Rolf Björheden

Climate effects of Forestry in the Nordic-Baltic Region

The predominant standwise management regime in the Nordic-Baltic region creates a forest landscape mosaic with multiform tiles of different ages.
Photo: Erik Viklund

Cover: A Komatsu harvester felling a 130-year stand of Scots pine in north Sweden, 2018.
In the foreground a fire-scarred stump of a tree from the previous stand, felled by axe,
possibly by an ancestor of the current harvester operator.

Photo: Rolf Björheden, Skogforsk

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Uppsala in November 2020
Rolf Björheden

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Executive summary

The climate effects of forests and forestry derives from the ability of trees to capture carbon dioxide through photosynthesis and then store carbon in their tissue. Products made from the harvested timber, in varying degrees, contribute to lowering the load of carbon dioxide on the atmosphere. This report accounts for these effects of the forest sector in the Nordic-Baltic region, denoting Denmark, Estonia, Finland, Latvia, Lithuania, Norway, and Sweden. The end line shows that the combined forest sector of these seven countries significantly contributes to mitigating the rising carbon dioxide levels in the atmosphere.

The European[1] emissions of carbon dioxide constitute a tenth of the total global emissions and are in the order of 3,500 million tonnes CO_2e per year. Of this, the Nordic-Baltic region contributes 220 million tonnes[2].

The importance of forests is evident when noting that the forest inventory of the Nordic-Baltic region corresponds to over 13,000 million tonnes of CO_2, equalling 60 years territorial emissions of CO_2 from the region at the present level. Further, the forest inventory is increasing in the Nordic-Baltic countries. Every year, around 315 million m^3 (stem volume) grow in the regions' forests, while annual harvesting sums to 218 million m^3. The current build-up of timber stock annually sequesters 74 million tonnes of carbon dioxide.

Even more important, from a climate point-of-view, is the use of forest products as a feedstock, substituting for fossil-based alternatives. Through substitution effects, the products from the forest sector reduce fossil CO_2 emissions by over 200 million tonnes annually. The emissions from the necessary forest operations, from forest road maintenance and from transports of wood to the forest industry were estimated at around 2.5 million tonnes of CO_2.

Much remains to be done, however. Utilizing more of the biomass from the felled trees is an obvious and very efficient way of improving the carbon balance. Annually, logging residues corresponding to almost 150 million tonnes of CO_2 are left on Nordic-Baltic logging sites. A large part of this resource could be sustainably harvested, e.g. to substitute for fossil fuels. Forest raw material may also be used in more climate-efficient ways than today. New products and materials may further increase these opportunities.

From the perspective of global climate change, it would be most desirable if the Nordic-Baltic countries can inspire more countries choosing to build a bioeconomy based on recycled, biogenic carbon from environmentally acceptable forestry and to reduce emissions from fossil sources.

This report aims to present current data over the carbon flows of Nordic-Baltic forests and forestry. Such data are of particular interest with respect to the current efforts to reduce the increase of atmospheric carbon dioxide, driving climate change. But forests are not primarily a climate tool. They are the basis for many people's livelihoods, not only in the forest sector, and supply biodiversity and functioning ecosystems with a variety of services and a good living environment. These benefits must be considered when choosing the appropriate paths for forests and forestry for the future.

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[1] Excluding Russia

[2] Territorial emissions. The extraterritorial emissions, caused by the regions' consumption, transports etc outside the regional border are almost entirely included in the figure for Europe.

Forestry in the Nordic-Baltic region

The global climate is driven by complex, interacting processes. The connections are not yet fully understood, but sophisticated models of the global climate and analysis of climate data strongly support the theory that ‘greenhouse gases’ contribute to global warming. Today, it is accepted that the carbon dioxide levels in the atmosphere is a factor that is influencing the climate, through the greenhouse effect. The level of carbon dioxide in the atmosphere has risen by 40 percent in the last century, mainly due to human activities such as deforestation and accelerating mobilization of fossil carbon sources.

The climate issue is, thus, largely a matter of managing and controlling the carbon flows. This gives forest management a key role, because forests have the potential to capture large quantities of carbon dioxide from the atmosphere and store carbon through their increment. Products based on forest biomass also store carbon and can reduce the use of carbon from fossil sources.

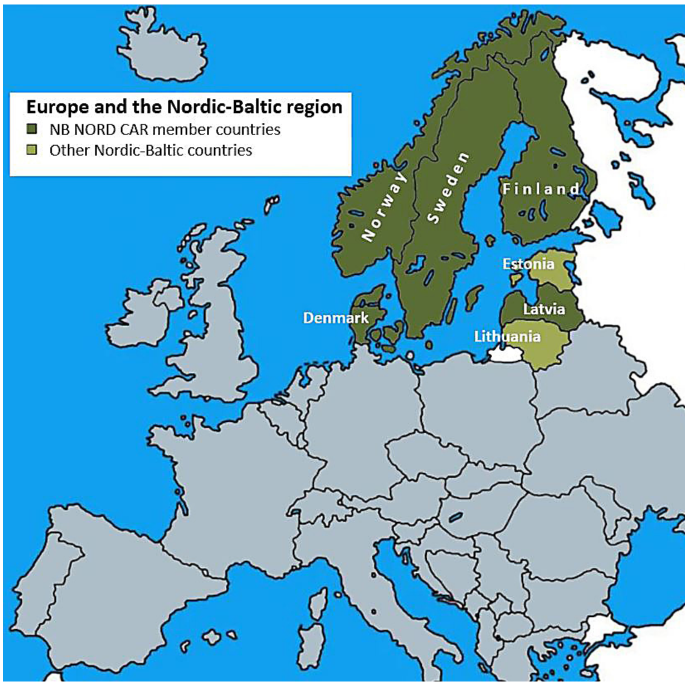

Figure 1. In this report, the’ Nordic-Baltic region’ denotes the member countries of the SNS CAR NB NORD[3], Estonia and Lithuania. The role of forestry in mitigating carbon dioxide emissions in this region is elaborated.

