National forestry accounting plan for Sweden

Government Offices of Sweden

Ministry for the Environment and Energy

1. General introduction

Forests cover more than 42% of the EU's land surface and represent a significant mitigation potential. EU regulation (EU) 2018/841 on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry in the 2030 climate and energy framework adopted in May 2018 for the first time integrates the greenhouse gas emissions and removals from forestry and other land use sectors into EU climate policy. Under the LULUCF Regulation, EU Member States must ensure that greenhouse gas emissions from land use, land use change and forestry are offset by at least an equivalent removal of CO_2 from the atmosphere in the period 2021 to 2030. The regulation implements the agreement of the European Council in October 2014 that all sectors should contribute to the EU's 2030 emission reduction target, including the land use sector. The regulation is also in line with the Paris Agreement, which points out the important role of the land use sector in reaching our long-term climate mitigation objectives.

In the long term climate strategy (COM(2018)733) the European Commission points out that sustainable biomass has an important role to play in a net zero greenhouse gas emissions economy. The Commission stresses that the long-term mitigation benefits are greater when the forest is actively managed and forest products substitute resources with higher carbon footprint. A net zero emissions economy will require increasing amounts of biomass compared to today's consumption and more biomass need to be mobilized. Sweden fully supports this view. The Effort Sharing Regulation on binding annual emission reductions by EU Member States adopted in 2018 sets the national emission reduction target for 2030 compared to 2005 for Sweden to 40 percent for the ESR sector. As indicated by guidance from the Riksdag (the Swedish parliament) in January 2019[1], to maintain the ambition level in the EU climate framework 2021-2030, Sweden will not use any possible credits from Managed Forest Land to meet its EU commitment in the ESR sector, nor be transferred to other Member States.

Total greenhouse gas emissions in Sweden excluding LULUCF, expressed in CO2 equivalent, were about 52.9 million tonnes (Mton) in 2016. This can be compared to the 71.5 Mton emitted in 1990, resulting in a decrease of total

1 Miljö- och jordbruksutskottets protokoll 2018/19:15 (http://www.riksdagen.se/sv/dokument-lagar/dokument/utskottens-protokoll/protokoll-utskottssammantrade-20181915_H6A1MJU15p).

emissions by about 26% compared to 1990. Total greenhouse gas emissions including LULUCF in 2016 were about 9 Mton.

1.1 Sweden's national climate policy framework

In June 2017, the Riksdag adopted a climate policy framework containing a climate act which lays down principles and timetables for the Government's actions, new ambitious climate goals and an independent climate policy council tasked to review the Government's policies. The framework aims to create order and stability in climate policy. It will provide business and society with the long-term conditions to implement the transition needed to address the challenge of climate change. The reform is a key component of Sweden's efforts to comply with the Paris Agreement.

The framework contains several new climate goals for Sweden.

1. By 2045, Sweden is to have net zero emissions of greenhouse gases into the atmosphere and should thereafter achieve negative emissions. Negative emissions will mean that Sweden overall helps to reduce the amount of greenhouse gases in the atmosphere. That is, the amount of greenhouse gases emitted by Sweden in ETS and ESR is less than the amount of greenhouse gases reduced through enhanced net removals in the LULUCF sector, through bio-CCS techniques, and through climate projects pursued by Sweden abroad. In addition, fossil emissions from activities within Sweden must be at least 85 per cent lower by 2045 than in 1990.

2. By 2030, emissions from domestic transport, excluding domestic aviation, will be reduced by at least 70 per cent compared with 2010.

3. By 2030, emissions in Sweden in sectors covered by the EU Effort Sharing Regulation should be at least 63 per cent lower than in 1990.

4. By 2040, emissions in Sweden in sectors covered by the EU Effort Sharing Regulation should be at least 75 per cent lower than in 1990.

The goal of net zero emissions of greenhouse gases by 2045 and the goals for 2030 and 2040 may, to a limited extent, be achieved through supplementary measures, such as increased net removals of greenhouse gases by the LULUCF-sector, BECCS or verified emission reductions from investments in climate projects abroad. Such measures may be used to achieve a maximum of 8 and 2 percentage points, respectively, of the emission reduction goals by 2030 and 2040. That is, by 2030, emissions from activities in Sweden should be at least 55 per cent lower than in 1990, and by 2040 at least 73 per cent lower than in 1990.

These goals reflect Sweden's climate leadership, and show that Sweden undertakes to achieve emission reductions that far exceed Sweden's required emission reductions under the EU Effort Sharing Regulation.

1.2 The forest resource in the national climate strategy

The Swedish forest policy has two equal objectives: the environmental objective and the production objective, see section 2.4.

Bio based fuels and materials that substitute fossil resources are important for transition to a low carbon society. Sweden is well suited to combine active forest management with high environmental standards whilst maintaining a substantial carbon sink.

Sweden places great importance on the continued development of a bio-economy, since an active and sustainable forest management will achieve the highest long-term climate benefit. Sufficient and secure access to sustainable biomass from the Swedish forest and continued profitability and willingness to invest along the forest value chains shall be ensured through sustainable forest growth within the framework of the national environmental quality targets. Sweden has adopted a national forest program with the overarching vision that forests, the "green gold", shall contribute to employment and sustainable growth in all parts of the country and to a growing bioeconomy.

In Sweden, active forest management contributes to an increased forest stock and increased harvest yield over time compared to the last centuries when the landscape was more intensively used for agriculture. The forest stock has more than doubled during the last 90 years, see figure 1.

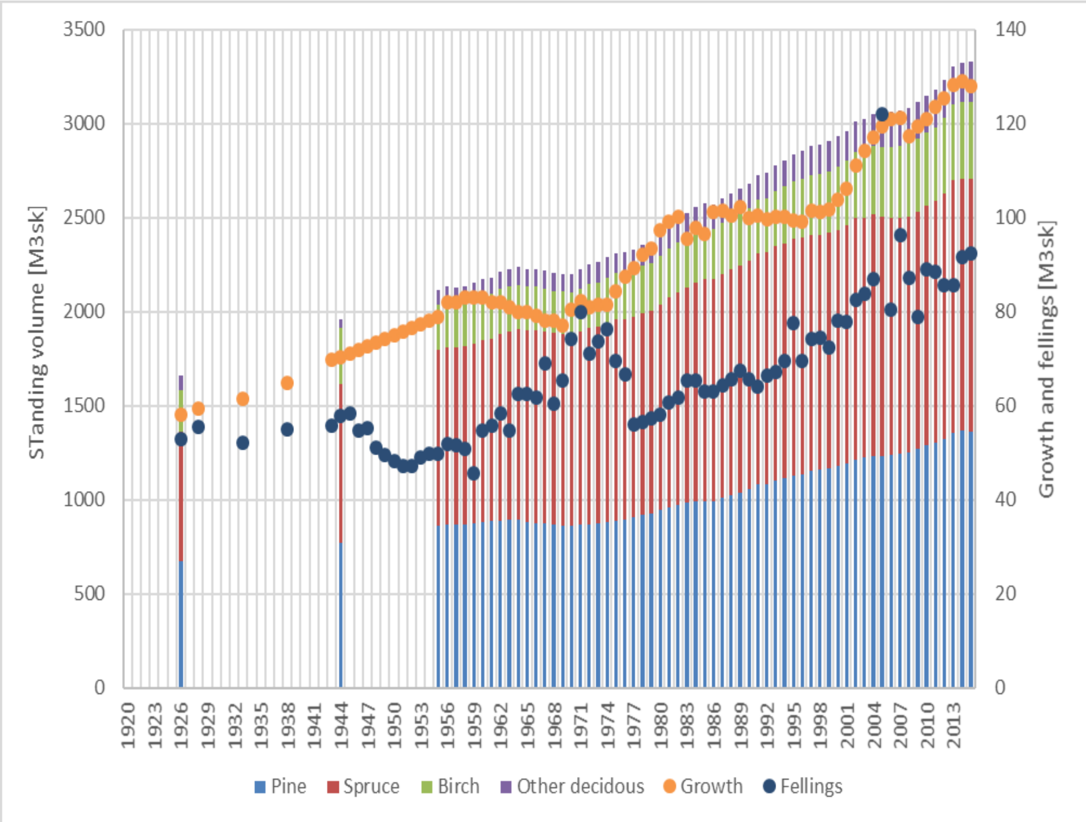


Figure 1. Forest stock development per tree species on left y-axis, development of growth and fellings on the right y-axis.

