenue.
- After this point in time, the low-harvest scenario performs worse for LULUCF than the high harvest scenario, which quickly increases the cost of carbon storage.

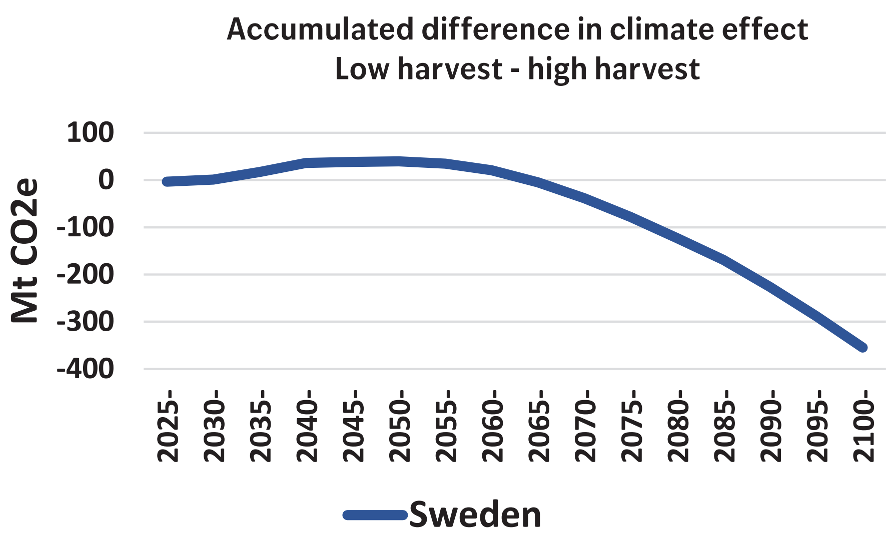
And by year 2100:

- Sweden has abstained 550 million cubic meters of harvest in the low harvest scenario.
- Climate benefits of 350 $MtCO_2e$ have been forgone, with LULUCF gains reduced to an accumulated 20 $MtCO_2e$.
- As a consequence, this is a lose-lose situation, with very large economic sacrifices, very large forgone climate benefits, and no gain in LULUCF storage.

Country	By year	Accumulated differences between scenarios. Low harvest – High harvest			Isolated LULUCF effectiveness (m^3 harvest abstained to achieve 1 tCO_2e stored)
		Harvest volume	Overall climate effect	LULUCF	
		Mm^3	$MtCO_2e$	$MtCO_2e$	m^3/tCO_2e
Sweden	2016	-210	20	150	1,6
	2100	-550	-350	20	32

Table 2 Comparison of results at years 2060 and 2100, along with Figure 13





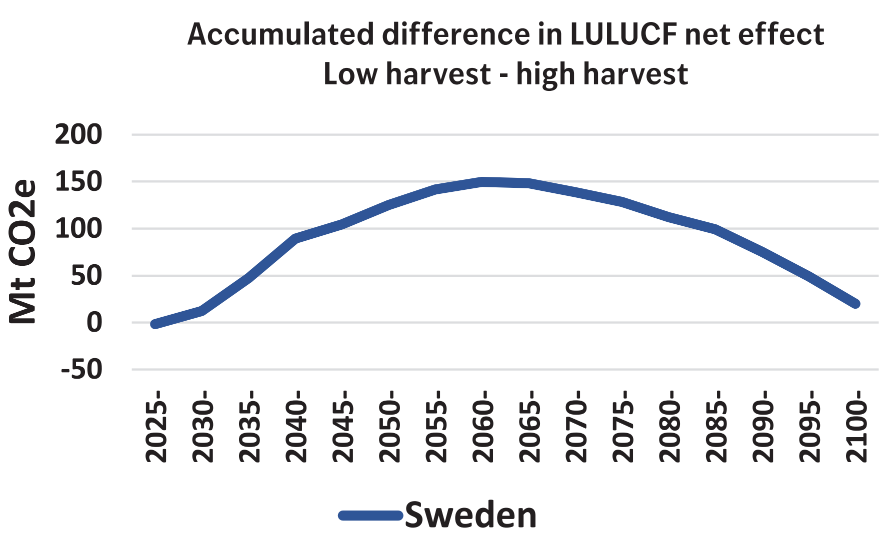


Figure 14 *Comparison of accumulated performance between scenarios. Low harvest scenarios lead to much lower harvesting volumes. Accumulated difference in overall climate effect is small for Sweden until 2060, after which the High harvest scenario is superior. Accumulated LULUCF net effect is higher in the Low harvest scenarios, except after 2060 in Sweden when the High harvest stores more carbon.*

Foto Rune Hedegart/WoodWorks!

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