In this report, the Nordic-Baltic region denotes Denmark, Norway, Sweden, Finland, Estonia, Latvia, and Lithuania (Figure 1). The 33 million inhabitants of these seven northern countries only make up 5.5 per cent of the total European[4] population, but the 74 million hectares of forest in the region correspond to 35 percent of the continents total forested area. A long tradition of forestry and a rich supply of woody biomass has made forestry an important part of the region’s economy.

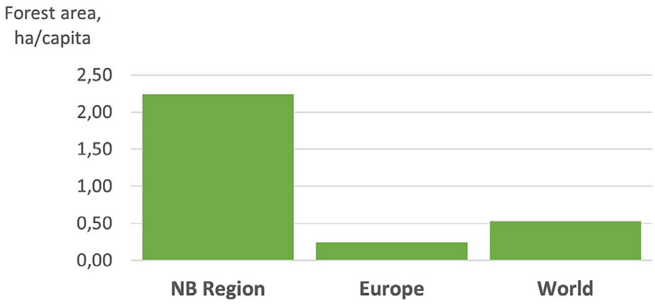

Figure 2. The available forest area per capita in the Nordic-Baltic region, in Europe[5] and globally.

The extensive forestry sector in the Nordic-Baltic region is managing very large flows of carbon. In recent years, the forestry sector has come into focus to counteract increasing carbon dioxide levels. It has become increasingly important to evaluate the impact of forestry on the carbon dioxide balance and, thus, the climate.

How does active forestry affect the dynamics of the carbon cycle? What forest management strategies and approaches are feasible options from a perspective including ecologic, economic, and social sustainability as well as that of carbon sequestration and mitigation of climate change?

Forests assimilate carbon dioxide and store carbon

Through photosynthesis, green plants use solar energy to convert water and carbon dioxide to sugar. The sugar is used to produce the substances they need for growth and as an energy source for their vital processes. Oxygen is a residual product of this process. The plants thus sequester carbon dioxide from the air into the pool of living biomass.

When a plant dies, its biomass is decomposed by organisms that live on the dead biomass, and most of the assimilated carbon is released back to the atmosphere, as carbon dioxide. A small portion of the carbon in litter and dead plants will flow to the soil carbon pool.

Since trees are dominant, large, and long-lived plants, over time forests build a significant store of organically fixated carbon. Trees are also the main source of organic carbon stored

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[3] NB NORD, the Nordic-Baltic Network for Operations Research and Development is a Center of Advanced Research (CAR) financed by SNS, Nordic Forest Research https://nordicforestresearch.org/

[4] Excluding Russia

[5] Excluding Russia and the NB region.

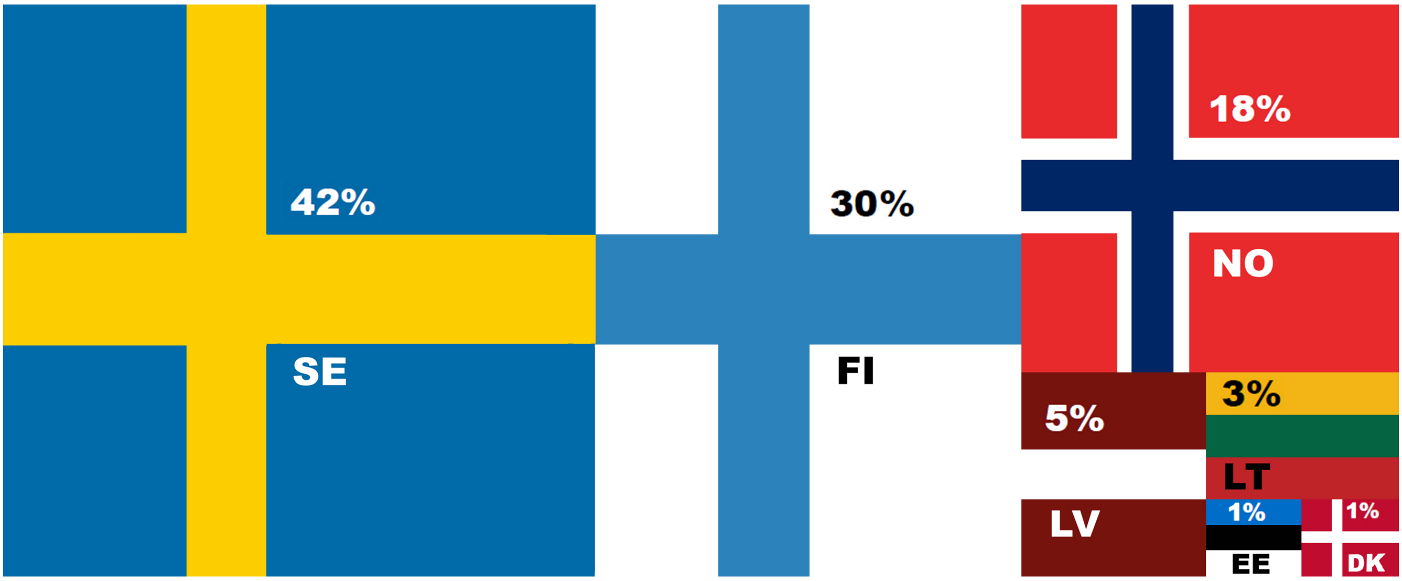

Figure 3. The distribution of the 74 million hectares of forest land in the Nordic Baltic region among the included countries.

in forest soils. If the carbon capture by photosynthesis exceeds the carbon release through respiration and decomposition, the carbon pool in living biomass and soil increases. The forest ecosystem acts as a carbon sink.

Carbon dynamics of natural forests

A natural forest that is not used to produce raw materials serves as a maximized carbon store (Figure 4). The combined plant communities utilize every available niche of the ecosystem. When a plant or tree dies and withers away, the space made available is claimed by neighboring or successive plants. In a natural plant community, increment and decomposition are in balance over time, apart from the proportion of organic carbon that is transferred to the soil.