Due to resource efficiency, residues from harvest operations and forest industry processes have increased the wood based bioenergy share of the energy mix considerably over the past decades. Today wood based bioenergy constitutes the major part the bioenergy supply in Sweden.

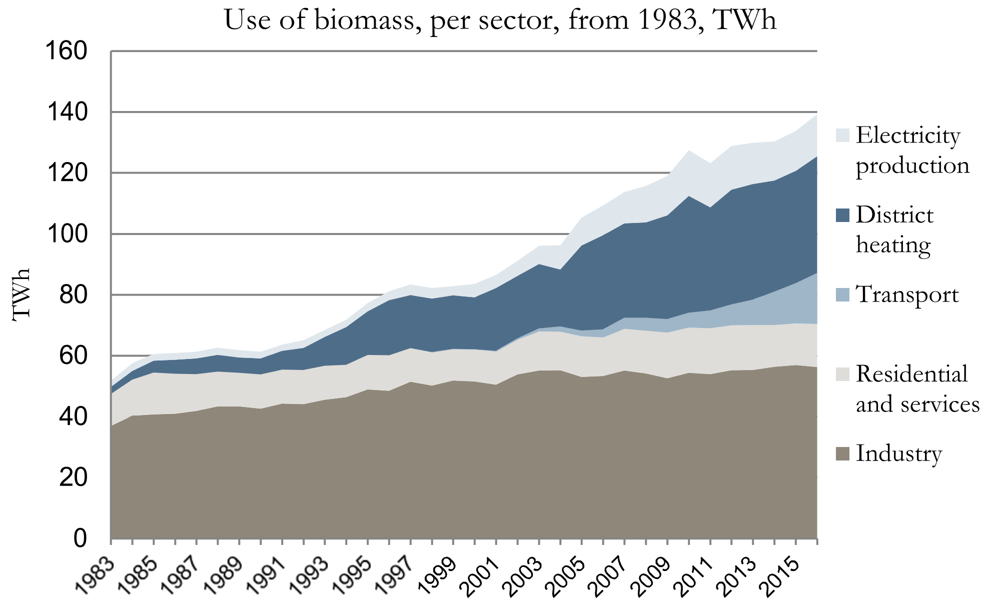


Figure 2. Use of biomass per sector in Sweden[2].

In parallel, until today 1,1 million hectares productive forest have been designated for nature protection in formally protected areas. 1,2 million hectares are voluntarily set aside forests, i.e. forest owners have set aside forests for nature conservation due to certification schemes.

In many other parts of the world, harvest operations have developed over the last decades to create better conditions for biodiversity and various ecosystem services. Trees and tree groups are left at harvest and dead wood is saved and created. In Sweden such actions are to be taken at every logging occasion, according to the law and such measures are also a key part of certification standards. It is site specific to the elements that need extra consideration, for example tree retention for buffer zones to watersheds or sensitive biotopes. But even sites that are less sensitive, tree retention applies to establish structures of old trees and dead wood in the next stand rotation. Thus, the not harvested areas at the harvest sites varies from site to site, but at a national average, the tree retention at harvest sites amounted to about 8 percent of the harvest site area during the reference period, according to an

2 Swedish Energy Agency (2018) Energy in Sweden 2018.

inquiry made by the Swedish Forest agency. These areas of tree retention (TR) will in total correspond to about 1.7 million hectares of production forest land nationally, under a future rotation period.[3] Retention forestry complements other types of conservation measures, i.e. voluntarily set-asides and nature reserves.

1.3 Definitions of terms used in this report

Productive forest is forest area with a yearly increment > 1 m3/ha/yr.

Production land is productive forest area primarily used for timber production including tree retention sites.

Tree retention (TR) is a part of Production land where trees area retained for biodiversity and other considerations at harvest sites.

Productive forest land managed for wood supply is Production land excluding tree retention sites.

Reserves are areas of productive forest publicly protected areas for nature conservation.

Voluntary set-asides are productive forest areas protected for nature conservation on a voluntary basis, often under a forest certification scheme.

Low-productive forest is forest area with a yearly increment < 1 m3/ha/yr. Includes low-productive forest in reserves.

1.4 Guidance by the EU Commission

The Commission presented a guidance for developing and reporting the forest reference levels on 24 July 2018. The stepwise approach of the guidance is, however, not applicable for the modelling methods that Sweden utilizes. Therefore, this report has been prepared on the basis of the regulation and follows the structure of Annex IV, rather that the exact approach of the guidance.

1.5 General description of the forest reference level for Sweden

The Forest Reference Level forest (FRL) for Sweden for the period 2021-2025 has been estimated to -30 556 kt CO_2-equivalents. The FRL includes

3 Claesson S., Duvemo K., Lundström A. and Wikberg P.-E. 2015.

carbon stock changes in carbon pools and other emissions of greenhouse gases on managed forest land (table 1).

Table 1. Average annual carbon stock changes, other emissions and the resulting FRL for managed forest land in Sweden 2021-2025.

[kt CO_2-equivalents]		**2021-2025**
Living biomass	Managed forest land, total	-17 570
	Production land incl TR (ca 21100 kha)	*-6 533*
	Productive forests set-aside for nature conservation (ca 2100 kha)	*-7 396*
	Low-productive forest land (ca 4000 kha)	*-3 641*
Mineral soils	Dead wood	-2 083
	Litter, Soil	-11 613
Organic soils	Dead wood	-271
	Litter, Soil (CO_2+DOC from drained soils)	5 191
	Drained organic soils (N_2O, CH_4)	1 189
HWP	Total	-5 495
	Sawn wood	*-4 561*
	Wood panels	*112*
	Paper and paper board	*-1 046*
Fertilisation (N_2O)		23
Mineralization (N_2O)		0
Indirect emissions (N_2O)		4
Biomass burning (CO_2, N_2O, CH_4)		69
TOTAL WITHOUT HWP		**-25 061**
TOTAL WITH HWP		**-30 556**

The proposed forest reference level (FRL) for managed forest land is the expected average annual net removals in 2021-2025, based on simulations of the carbon stocks on managed forest land starting from 2010 assuming the continuation of forest management practices as observed 2000-2009. Both addition of areas to and subtraction of areas from forest land related to afforestation (after 30 years from afforestation year) and deforestation have been considered in the simulation. Climate change effects according to

RCP4.5 are also reflected in the simulations with a positive effect on forest growth.

The development of carbon stocks has been simulated using the documented forest management practice 2000-2009, including measures in forestry and biodiversity. The harvest level in the simulation equals the growth on production land, reduced by the volumes left for tree retention, which was considered as the practice 2000-2009 (and still is) in forestry in Sweden. On productive forest land no harvest was assumed in areas formally protected or voluntarily set-aside for nature conservation, in low-productive forest land or tree retention areas at harvest sites. Given these assumptions, the relative harvest level on managed forest land during the commitment period 2021-2025 is estimated to 85 percent (annual harvest/annual growth on managed forest land,), see table 12.

In the calculations, the same sample plots from the National Forest Inventory (NFI) and the Swedish Forest Soil Inventory (SFSI) as in the reporting of the LULUCF-sector to the EU and the Climate Convention (UNFCCC) have been used.

The FRL comprises all forest carbon pools currently reported to the EU and the UNFCCC (Living biomass above ground, Living biomass below ground, Dead wood, Litter, Soil organic carbon and HWP) as well as other emissions associated to managed forest land included in these reports (fertilization, emissions from drained organic soils, biomass burning).

Development of forest carbon stocks have been simulated using well established models. Biomass is simulated on NFI-plot level using the Heureka RegVis tool and the litter and soil organic carbon pool on mineral soils is simulated using the Q-model. Other emissions are based on average emissions 2000-2009 and the state of forests and areas 2010.

Historical data is presented in the annual greenhouse gas inventory reported to the EU and the UNFCCC[4] whereas the FRL is described (with relevant references) in this submission and in the final report of a Government commission[5].

4 National Inventory Report Sweden 2018.

5 SLU 2018.

1.6 Consideration to the criteria as set out in Annex IV of the LULUCF Regulation

In the following, we describe how the criteria to determine the forest reference level (FRL) according to Annex IV, section A and B (where appropriate), have been met in the establishment of a FRL for Sweden.