The formation of soil organic carbon is a slow process – only fractions of a percent of the rate of carbon fixation through forest growth. Typically, soil organic carbon accumulates at a rate of 5–15 kg C/ha, yr. The carbon dynamics of hydromorphic soils, characterized by long-term waterlogging of the soil pores, differ markedly from the carbon cycling in forests on natural-

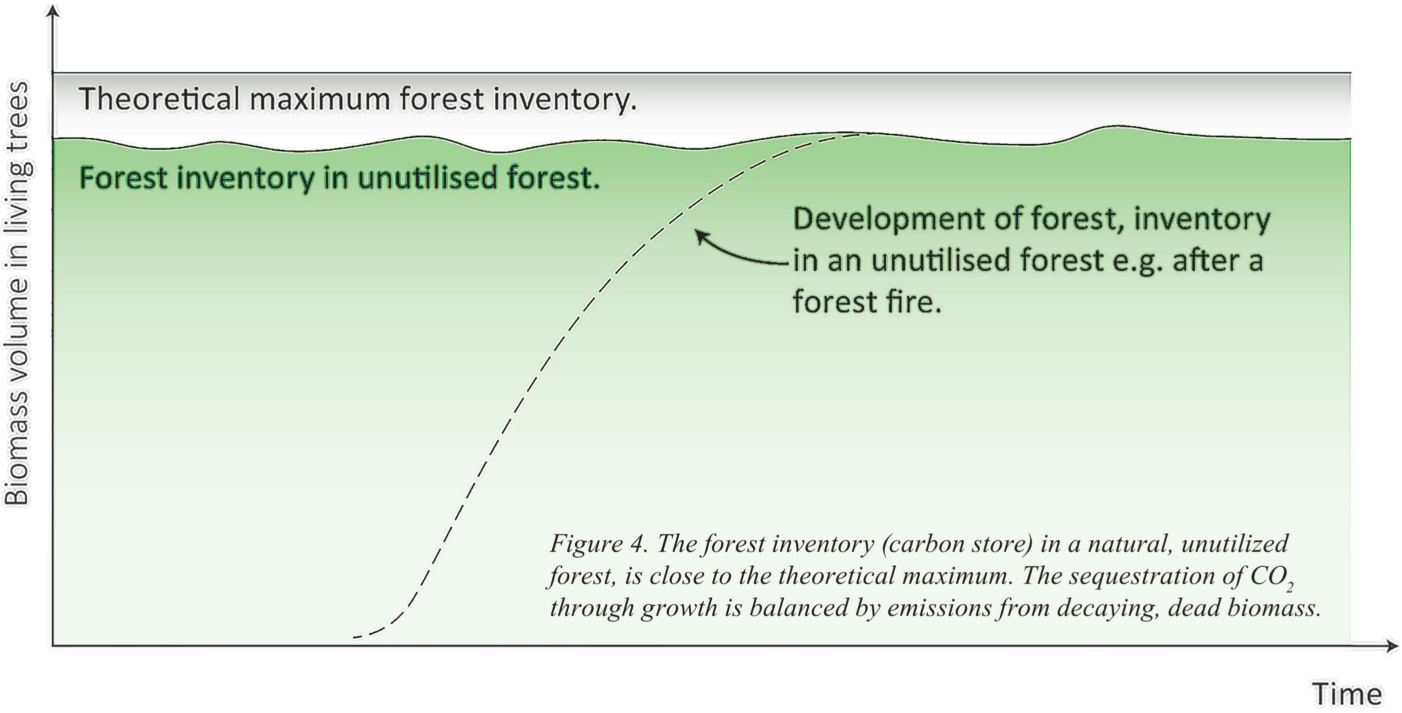

Figure 4. The forest inventory (carbon store) in a natural, unutilized forest, is close to the theoretical maximum. The sequestration of CO_2 *through growth is balanced by emissions from decaying, dead biomass.*

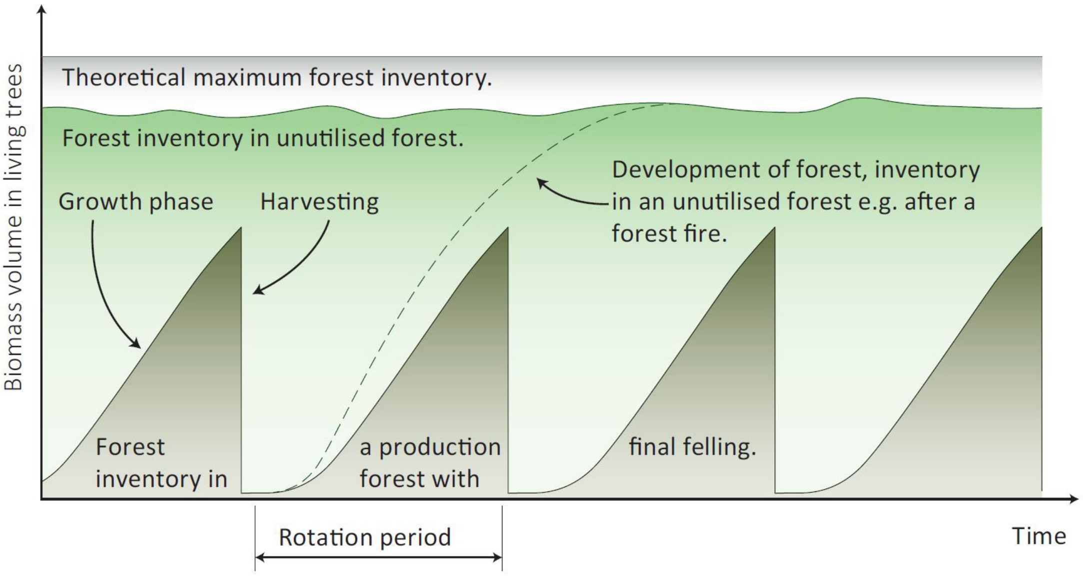

Figure 5. *In a working forest, the inventory never reaches the same levels as in a natural forest, but a continuous net uptake of CO_2 is enabled through repeated harvesting. The forest products may be used to substitute for fossil-based feedstock. Managed forests are a prerequisite for a high and sustained net CO_2 uptake.*

ly drained soils. In the Nordic-Baltic region, peatland forests are common. Due to the anaerobic conditions, soil respiration is limited to a thin aerobic layer of the soil. Large portions of the litter will not be decomposed, and undrained, natural peatland accumulate carbon at an average rate of 250 kg C/ha, yr. This may be compared to the average net carbon fixation in the region's managed forests, 1,750 kg C/ha, yr (with a variation from 800–4,000 kg C/ha, yr). Despite the slow rate, over time a significant store of organic carbon accumulates in forest soils. In the Nordic-Baltic region the forest soils contain more carbon than the trees.