Annex IV, section A
(a) the reference level shall be consistent with the goal of achieving a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century, including enhancing the potential removals by ageing forest stocks that may otherwise show progressively declining sinks;

On forest land managed for wood supply, the intention is that the FRL should promote a high sustainable growth for providing biomass to meet future demands for energy and timber. The yield (harvested growth) will substitute fossil based materials and energy. If this is achieved it is likely that future growth (removal) is balancing the harvest (emission; including self-mortality). It is also likely that other pools, such as dead wood, litter and soil organic carbon, ultimately reaches a steady state.

The Swedish Government has established a national forest program in which sustainable forest management is the base. The definition in this program is equivalent with sustainable forest management defined within the pan-European forest cooperation Forest Europe and adopted in the EU Forest strategy.

Productive forests not used for wood supply (productive forests set-aside for nature conservation) are preserved mainly for nature conservation/biodiversity. No harvesting is assumed in these areas nor in low-productive forests and the projection of their development is reflecting their natural development.

With these assumptions, the resulting relative harvest level on managed forest land during the period 2021-2025 is estimated to 85 % (annual harvest/annual growth on managed forest land).

In figure 3 we show the development of the standing volume and the development of net growth[6] and harvest respectively for managed forest land from 2010 to 2110, and for information also the historical data

6 Net growth is total growth minus natural losses.

representing 1990-2014. It is a continuation of the simulations used for the reference level calculations. The standing volume (stem volume from stump height up to top including bark) is steadily increasing while allowing a high and sustainable harvest level due to a continuous increase in growth. Net removals in Living biomass is on annual average just above -19 Mt CO_2 over the 100 year period to be compared to net removals in Living biomass in the FRL which for the period 2021-2025 is estimated to -17.6 Mt CO_2.

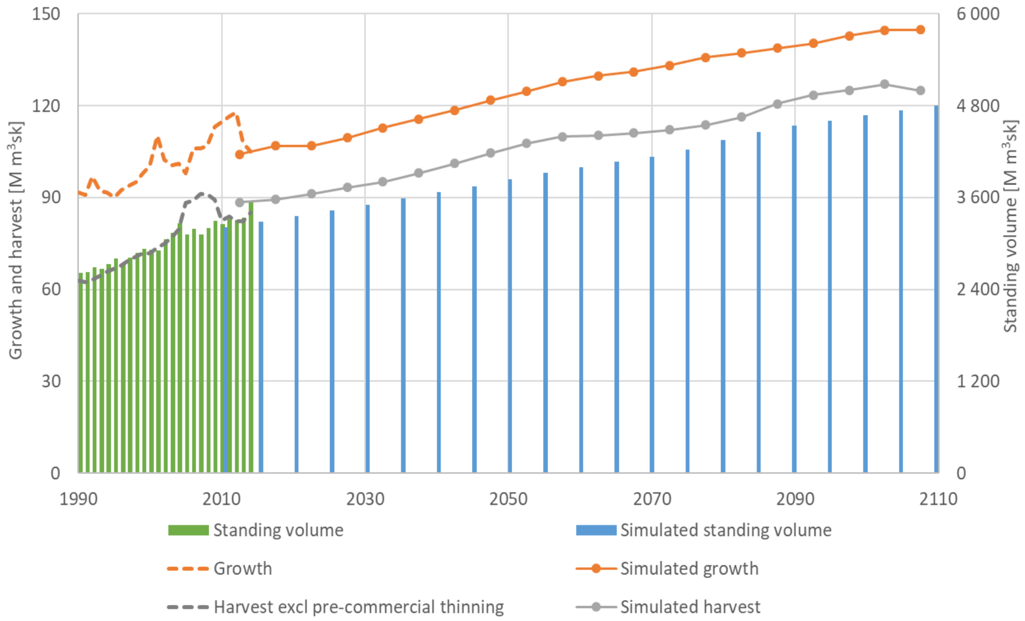


Figure 3. The development of the standing volume of biomass, annual net growth and harvest in Managed forest land 1990-2014 based on data from the NFI and for 2010-2110 based on the continuation of the simulated FRL.

Annex IV, section A

(b) the reference level shall ensure that the mere presence of carbon stocks is excluded from accounting

This criterion is compatible with Decision 16/CMP.1 under the Kyoto protocol[7], where the same principle was affirmed. It reflects the objective of enhancing the carbon stocks and the net carbon sinks where possible, instead of only preserving existing carbon stocks. It is understood that a pre-existing carbon stock in terrestrial vegetation such as a forest on a given area of land does not contribute towards the reduction of atmospheric carbon. The FRL intends to support accounting for differences in net changes

7 FCCC/KP/CMP/2005/8/Add.3.

(between actual changes and changes in the FRL) in forest carbon stocks, rather than accounting for total existing carbon stocks in forests.

Annex IV, section A
(c) the reference level should ensure a robust and credible accounting system that ensures that emissions and removals resulting from biomass use are properly accounted for

Any change in carbon stock on managed forest land are accounted for in the LULUCF sector (e.g. the harvest is indirectly accounted as an emission from the living biomass pool). This is needed because combustion of wood is excluded from the accounting within the energy sector. The consumer of the biomass will benefit from the direct substitution of fossil based energy and the end use of HWP only if the biomass is used for substitution.

All carbon pools (Living biomass, Dead wood, Litter, Soil carbon and HWP) are included in the FRL and in the reporting for Sweden, which ensures that all emissions and removals of carbon dioxide are accounted for.

Annex IV, section A
(d) the reference level shall include the carbon pool of harvested wood products, thereby providing a comparison between assuming instantaneous oxidation and applying the first-order decay function and half-life values

In table 1 we report the outcome for the calculation of the FRL. For the required comparison we present the FRL using either instantaneous oxidation or the production approach applying the first-order decay function and half-life values for HWP.

Annex IV, section A
(e) a constant ratio between solid and energy use of forest biomass as documented in the period from 2000 to 2009 shall be assumed

The average ratios between produced amounts of raw material from domestic forests and the production of the product categories sawn wood, wood based panels, paper products and energy were held constant during the simulations.

The fraction of solid wood (sawn wood and wood based panels) was calculated separately. The ratio between sawn wood and the entire logs was 0.48 (m^3 under bark) on average during 2000-2009. The three other categories wood based panels, paper products and energy use were compared to the amount of raw material used by the wood fiber industry which are chips and saw dust from saw mill waste and pulp wood. The ratios raw material/pulp was 0.89, raw material/wood based panels was 0.02, and raw material/energy was 0.09. These ratios were held constant during the simulations for the FRL.

Annex IV, section A
(f) the reference level should be consistent with the objective of contributing to the conservation of biodiversity and the sustainable use of natural resources, as set out in the EU forest strategy, Member States' national forest policies, and the EU biodiversity strategy;

The Swedish forest policy has during the last decades increased compliance with the Convention on Biological Diversity and the EU forest strategy. The policy aims to manage forests in a sustainable way. The Swedish Parliament already in 1998 adopted a set of environmental quality objectives which are considered a cornerstone of Swedish environmental policy. Reoccurring assessments show that further actions are needed to reach the ambitious objectives regarding forests, climate and biodiversity. Measures have been taken and up to date, more forest has been designated for nature conservation and sustainable forest management is continuously improving.

The following assumptions were made when developing the FRL. In December 2010, 780 kha of the productive forests were assumed formally protected as nature reserves (national parks, nature reserves and habitat protection). The non-formal protection cover an estimated area of 1 345 kha voluntarily set-aside areas and 1 487 kha tree retention areas at harvest sites. All low-productive forest land (around 4 037 kha) were assumed protected, i.e. no harvest was expected in the calculations.

The area of voluntary set-aside productive forest land in the analysis is based on an inquiry made by the Swedish Forest agency[8]. The inquiry represents the state of the forest 2009-2010 and a total area of 1 045 kha was considered as voluntarily set-aside productive forest land. Voluntarily set-aside productive forest land areas above the limit for mountain forests 200 kha was amended based on assumptions made by the Swedish Forest agency[9]. 100 kha was amended in the analysis to include areas within

8 Ståhl, P-O et.al.. 2012. ,Skogsstyrelsen 2008.

9 Skogsstyrelsen 2008.

ecoparks of the state owned forest company Sveaskog (based on geographical information of the ecoparks from Sveaskog).

Annex IV, section A
(g) the reference level shall be consistent with the national projections of anthropogenic greenhouse gas emissions by sources and removals by sinks reported under Regulation (EU) No 525/2013;

The FRL for Sweden is consistent with the reported national projections when it comes to the coverage of carbon pools, both the FRL and the projections under regulation (EU) 525/2013 includes all carbon pools (Living biomass, Dead wood, Litter, Soil carbon and HWP).