The principle of the undisturbed forest as a maximized carbon store is only true when seen over a prolonged period or over a larger area. Also undisturbed forests are subject to dramatic changes affecting the inventory, e.g. after windthrow, forest fire or outbreaks of various pests (**Figure 6**). After such events, the carbon in the affected biomass is decomposed and released as carbon dioxide.

Since growth and decomposition balances each other, a natural plant community is carbon neutral. The same amount of carbon is released as is fixated by growth. Thus, the climate benefit of an undisturbed forest is delimited to storage of carbon and the build-up of soil organic carbon.

The carbon dynamics of sustainably managed forests

The carbon balance of forestry is more complex than that of the unmanaged forest. Forest operations, transports and industrial processing cause carbon emissions. But forest products substitute for fossil energy and fossil-based products, thus reducing the emission of additional carbon into the biosphere.

One quarter of the forest area, over 18 million hectares, are excluded from forestry, mainly for environmental reasons. The large forest resource of the region makes forest management practices important for the EU climate policy and for the contribution of the European continent to fighting the rising levels of carbon dioxide in the atmosphere. No other sector manages such large flows of carbon as those resulting from annual forest growth, logging, and manufacture on wood-based products. The forest sector's influence on the atmospheric carbon dioxide content can be summarized as follows:

- Growing forests assimilate carbon dioxide from the atmosphere.
- The carbon is stored in the biomass of the trees and in the forest soil.
- Products based on woody biomass prolong the storage period, and substitute for fossil-based products and fuels, thus reducing the supply of "fossil" carbon dioxide to the atmosphere.

Only sustainably managed working forests can fulfill these purposes. The principles are illustrated in Figure 5. In a sustainably managed working forest, the conditions allow continuous net increment through repeated extraction of wood. To keep the forest vigorous and to choose the best crop trees, it is thinned before the competition leads to reduced vitality and self-thinning. In principle, regenerative felling takes place at an age maximizing average yield. In this way, the amount of forest raw material that can be delivered is maximized[6].

Continuous-cover forestry methods are interesting for several

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[6] In practice, this ideal management is not always implemented. Thinnings may be inoptimally postponed and regenerative felling may be carried out before or after the culmination of average annual growth, decreasing the average carbon sequestration. From a carbon sequestration point-of-view, a slight prolongation of the rotation period is less risky than felling ahead of time.

Figure 6. *Undisturbed forests may also be subject to dramatic changes affecting the carbon pool. After events such as windthrow or forest fire, the carbon in the decomposing biomass is released as carbon dioxide.*

different reasons, e.g., to support multi-functionality of forested areas. They deserve a place in the forest management toolbox. But, at least in most boreal and hemiboreal forests, they are not positively contributing to the carbon balance. Continuous-cover forestry is estimated to reduce average yield by 20 % compared to the even-aged stand management described above[7]. This will decrease the net fixation of carbon. Continuous-cover forestry also entails higher emissions during silviculture and harvesting, strongly delimits the possible choice of crop tree species, and makes it difficult to extract logging residues for energy.

To stop or significantly postpone felling is often suggested as means to counteract climate change. Adhering to such measures would quickly increase the carbon sequestration rate and carbon sink of standing forests. But these positive climate effects are delimited to the short term. In the medium to long term, they will imply several risks. The ensuing loss of forest products may be detrimental if it entails increased use of fossil carbon reserves. Further, a reduced financial attractivity of forest investments would decrease not only the forest industry, but also silvicultural activity and forest regeneration efforts. A long-term strategy for forest-based climate action should therefore include the purposeful utilization of forest biomass.

While it is probably not correct to say that forestry is ”good for the climate”, it is difficult to find alternative ways for production of goods, utilities, and benefits with as small negative effects on climate, environment, and biodiversity as forestry. Ongoing product and process development in the forest sector will underline this statement further.

In view of the goal of increasing the forest’s climate benefit, such forest management measures should be taken that can increase growth. Examples include rapid regeneration after felling with adapted tree species selection and best available, preferably improved, plant material; clearing and thinning at the right time; fertilization etc. Low-utilized land with sparse, low-stocked stands should be prioritized for felling and rejuvenating, before well-closed, highly productive forests. Such measures provide increased sequestration of carbon dioxide and thus a higher climate benefit. Increased growth also boosts the rate of SOC (Soil Organic Carbon) accumulation, as an effect of higher litterfall. A Swedish study showed that a 20 percent investment increase in silviculture[8], could increase yield by about 10 per cent, or 10 million m^3st ob/year[9].

Although carbon sequestration is an important goal for the international climate policy, it is far from the only goal. This publication deals with forests and forestry from a climate perspective but maximizing carbon sequestration and carbon sinks cannot be the global goal for forest management. Apart from the economic imperatives of the forest sector, forestry must be carried out with consideration for e.g. biodiversity and other environmental values, recreation and the needs of other sectors that depend on the forest. How these goals are to be balanced against each other is not a scientific issue. It must be decided through a continuous dialogue between the forest owners, the industry, and other relevant stakeholders. The role of science may be to support this dialogue. The aim of the current report is to support this dialogue with facts on the effects of current forestry practices in the Nordic-Baltic region on atmospheric carbon dioxide levels.

[7] With even larger yield losses during the transition stage between even-aged and multi-storeyed stands.

[8] Currently, silvicultural costs make up 15 per cent of the total Swedish forestry cost which chiefly consists of costs for logging (43 per cent) and for transports and roads (42 per cent)

[9] The measure m^3st ob denotes solid stem volume of a tree, above stump height and over bark.

A carbon balance for the Nordic-Baltic forests

This section elaborates the effect of Nordic-Baltic forests on the concentration of atmospheric carbon dioxide. Official statistics concerning basic forest and forestry data have been used, and conversion factors are based on data from scientifically published reports. The material has been complemented with a query to experts from the NB NORD member countries.

The carbon balance varies widely between different areas and forest types, depending on climatic gradients, soil moisture, soil type, management, etc. The data presented here are based on area weighted averages for whole countries and do not to represent smaller regions.

To elaborate a carbon balance for the Nordic-Baltic forests, we need information on

- The standing inventory, converted to the amount of carbon stored in the trees' biomass
- The proportion of softwood and hardwood respectively (the relative content of carbon in the biomass differs)
- Store of Soil Organic Carbon (SOC) in the forest soils
- Inventory dynamics (net effect of growth, harvesting and other loss)
- Impact of forestry on SOC
- The carbon dioxide emissions from forest operations

Since climate change has been coupled to carbon dioxide as a greenhouse gas, all carbon pools and flows will be expressed as tonnes carbon dioxide equivalents, t CO_2eq, regardless of the form in which carbon occurs in these flows and pools.

Carbon pool in forests and forest soils

The forest inventory is commonly stated as a volume, e.g., cubic meters stem volume over bark, m^3st ob. But carbon is stored throughout the tree. The entire tree's biomass, including branches, foliage, and stump-root systems, needs to be specified. The amount of carbon per cubic meter differs between tree species and between different fractions of a tree since the density per volume varies greatly. In this context, we are mainly interested in the amount of carbon. This makes it appropriate to recalculate the volumes to a corresponding weight, expressed as tonnes of dry biomass, t DM.

Mainly due to differences in lignin content, deciduous trees have a slightly lower carbon content (approx. 48 per cent) than conifers (approx. 52 per cent). Therefore, the distribution of timber stock between coniferous and broad-leaved trees should be included in the calculation.

The stock of dead wood in the forests is significant. Currently the average for the Nordic-Baltic region is 7.5 m^3st ob/ha. The volume is increasing, partly as an effect of nature conservation measures. In the long run, a stable level will be reached, where the amount of dead wood in the forests is balanced by the annual decomposition. Dead wood should therefore be included in the calculation of the forest's stocks of carbon. When calculating carbon in dead wood, no addition was made for biomass in branches, which could possibly lead to a minor underestimation of the amount of carbon bound in tree biomass.

A fraction of the carbon that is fixated through photosynthesis is transferred to the forest soil after decomposition of litter and dead trees. This is a slow process, but over time the pool of soil organic carbon, SOC, becomes significant. Large differences in climate, vegetation, topography, humidity and soil conditions affect the conditions for both growth and degradation.[10] The average SOC levels vary from 40 tonnes of carbon per hectare in the northern parts of the Nordic-Baltic area to over 160 tonnes in the southern and western parts of the region. The total stock of SOC in forest soils, shown in **Table 1**, is over 7,000 million tonnes corresponding to over 25,000 million tonnes as CO_2eq. The table also shows the stock of carbon in the total forest inventory, corresponding to some 13.400 million t CO_2eq. Thus, more carbon is stored in the soil than in the woody biomass of forests.

Table 1

Living inventory	...all forest land	...of which deciduous	...of which dead trees
m^3st ob	9 460 000 000	2 327 697 000	548 238 000
t DM biomass	7 277 000 000		
Tree biomass as tonnes CO_2eq	13 400 000 000		
SOC, t CO_2eq	25 690 000 000		
Total carbon store, t CO_2eq	39 090 000 000		

Table 1. *Forest inventory and forest soil organic carbon (SOC) on all forest land in the Nordic-Baltic region as m^3st ob, t DM biomass and as t CO_2eq, including the proportion of deciduous trees and of dead trees as m^3st ob*

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[10] The rate of soil humus formation is very uncertain.

Table 2

	Annual yield	...harvesting	...other drain	...inventory change
m^3st ob	314 319 000	218 236 000	44 773 000	+ 51 310 000
t DM biomass	241 711 000	167 824 000	34 430 000	+ 39 457 000
t CO_2eq	454 127 000	315 307 000	62 701 000	+ 74 132 000

Table 2. *Annual yield, harvesting and other loss and net inventory change in the Nordic-Baltic region as m^3st ob, as t DM biomass and as t CO_2.*

Carbon flux

The carbon stock levels in forests are affected by dynamic processes such as forest growth, harvesting and other loss of biomass. Management practices and policies will also impact the carbon stock in biomass and soil. The earliest proper inventories indicate a regional growing stock of approximately 4 billion m^3st ob in the early 1900's. Since then, the inventory has doubled, to 7.9 billion m^3st ob.

The average yield level of the regions forests is around 4.2 m^3st ob/ha, yr. This means that about 6 tonnes of CO_2 are assimilated per hectare and year. The region's annual forest growth is around 315 million m^3st ob/yr, while harvesting and other losses reduce the actual build-up of inventory to around 55 million m^3st ob/yr.

Table 2 summarizes yield, harvesting, other drain and net annual inventory change as m^3st ob, as t DM biomass and as a corresponding amount of CO_2. (The amount of dry matter and CO_2 in the inventory is based on the entire biomass of the trees and adjusted for the distribution between conifers and deciduous trees).

The average stock of SOC in forest soils of the NB region was estimated at 94 tonnes C/ha, which has been accumulated over a period of some 10,000 years, following the melting of the latest glaciation ice sheet. Thus, an average of 9.4 kg C/ha, yr has been stored in the forest land.