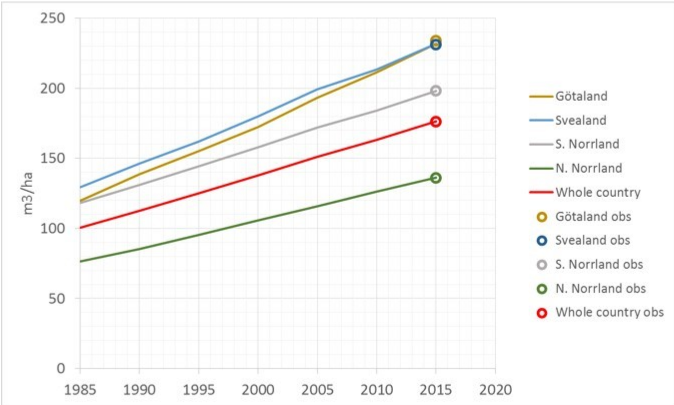
The format related to land use categories and accounting categories may deviate slightly, for instance due to the change from 20 to 30 years for the transition time of forested land. The allocation of carbon stock changes to different categories may therefore differ.

Annex IV, section A
(h) the reference level shall be consistent with greenhouse gas inventories and relevant historical data and shall be based on transparent, complete, consistent, comparable and accurate information. In particular, the model used to construct the reference level shall be able to reproduce historical data from the National Greenhouse Gas Inventory.

For transparency and consistency, the FRL is developed using the same definitions of carbon pools and based on the same sampling units as the Swedish reporting of greenhouse gas inventories under EU and UNFCCC. For both the carbon reporting and the FRL, the reporting is complete.

Due to slightly different rules (e.g. that afforested land is continuously accumulated from 1990 under the Kyoto protocol while afforested land stays in the transition class for 30 years under the new EU regulation) the initial state in 2010 is not exactly the same. For example, basing the FRL on the average management 2000-2009, makes the different approaches less comparable after 2010. Finally, the sampling accuracy should be similar but a projection introduces uncertainty. From the reporting of emissions and removals for 2020 and onwards the estimates will be fully comparable since the annual reporting will be based on the LULUCF regulation from the submission 2022.

To study differences arising from potential errors in the models, the Heureka simulation model was applied to NFI plots and compared with the measured biomass on the same plots. The plots were inventoried at consecutive surveys (five-year cycle). If a plot was subject to harvest it was removed from the simulation and validation. The results verify that the models used in Heureka RegVis appropriately can reproduce changes in living biomass (figure 4).



	Volume, m3	
	1985	2015
Measured	100.635	176.345
Simulated	100.635	176.340

Figure 4. Simulated and observed 30-year development of standing volume on permanent sample plots (n=1071).

In order to verify the reporting of changes in the soil organic carbon pool a project was initiated comparing the precision and the uncertainty in the determination of litter and soil carbon pool changes using different methods[10]. Results from two soil carbon models, Yasso07 and Q, were compared with repeated measurements of the Swedish Forest Soil Inventory (SFSI) during the years 1994 to 2000. Soil carbon fluxes were simulated with the two models from 1926 to 2000 with Monte Carlo methodology to estimate uncertainty ranges. The results from the models agreed well with measured data regarding the development of the carbon stocks. However, the annual change in soil organic carbon varied substantially between the three methods mainly due to different assumptions regarding annual variation in climate data. The average soil organic carbon change for two five-year periods indicated that the size and direction of the estimated annual changes agree reasonable well (figure 5). It was concluded that the models are particularly useful for projections.

10 Ortiz CA et.al. 2009.

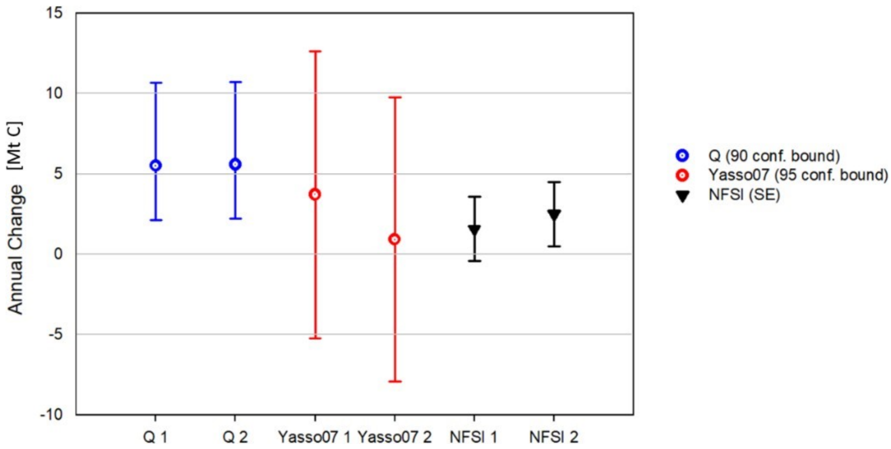


Figure 5. Figure from Ortiz CA et.al. 2009. Change of SOC. Average for two 5-year periods 1994 to 1998 (1) and 1996 to 2000 (2) together with the uncertainty bounds of the modelled change and the standard error of the repeated measurements

Annex IV, section B

(e) a description of how each of the following elements were considered in the determination of the forest reference level:

(i) the area under forest management;

(ii) emissions and removals from forests and harvested wood products as shown in greenhouse gas inventories and relevant historical data;

(iii) forest characteristics, including dynamic age-related forest characteristics, increments, rotation length and other information on forest management activities under 'business as usual';

(iv) historical and future harvesting rates disaggregated between energy and non-energy uses.

(i) The area under managed forest land used in the calculation of the forest reference level is the projected area of managed forest land for the period 2021-2025. The projected area of managed forest land considers both an increase in area due to the inclusion of forested land after 30 years and an decrease due to deforestation 2021-2025. To avoid double counting, both the addition of areas due to afforestation and losses of areas due to deforestation will be recalculated (technical correction) using actual numbers at the end of the compliance period.

(ii) Emissions and removals from forests and harvested wood products as reported to the EU and the UNFCCC are shown in figure 6 and table 2[11]. The total net removals for forest land remaining forest land is stable over the reported period with tendencies towards a slight increase in total net removals over time. The carbon stock change estimates reported to

[11] National inventory report Sweden 2018.

the EU and the UNFCCC are not directly used in the FRL-estimate. However, the same NFI and SFSI-plots (mainly to estimate Living biomass, Soil carbon and Areas) are used as the basis for estimating the FRL as for the reporting to the EU and the UNFCCC. For emissions other than carbon stock changes, the reported data are directly used in the FRL-estimate. Either averages for the reference period 2000-2009 or annual estimates for 2010 is applied.

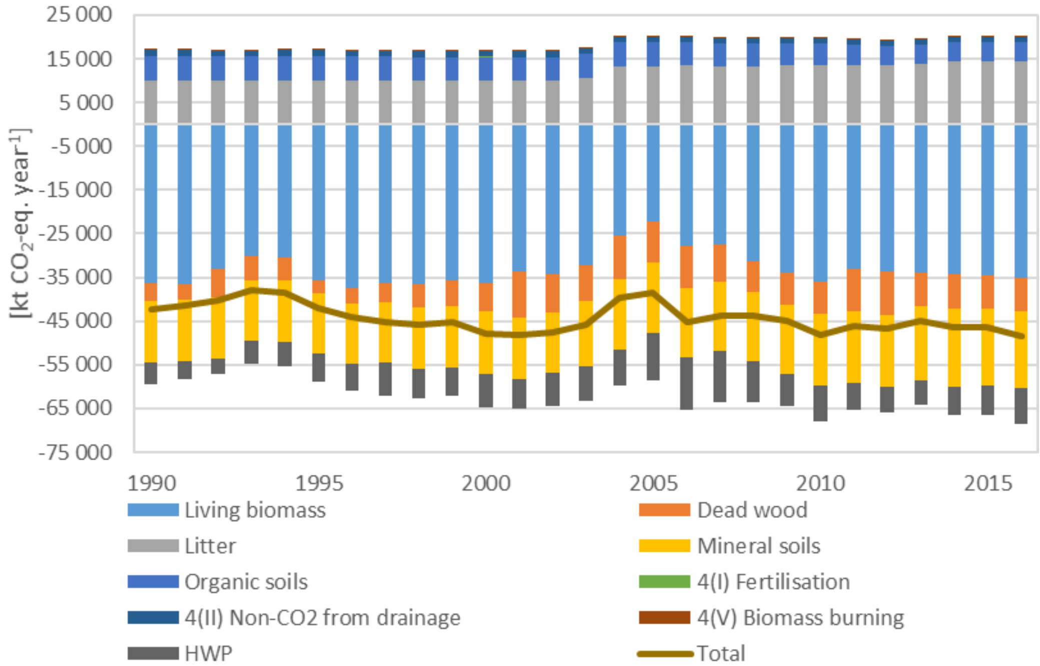


Figure 6. Emissions and removals for Forest land remaining forest land as reported to the EU and the UNFCCC in Submission 2018.