The dynamics of soil organic carbon (SOC) are also affected by forestry. When a stand is harvested, the continuous supply of organic carbon to the soil is interrupted, while soil respiration continues. After harvesting, SOC increases due to the large amounts of felling residues, especially root systems, which decompose after felling. During the plant and young forest phase, SOC levels decrease as a result of a low litterfall. The soil emits carbon dioxide and SOC decreases. It cannot be expected to reach the level that prevailed at the time of felling until the new forest has reached an age of about 30 years. Assuming a linear process of SOC formation, 30 years loss of annual build-up of SOC corresponds to, in average, about 282 kg of C/ha and rotation period[11].

The rotation periods in the Nordic-Baltic region vary from some 50 to 150 years. If an area-based average of 100 years is assumed, forestry, through harvesting, reduces the accumulation of SOC on working forest land by 2.5 to 3 kg C/ha, year (total 140,000—170,000) tonnes per year. The simple calculation gives an idea of the magnitude of the changes in the stock of SOC that occur because of final felling under current conditions (**Table 3**).

Table 3

		Annual SOC accumulation		
	Current SOC store, AFS	WFS	EFS	AFS
kg C[1]/ha100 cm	92 000	6.6	9.4	7.3
Total, t C1	7 006 000 000	371 000	171 000	542 000

[1] The figures are given as mass of carbon. The conversion factor from carbon to CO_2 is 3.67.

Table 3. *Estimated total current store of SOC on all forest soils (AFS) to a depth of 100 cm in the regions forests, and build-up of SOC on working forest soils (WFS), excluded forest soils (EFS) and totally (AFS).*

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[11] Compared to drier soils, the effects of forest management on SOC are more pronounced for hydromorphic soils such as peat, where ditching has often been applied to reduce the water surplus. Ditching increases the thickness of the aerobic layer. The transpiration of growing trees furthers this process. Stored organic material decomposes, releasing carbon dioxide to the atmosphere. On peatland forests, providing the drainage system is maintained, the SOC stock may decrease by 800-2600 kg C/ha, yr.

Table 4

Operation	Extent per year	Used energy as m^3 diesel	Total emission as tonnes CO_2	Emissions, kg CO_2 /m^{3}st ob
Scarification, ha	479 000	11 900	31 400	0.14
Planting, ha	455 000	36 500	96 300	0.44
Cleaning, ha	1 015 000	10 100	26 600	0.12
Fertilization, ha	60 000	740	2 000	0.01
Harvesting, m^{3}st ob	218 236 000	192 000	506 900	2.32
Forwarding, m^{3}st ob	218 236 000	144 900	382 600	1.75
Forwarding energy wood, m^{3}s	29 969 000	36 000	94 900	0.44
Comminution energy wood, m^{3}s	29 969 000	59 900	158 200	0.73
Road transport roundwood, m^{3}s ub	181 300 000	416 600	1 099 900	5.04
Road transport, energy wood, m^{3}s	29 969 000	56 900	150 300	0.69
Roads, maintenance etc., m^3	211 105 000	69 900	184 500	0.85
Total	**-**	**1 035 500**	**2 733 700**	**11.98**

Table 4. *Assumed 'normal' extent of forest operations and transports in the Nordic Baltic region and the subsequent need for energy (m^3 diesel per year), and emissions of CO_2eq, totally and per harvested m^{3}st ob.*

Emissions of carbon dioxide from forest operations

Forest operations lead to emissions of carbon dioxide, not only from forest machines of various kinds, transports, and forest road maintenance, but also greenhouses where plants are grown, the production of fertilizers etc. The size of the emissions depends partly on the amount of work (as area, volume etc.) but is also affected by regional conditions such as tree size and transport distance. The data for the section has been obtained from official statistics regarding the scope of various works as well as from published studies of energy consumption in forestry work and transport.

The calculations are based on average energy consumption (or fossil CO_2 emissions) per unit (hectare, kilometre, cubic metre etc) as reported in various studies. The most complete and current (2002-2016) datasets have been found for studies concerning Finnish, Norwegian and Swedish forestry. Since these three countries represent 80 per cent of the regional inventory and 82 percent of the annual harvesting, the figures are believed to be reasonably accurate. An annual regional logging volume of 218 million m^{3}st ob and approximately 12 million m^{3}s of primary forest fuels, mainly logging residues, have been assumed. The energy use was transformed into l diesel per harvested m^{3}st ob. (One litre of diesel was assumed to emit 2.64 kg CO_2 when combusted). The results (**Table 4**) show that the total energy consumption of forest operations in the region corresponds to 1 035 000 m^3 diesel. Of the energy consumption, silvicultural operations account for 6 per cent, logging and terrain transportation for 42 per cent while secondary transportation and forest roads account for 52 per cent. The emissions from forest operations and transports equal 2.7 million tonnes CO_2eq/yr, or expressed as carbon, 746 000 tonnes C/yr, or 3.4 kg C/m^{3}st ob.

Forest products may prolong carbon storage and substitute for fossil carbon

The main purpose of this report has been to outline the carbon dynamics of forests and forestry in the Nordic-Baltic region under its current management and practices. But a large part of the climate benefit of the forest sector arises from the processing and use of forest raw materials, through so-called substitution effects, which will also be briefly described.

Substitution effects occur when the use of forest products based on forest raw material replaces fossil-based materials or results in lower use of fossil carbon compounds. A simple example is the use of fuel chips instead of coal, oil or natural gas in energy production. More complex relationships apply to the use of wood in construction, as packaging material etc. Forest products benefit the climate in the following ways:

- During their lifetime, they provide a continuation of the carbon storage in woody biomass.
- By reducing mobilization of fossil carbon, they counteract increase of atmospheric carbon dioxide.
- Emissions of carbon dioxide from burnt or decomposed forest products, do not increase the carbon dioxide content in the atmosphere, provided that harvesting levels are sustainable[12].

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[12] Meaning that the extraction of biomass over time does not exceed growth.

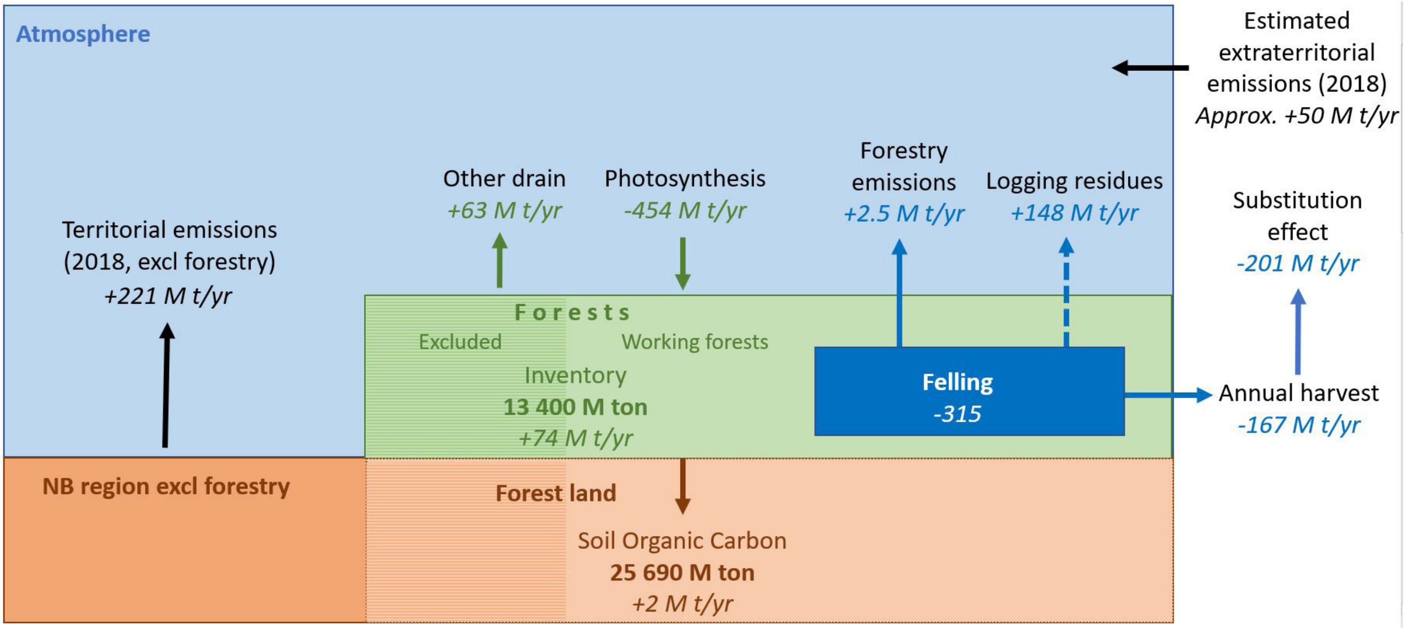

Figure 7. *A carbon balance of the Nordic-Baltic region with separate accounting of the effects of forests and forestry. Forests excluded from forestry are rasterized. All figures expressed as million tonnes* CO_2.

By recycling carbon from forest products, the forest sector contributes to the transition to a bio-based, circular economy. Building materials, paper and packaging materials, textile fibers, various chemicals and biofuels are some examples.

The substitution effects are difficult to elaborate. Biofuels often directly substitute for fossil fuels, but although they reduce flux of fossil carbon to the biosphere, the substitution factor may be smaller than 1, as, for example, wood chips are a less efficient fuel than the fossil alternatives[13]. Other types of products, such as wood for construction products can have substitution factors up to 5. The variation is large. In a review of more than fifty studies, the European Forest Institute, EFI, proposes an average substitution factor of 1.2. This means that every kg of carbon in the timber-based products reduces the carbon dioxide load in the atmosphere by the equivalent of 1.2 kg calculated as carbon, i.e. 4.4 kg CO_2. Applying a substitution factor of 1.2 to the annual extraction assumed for the NB NORD region in the above calculations add an additional climate benefit of just over 200 million tonnes of CO_2/year.

A carbon balance for the Nordic-Baltic region

Figure 7 summarizes the results of the above calculations. The figure shows stocks and flows of carbon expressed as millions of tonnes of carbon dioxide in the region's forests and forest soils, as well as the territorial carbon dioxide emissions of the region. The figure shows that the region's forests annually absorb over 454 million tonnes of carbon dioxide and that biomass corresponding to some 315 million tonnes is felled annually. Of the annual felling, 148 million tonnes return to the atmosphere due to decomposition of felling residues and dead trees while corresponding to 167 million tonnes are extracted in the form of raw materials. A substitution factor of 1.2 may be applied to this feedstock, meaning that the use of forest biomass from the Nordic-Baltic region will prohibit the emission of over 200 million tonnes of carbon dioxide of fossil origin. Annually, 74 million tonnes are added to the forest's stock of carbon by increasing the region's forest inventory and corresponding to 2 million tonnes are added to the forests' stock of soil organic carbon[14].

The territorial, regional carbon dioxide emissions are 223.6 million tonnes, of which forestry accounts for 2.5 million tonnes. In

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[13] Thus, CO_2-emissions per produced energy unit may be higher from a bio-boiler than from a coal-boiler. (But if the forest inventory is maintained, the use of biomass does not lead to increased levels of atmospheric CO_2).

[14] Possible historical loss of SOC, e. g. due to drainage and ditching has not been investigated.

addition, the regional consumption leads to emissions in other countries. The available data over such extraterritorial emissions indicate that, for an individual country, they are in the same order as the territorial emissions. A significant part of trade exchange takes place inside the region and the majority of extraterritorial emissions are covered under the emission levels reported by the EU. Thus, the regions consumption outside the EU is limited, and was estimated to cause emissions of 50 million tonnes CO_2eq/year.

If the net growth of forests, annual SOC build-up, and substitution effects of raw materials from the forests are added, the current management and utilization of the region's forest reduces the carbon dioxide load on the atmosphere by almost 280 million tonnes per year.