Table 2. Emissions and removals for Forest land remaining forest land as reported to the EU and the UNFCCC in Submission 2018.

[kt CO_2-equivalents]	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2016**
Living biomass	-36 284	-35 613	-36 266	-22 378	-36 036	-34 569	-35 195
Mineral soils Dead wood	-1 508	-1 505	-1 710	-1 782	-903	-1 689	-1 992
Litter+Soil	-5 816	-4 900	-7 971	-8 749	-8 164	-8 058	-7 792
Organic soils Dead wood	-281	-281	-320	-326	-149	-270	-318
Litter+Soil+DOC	5 074	5 259	4 691	4 262	4 009	3 799	3 843
Non-CO_2	1 349	1 351	1 343	1 325	1 189	1 126	1 126
HWP	-5 016	-6 403	-7 777	-10 797	-8 194	-6 658	-8 226
Fertilisation (N_2O)	49	18	17	22	56	23	21
Biomass burning (non-CO_2)*	2	2	4	6	1	2	3
Total	**-42 432**	**-42 072**	**-47 990**	**-38 417**	**-48 190**	**-46 293**	**-48 530**

* CO_2 is included in the Living biomass estimate based on carbon stock changes on permanent plots.

(iii) Here "Business as usual" is interpreted as the average management practices in managed forest land during 2000-2009 for production land (no management for wood supply is considered on other types of forest land). The projected age distribution is restricted by the initial state (e.g. the age distribution 2010), the natural conditions (e.g. site fertility), BAU-management and harvest level (figure 7 to 9). The BAU-management sets e.g. the distribution between final felling and thinning, harvested species distribution, regeneration methods, regenerated species distribution, fertilization which steers the development of the growth (table 3 and 15). The rotation period length is an indirect result of the simulations. The minimum stand age when final felling is allowed is regulated by the Forestry Act and is dependent on-site fertility, dominating species and region. A rule of thumb is that forest companies normally harvest at the minimum age for final felling plus 10 years. The normal length of the rotation period is between 45 and 90 years in southern Sweden and between 65 and 100 years in northern Sweden. Note also that normal forestry practices include thinning of the forest two to four times during a rotation period.

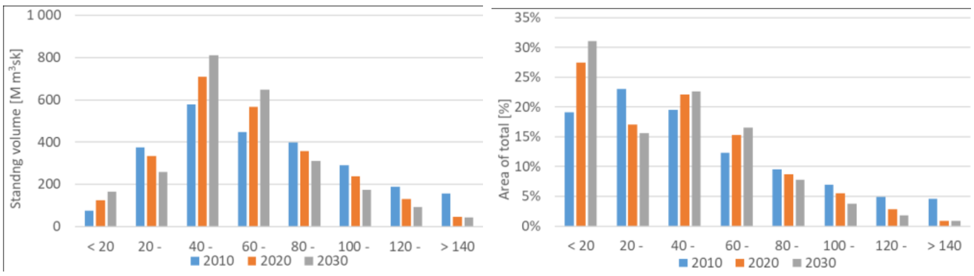


Figure 7. Age class distribution for productive forest land managed for wood supply, i.e. production land excluding tree retention volumes and areas, representing 2010 (start of simulation), 2020 and 2030, for volume and area (share of total area of forest land managed for wood supply) respectively.

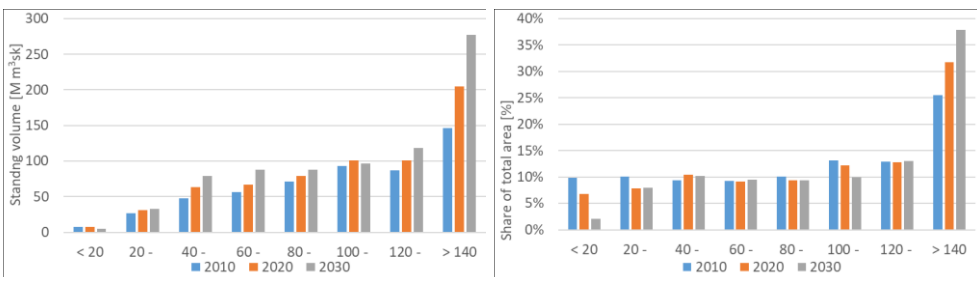


Figure 8. Age class distribution for productive forest land formally and voluntarily set-aside for nature conservation, including tree retention representing 2010 (start of simulation), 2020 and 2030, for volume and area (share of total area of productive forest land set-aside for nature conservation) respectively.

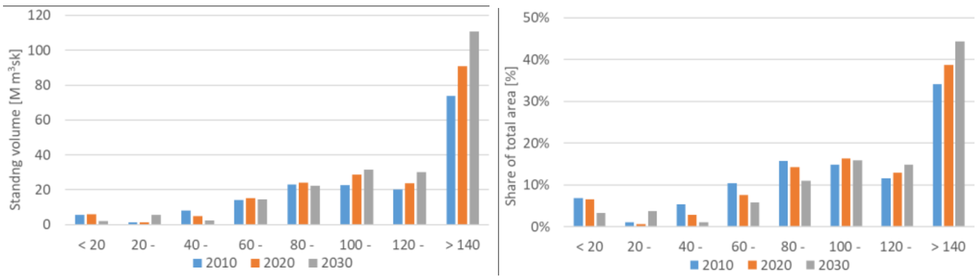


Figure 9. Age class distribution for low-productive forest land representing 2010 (start of simulation), 2020 and 2030, for volume and area (share of total low-productive forest area) respectively.

Table 3. Net annual increment for productive forest land managed for wood supply 1990-2010 according to the NFI and according to the projections for 2015 to 2025.

	1990	1995	2000	2005	2010	2015	2020	2025	2030
Net growth [M m³sk]	81	82	85	90	97	90	92	91	94

(iv) Historical and future harvesting rates disaggregated between energy and non-energy uses are shown in figure 10. The allocation of harvested round wood to different product categories such as solid wood products, paper products and energy use was calculated using data from the Swedish Forest Agency. The peaks of 2005 and 2007 are due to large storms.

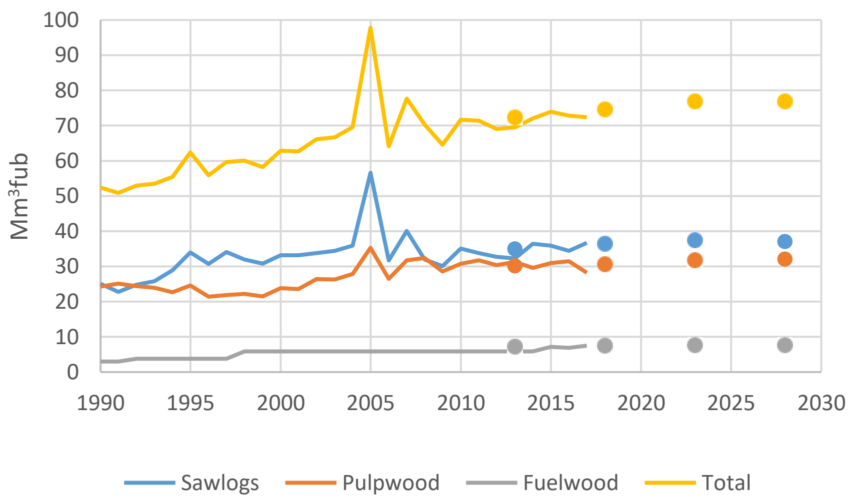


Figure 10. Observed annual net harvest 1990-2017 and simulated net harvest for the periods 2015-2020, 2020-2025 and 2025-2030. If needed for comparisons, m3fub can be converted to m3sk by dividing by 0.83.

2. Preconditions for the forest reference level

2.1 Carbon pools and greenhouse gases included in the forest reference level

The forest reference level for Sweden includes changes in the carbon pools Living biomass (above and below ground), Dead wood, Litter, Soil organic carbon and Harvested wood products. No carbon pools have been omitted in the forest reference level for Sweden.

The forest reference level also includes emissions from forest fertilization (N_2O), from drained organic soils (N_2O, CH_4 and DOC), mineralization (N_2O) and biomass burning (CO_2, N_2O and CH_4).

2.2 Demonstration of consistency between the carbon pools included in the forest reference level

Living biomass refer to the biomass of all living trees with a height of at least 1.3 m. Thus, small trees, shrubs and other vegetation, such as herbs are not included in the biomass estimates. Both the aboveground and belowground biomass pools are reported.

Aboveground biomass is defined as living biomass above stump height (1 % of tree height). Belowground biomass is defined as living biomass below stump height (1 % of tree height) down to a root diameter of 2 mm (fine roots, <2 mm, are operationally defined as belonging to the dead organic matter pool or in the soil organic carbon pool).

Dead wood is defined as fallen dead wood, snags or stumps including coarse and smaller roots down to a minimum root diameter of 2 mm. Dead wood of fallen dead wood or snags should have a minimum "stem diameter" of 100 mm (at the smaller end) and a length of at least 1.3 m.

Litter includes all non-living biomass not classified as dead wood, in various states of decomposition above the mineral or organic soil. This includes the litter, fumic, and humic layers. Live fine roots (<2 mm), are included in litter if found in the O horizon since they cannot be separated during sampling. Coarse litter is defined as dead organic material with a "stem diameter" between 10-100 mm and originating from dead trees. Fine litter from the previous season or earlier is regarded as part of the O horizon.

The soil organic carbon pool includes all carbon in the mineral soil below the litter, fumic and humic layers in mineral soils and all organic carbon in soils classified as Histosols. The carbon pool considered is soil organic carbon down to a depth of 0.5 m measured from top of the mineral soil.

Harvested wood products are defined as wood material leaving the harvest site. Emissions from the HWP-carbon pool are based on pool changes of three product categories; sawn wood, wood based panels, and paper products.

2.3 General description of forests and forest management in Sweden

In total Sweden's forest land amounts to about 28 Mha of which 23.4 Mha is regarded productive forest. There are 4.7 Mha low-productive forests. Until today 1.1 million hectares have been designated for nature protection in formally protected areas. The amount of voluntarily set aside forests is about 1.2 million hectares according to an inquiry made by the Swedish Forest Agency[12]. In addition, an inquiry made by the Swedish Forest agency shows there are about 8 percent of forest land tree retention at final felling sites. These areas are assumed to in total consist of 1.6 million hectares of productive forest land, under a future rotation period[13].

Of the productive forests, 48% are owned by individuals, 24% by private companies, 6% by other private owners and 21% by state-owned companies, the central Government and other public owners[14].

A continuously increased demand for forest raw materials by the forest industry has led to an increase in felling during the period 1990–2015 (figure 10). The volume felled varied greatly in two years because of two storms, Gudrun (2005) and Per (2007). Gudrun, the more severe of the two, brought down some 80% of the normal annual volume felled in Sweden. Despite increased felling, the aggregate standing volume of timber rose from some 2 800 M m^3 in 1990 to 3 300 M m^3 in 2009 and 3 500 M m^3 in 2014.

The area of regeneration felling in which harvesting residues are extracted for energy purposes was small at the beginning of the 1990s. Since then, the area planned for forest residue extraction notified to the Swedish Forest Agency has expanded and has varied between 86 and 156 kha since 2006 with no clear trend.

[12] Swedish Forest Agency 2017 (Meddelande 4 2017).

[13] Swedish Forest Agency 2012 (Rapport 10 2015). 14

Swedish Forest Agency 2018.

2.3.1 Forest management practices 2000-2009

Information on silvicultural activities in Sweden are based on questionnaire surveys. Until 2014, the Swedish Forest Agency annually conducted a survey of nearly all corporate forest holdings and of other large forest holdings and a sample of private forest owners of different size. Detailed information can be found in the statistical yearbooks produced by the Swedish Forest Agency [15] (Skogsstyrelsen 2000-2011). The information from these surveys as well as observations from the NFI (representing the years 2000-2006) forms the basis for the settings in the simulation of the FRL.

The statistics include annual information on:

- Pre-commercial thinning of young forests (320 kha in average 2000-2009)
- Soil scarification (160 kha in average 2000-2009)
- Planted area (157 kha in average 2000-2009)
- Fertilized area (33 kha in average 2000-2009)

2.4 General description of national policies and legislation with effect on forestry in Sweden

Current legislation affects emissions and removals in the sector, mainly due to regulations on forest management in the Forestry Act and provisions on nature reserves and habitat protection in the Environmental Code and nature conservation agreements. The Forestry Act and the Environmental Code are described in the next section.

A governmental bill on Biological Diversity and Ecosystem Service was presented in March 2014 including five environmental interim targets linked to already established environmental quality objectives. These interim targets include a target stating that at least 20 percent of land areas should contribute to attain objectives for biological diversity. Protected areas should increase by at least 1 142 kha between the years 2012 and 2020, including the additional formal protection of 150 kha of forest land and 200 kha of forest land to be set aside voluntarily.

To reach the objectives of the environmental and forest policies voluntary efforts by the landowners are crucial. Advice to the forestry sector from the central government to promote effective and functional conservation

[15] Swedish Statistical Yearbook of Forestry. 2001-2010.

measures for the environment and improved forest management play a fundamental role.

On 17 May 2018, the Government adopted a strategy for Sweden's National Forest Program. In July 2018, the Government adopted an action plan with specific measures. The action plan will be updated in dialogue with interested parties. The core of the National Forest Program is the broad dialogue on the role forests play to ensure a sustainable society and a growing bioeconomy. The work is guided by the program's vision: "Forests – our 'green gold' – will contribute to creating jobs and sustainable growth throughout the country, and to the development of a growing bioeconomy."

2.4.1 The Swedish Forestry Act and the Environmental Code

The Swedish Forestry Act has two overarching, equal objectives: a production objective and an environmental objective.

The production objective means that forests and forest lands should be used effectively and responsibly in order to produce sustainable yields. The direction of forest production should be given flexibility in the use of what the forests produce.

The environmental objective means that the natural productive capacity of forest land should be preserved. Biodiversity and genetic variation in forests should be secured. Forests should be managed in a manner that enables naturally occurring flora and fauna to survive in natural environments and in viable populations. Threatened species and habitats should be protected. The cultural heritage of forests and their aesthetic and social values should be safeguarded.

Under the current Forest policy, production subsidies are abolished, and forest owners have considerable freedom and responsibility to independently conduct long-term sustainable forest management. The regulations concerning wood supply cover the notification of felling allowed, the lowest age for felling, requirements for reforestation, guidelines for thinning and measures to limit damage. Special regulations apply to certain types of forests, such as subalpine forests and deciduous forests. Examples of regulations concerning nature conservation and cultural heritage include not disturbing important biotopes, buffer zones and arable land, and leaving older trees, high stumps and dead wood in situ. Sustainable forest management influences carbon dioxide removals and emissions in various ways, through the production of renewable raw materials that can replace fossil fuels and materials that generate emissions of greenhouse gases while maintaining or increasing carbon stocks in biomass, soils and harvested wood products.

The Swedish Environmental Code is a coordinated, broad and strict environmental legislation aimed at promoting sustainable development so that present and future generations can live in a good, healthy environment. For example, the Code contains regulations on land drainage. In central parts of the southern Swedish highlands and north of the *Limes Norrlandicus* (north of 60°N), drainage – defined as drainage intending to permanently improve the suitability of a property for a certain purpose – may only be undertaken with a permit. In the rest of the country, and on sites specially protected under the RAMSAR Convention, such measures are prohibited. Protection and restoration of peatlands with high carbon stocks can reduce emissions of carbon dioxide to the atmosphere.

Conservation measures (site protection, nature conservation agreements and voluntarily set-aside of land) not only preserve biodiversity, but also positively impact carbon stocks in forest biomass and soil carbon, by allowing them to be maintained or to continue to increase. Protected forest ecosystems have a large capacity to sequester carbon, even long after a conservation measure is implemented, although there are exceptions in areas where natural disturbances like forest fires are frequent. There are also targets for the conservation and protection of areas containing both wetlands and forest land. Since such areas are usually excluded from felling, their stocks of carbon in biomass and soil will, in most cases, be larger than those of productive forests.