Figure 8. *An intensified recovery of logging residues on suitable areas would greatly enhance the climate benefit of forestry. Forest chips substitute for fossil fuels, but logging residue is also a potential feedstock for various emerging bio-refineries.*

Increasing the climate benefits of Nordic-Baltic forests?

Wood and boards for construction, interior design and furniture are long-lasting products that extend the storage time of carbon considerably. They often replace emission-intensive alternatives. In addition, while the sawmill's largest by-product is fresh chips for the pulp industry, they also supply bark, shavings, and dry chips for energy purposes.

The pulp and paper industries generate the largest flows of wood raw material. Some pulp is exported, but most is processed within integrated pulp and paper mills. A paper fibre can be recycled up to seven times. Improving the systems for recycling means increasing the climate benefit.

Today, the forest industry seeks to develop new products that can replace fossil-based, difficult-to-degrade or energy-intensive products. Production of bio-based plastics has already been started, with a wide use for everything from bottles and food packaging to disposable items, medical materials, and car interiors. Another example that is up and running is wood-based textile fibers with a low environmental impact.

Forest chips and other wood fuels are a main source of energy for the forest industry. They are also the dominant fuel for district heating, often carried out as Combined Heat and Power production. Wood heats many private homes. After their economic life, virtually all wood and paper products can be used for energy, as a final step. Liquid biofuels are produced from residual products from the pulp industry. The production of renewable fuels based on pyrolysis oil, methanol, and ethanol for motor fuels could be significantly increased.

Without harvesting more, the climate benefit of the forest sector could be increased if more of the harvested trees is utilized. An intensified recovery of small trees, stumps, branches, and tops is entirely possible (**Figure 8**). These wood fractions are currently normally left on the logging site. Not all soils are suitable for a more complete harvest, though. Foliage and fine twigs contain a larger proportion of nutrients than wood. Therefore, on weaker soils, in the same way as in agriculture, there may be a need for fertilization to compensate for an increased removal of mineral nutrients.

Leftover wood and logging residues also have a value as a substrate for various wood-living organisms and provides protection for many species in the field layer. In sensitive areas, logging residues may be used to reinforce strip roads, providing physical protection against rutting. Thus, intensified recovery of the felled biomass cannot be uncritically implemented. Its effects should be monitored and, if needed, counteracted, to establish a sustainable level.

The Nordic-Baltic forests and climate change in a global perspective

Climate work accelerates the development of a sustainable bioeconomy. In the Nordic-Baltic region, the large forest resource is given a special position to carry that change. Much of the infrastructure is in place for such a shift and a wise utilization of the forest's products already meets important needs, with a low impact on the environment and climate.

But much remains to be done. To achieve results quickly, it is now important to increase, develop and improve the production and use of sustainably produced forest raw materials in partnerships between forestry, the forest industry and its customers.

Wood construction and building is deeply rooted in the region. Industrial know-how and products, developed in the Nordic-Baltic region, could be launched internationally. Today, however, building standards and a lack of tradition are important obstacles to such exports.

The climate threat cannot be met by the Nordic-Baltic region and its forestry sector alone. The threat is global and must be resolved internationally. To meet this challenge, more countries need to shift their consumption to sustainable alternatives. Developing a more sustainable forest sector may be an important part of this transition. The Nordic-Baltic region may inspire and show opportunities. The combination of protected and cultivated forests under a retention forestry regime, with sustainable growth through replanting and forest management and increasing or stable inventory of forest may serve as examples, worth following.

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Basic forest data for the countries of the Nordic-Baltic region

In this appendix, some basic forest data for the countries of the Nordic-Baltic region, that have been used for the calculations in this report, are presented.

Appendix Table 1

Appendix Table 1. Total forest area, forest area excluded from forestry, live and dead inventory and proportion of softwood in the countries of the Nordic-Baltic region (2018).

	Forest area, ha	Excluded forest area, ha	Live inventory, 1 000 m^{3}st ob	Dead inventory, 1 000 m^{3}st ob	Softwood, %
Denmark	627 338	12 326	135 496	1 883	43
Estonia	2 230 200	731 200	486 000	18 041	60
Finland	26 246 000	7 670 000	2 475 200	117 601	80
Latvia	3 244 920	216 000	677 107	56 059	52
Lithuania	2 184 000	495 768	489 800	32 007	58
Norway	12 089 000	3 791 000	1 160 045	100 000	74
Sweden	28 008 000	5 306 000	3 488 000	222 700	79
N-B region	74 630 458	18 222 294	8 911 648	548 238	74

Appendix Table 2

Appendix Table 2. Annual growth, felling, other drain and average soil organic carbon in the countries of the Nordic-Baltic region.

	Annual growth, 1 000 m^{3}st ob	Annual felling, 1 000 m^{3}st ob	Other drain[1], 1 000 m^{3}st ob	Extracted primary forest fuel[2], 1 000 m^{3}s
Denmark	6 495	3 136	1 652	1 883
Estonia	3 800	12 500	1 770[3]	18 041
Finland	107 800	78 167	15 507	117 601
Latvia	26 626	17 632	6 247	56 059
Lithuania	3 800	7 000	1 784[3]	32 007
Norway	27 183	15 461	6 042	100 000
Sweden	121 110	84 340	11 770	222 700
N-B region	314 319	218 236	44 773	548 238

[1] Other drain include trees subject to windfall and other calamities. Since some such volumes are partly used by industry and reported as part of annual felling, the total drain is probably overestimated.

[2] No n-roundwood primary forest fuel sorts as logging residues, small trees and stumps.

[3] Other drain for Estonia and Lithuania has been estimated based on the average ratio for the other five countries.

Appendix Table 3

Appendix Table 3. Average conversion factors used for the analysis

1 m^{3}st o b = 0.769t DM biomass (including biomass in branches, foliage and stump-root system)
1 kg C = 3.667 kg CO_2
1 l diesel = 2.64 kg CO_2
1 t DM biomass = 1878.8 kg CO_2
Carbon content = 52 per cent for softwood biomass, 48 per cent for hardwood biomass