2.5 Description of future harvesting rates under different policy scenarios

Several projects have studied the development of the forest resources in Sweden under different scenarios. The latest national forest resource assessment[16] included four scenarios representing different assumptions regarding the demand for timber and the level of implementing strategies for protecting forest land. The reference (business as usual) scenario represents the development of the forests on productive forest land under current forest management practices assuming highest sustainable harvests. One scenario studied the development with a lower demand for timber (-10%)

[16] Skogliga konsekvensanalyser 2015 – SKA 15, Skogsstyrelsen Rapport 10 2015.

and another assuming higher demand for timber (+10%). The last scenario included an expansion of the set-aside areas for nature conservation by 100%, the rest of the forests were managed as in the reference scenario. Another recent study used these scenarios to study the total climate benefit of forests and forest products under different forest strategies[17] including also a scenario where measures to increase the production was implemented including increase of the use of fertilizers, more efficient thinning operations etc. The scenario uses the same principles for harvest as in the reference scenario. Finally, the harvest level used as reference scenario in the reporting of scenarios to the EU is presented[18]. The development of the harvest level is assumed to develop from lower than the current levels to meet the gradually increase in demand of timber from society.

In figure 11 below we present these six scenarios. The business as usual scenario (DS) is the development under the continuation of current forestry with highest sustainable harvest. DS90 and DS110 represent the scenarios with lower or higher demand for timber, respectively. The scenario studying the development when the set-aside area is doubled compared to the current area is denoted DN, the scenario PROD represents the scenario with focus on increased production and TREND the scenario reported to the EU. All scenarios results in higher harvest levels in the end of the century compared to the harvest level at the start of the simulation (today's situation). It can be noted that even the scenario with double set-aside areas have an increase in harvest that exceeds the harvest for the reference scenario at the beginning of the period.

[17] Underlag till nationella skogsprogrammet.

[18] Report for Sweden on assessment of projected progress, March 2017.

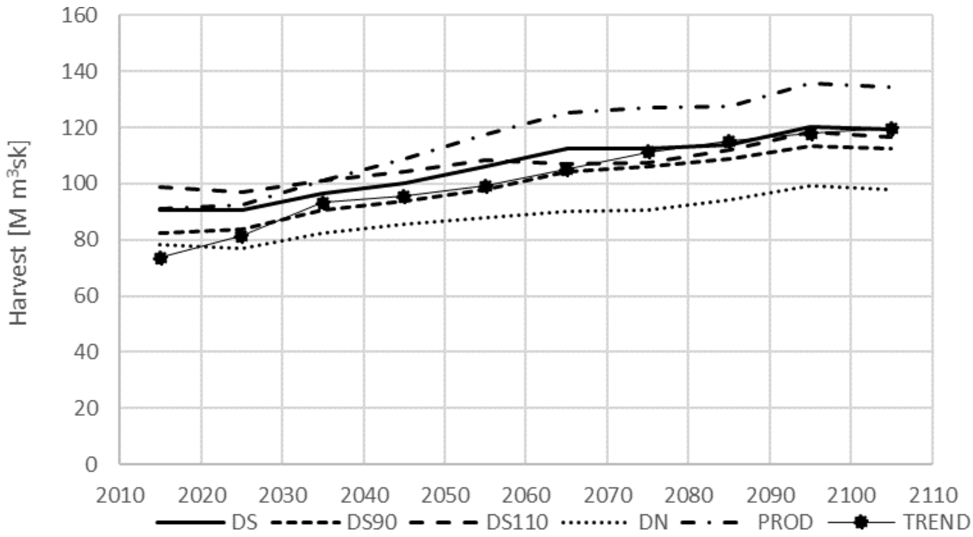


Figure 11. The development of harvest levels under different strategies. Scenario DS represents the development under current forestry, DS90 represents DS with lower and DS110 current forestry with higher harvest intensities respectively. DN represents a doubling of the protected area, PROD represents the production scenario and TREND the scenario reported to the EU.

3. Description of the modelling approach

This section includes the information required according to Annex IV, B third bullet point:

Annex IV, B
c) a description of approaches, methods and models, including quantitative information, used in the determination of the forest reference level, consistent with the most recently submitted national inventory report, and a description of documentary information on sustainable forest management practices and intensity as well as of adopted national policies;

3.1 Description of the general approach as applied for estimating the forest reference level

The proposed reference level for managed forest land (FRL) is the expected average annual net removals of greenhouse gases in 2021-2025, based on simulations of the carbon stocks on managed forest land starting from 2010 assuming the continuation of forest management practices as observed 2000-2009.

In the calculations, the same sample plots from the National Forest Inventory (NFI) and the Swedish Forest Soil Inventory (SFSI) as in the reporting of the LULUCF-sector to the EU and the Climate Convention (UNFCCC) have been used.

The FRL comprises all carbon pools currently reported to the EU and the UNFCCC (Living biomass above ground, Living biomass below ground, Dead wood, Litter, Soil organic carbon and HWP) as well as other emissions associated to forest land included in these reports (fertilization, emissions from drained organic soils, biomass burning).

Development of carbon stocks are simulated on plot level using well established models. Biomass is simulated using the Heureka RegVis tool and the soil organic carbon pool on mineral soils is simulated using the Q-model. Other emissions are based on average emissions 2000-2009 and the state of forests and areas 2010.

The development of carbon stocks have been simulated using the documented forest management practice 2000-2009, including measures in forestry and biodiversity. The harvest level in the simulation equals the growth on production forest land managed for wood supply, reduced by the volumes left for tree retention, which was considered as the practice 2000-2009 (and still is) in forestry in Sweden. On productive forest land formally protected or voluntarily set-aside for nature conservation and low-productive forest land no harvest is assumed, as well as on tree retention areas at harvest sites.

The resulting relative harvest level on managed forest land during the period 2021-2025 was estimated to 85% (annual harvest/annual growth on managed forest land).

3.2 Detailed description of the modelling framework as applied in the estimation of the forest reference level

3.2.1 Carbon pools and other emissions

The forest reference level for Sweden includes changes in the carbon pools Living biomass (above and below ground), Dead wood, Litter, Soil carbon and Harvested wood products. No carbon pools have been omitted in the forest reference level for Sweden and the carbon pools follows the same definitions as in the Swedish greenhouse gas inventory.

The forest reference level also includes emissions from forest fertilization (N_2O), from drained organic soils (CO_2, N_2O, CH_4 and DOC), mineralization (N_2O) and biomass burning (CO_2, N_2O and CH_4).

Carbon stock change in Living biomass above and below ground and Dead wood is calculated using the Heureka RegVis system while Litter and Soil organic carbon is calculated using the Q-model. Emissions from drained organic soils are based on the same method as in the Swedish greenhouse gas inventory using the drained area and emission factors. HWP is based on the same model as in the greenhouse gas inventory. All other emissions are based on the average emissions during the period 2000-2009 (fertilization, mineralization and biomass burning). Figure 12 gives an overview of the model set-up for the FRL-calculations.

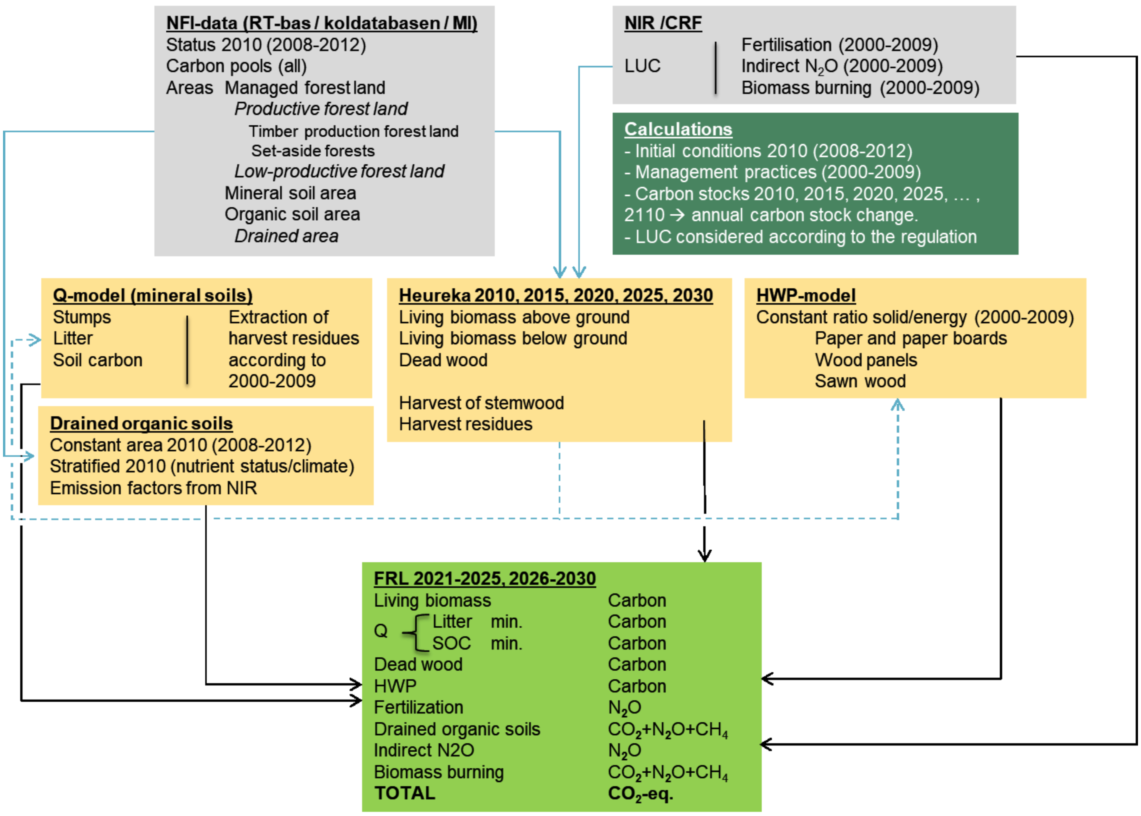


Figure 12. Overview of the model framework for the Swedish FRL.

3.2.2 Heureka RegVis

Simulations of forest development and biomass harvest were made with the Heureka RegVis simulator, which is a forecast tool for forests and forestry on a large scale regional level. A number of prerequisites when it comes to forest management, harvest, climate, nature conservation and so forth are set by the user. The prerequisites form a so-called scenario and the simulation aims at showing the forest development if the specific scenario would take place.

The core of the tool is simulation models for the tree-layer: growth, mortality and ingrowth[19]. Models for individual trees simulate height growth in young stands (mean height < 7 m)[20], and basal area for established stands (mean height ≥ 7 m). It also includes models for management, harvest, effect of climate change, and storm fellings. Natural mortality provides a flow of biomass to the dead wood pool where decay functions transfer the dead wood between decay classes.[21]

The simulations are made in five-year intervals and measures such as soil scarification, planting, pre-commercial thinning, thinning, fertilization and final felling's are simulated during each interval (Figure 13).

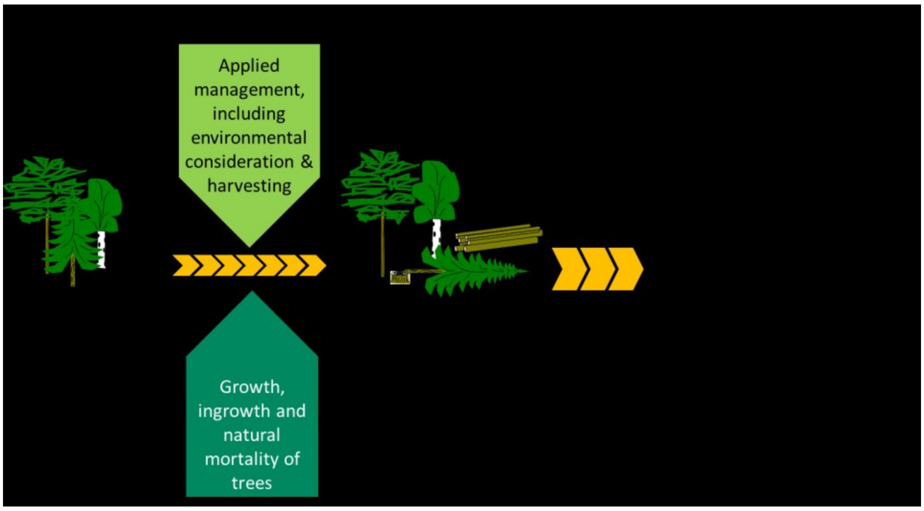


Figure 13. Overview of the functionality of the forest simulator Heureka RegVis.

New functionality has been added to the Heureka system within this project to improve the harmonization between the forest reference level and the national reporting of greenhouse gas emissions. With previous versions, only the development of productive forests land has been possible to simulate. Since the national reporting of greenhouse gas emissions covers all forest land, including low-productive forest, new models for growth and mortality

[19] Wikberg 2004.

[20] Fahlvik N., Elfving B., Wikström P. 2014.

21 Fridman J, Ståhl G. 2001.

of low-productive forest land have been implemented. Further, routines for land use changes has been implemented to keep track of areas of different land-use classes and the transformation between land-use classes since it is an important part of the national reporting of greenhouse gas emissions.

Both addition of areas to and subtraction of areas from forest land related to afforestation (after 30 years from afforestation year) and deforestation have been considered in the simulation. Climate change effects according to RCP4.5 are also reflected in the simulations with a positive effect on forest growth.

3.2.3 The Q-model

Changes in the combined litter and soil carbon pool (hereafter referred to as the SOM carbon pool) were estimated with the Q model, which is a process based model based on the continuous quality theory[22]. It has previously been used in several national studies of forest and forest soil carbon balance studies in Sweden[23]. Litter that enters the soil is modelled as discrete cohorts of dead needles, fine roots, branches, coarse roots, stumps, stems and ground vegetation with different initial qualities. During the decomposition there is a continuous decline in the quality of the decomposing organic matter. For coarse woody litter, there is an invasion time before the decomposers can access the substrate completely, which gives rise to an initial lag phase. The model parameters[24] reflect properties of the decomposer community, different litter qualities depending on litter types and tree species, and climate effects.

For the SOM carbon modelling, plot-wise litter data was aggregated to regional level (4 regions, see the description of the Heureka model for details) before running the Q model. The input of organic matter to the soil consisted of litter from living above- and below ground biomass, harvest residues, natural mortality and ground vegetation. The Heureka system calculates all fractions of tree litter produced based on standing biomass, its turnover rates and harvested biomass. The biomass turnover rates are given in table 4. Ground vegetation litter was estimated based on biomass

22 Ågren & Bosatta, 1996.

23 Ågren G. & Hyvönen R. 2003, Ågren G. et al. 2007. Ortiz, C.A.,et.al. 2014. Gustavsson, L. et. al. 2017.

24 Ågren G. & Hyvönen R. 2003.

functions for different plant litter types[25] and their turnover rates[26], given in table 5. The biomass functions were based on stand age with separate functions for each tree species, and they were applied on forest statistics of volume and tree species distribution within each region. The average estimated litter input from ground vegetation was 451 kg C ha^{-1} $year^{-1}$. Input from harvest residues was estimated separately for foliage, branches, stems and tops, stumps, and roots. Harvest residue extraction levels for branches and tops were implemented to meet an energy production of 7 TWh for the whole of Sweden which was the reported average extraction level for the period 2000-2009[27]. The regional distribution of harvest residue quantities was based on a previous forest resource assessment for Sweden[28]. The model was initialized with a spin-up period during 1990-2009, assuming a constant annual litter input at the same level as the first period of the forest simulation (2010-2014). At the start of this period the soil decomposition was assumed to be in steady state with the litter input during the first period. The initial C stocks for the different regions were calculated from the Swedish Forest Soil Inventory.

Since the Q-model is not adapted to organic soils the method used in the Swedish reporting to the UNFCCC was applied. This method estimates the emissions of CO_2, N_2O and CH_4 using emission factors that are applied to the area of drained organic soils.

Table 4. Turnover rates [years] and parameters for calculation of litter production

Parameter	Pine	Spruce	Source
Needles	1.656-0.0231*Latitude	0.489-0.0063*Latitude	Ågren et al. (2007)
Branches	$0.0574 \cdot e^{(-0.00482\ MeanDiameter^{2})} + 0.00648$	0.0125	Peltoniemi et al. (2004) / Muukonen & Lehtonen (2004)
Roots (2-5 mm)	0.10	0.10	Eriksson et al. (2007)
Fine root litter	1.51*needle litter	1.51*needle litter	Ågren & Hyvönen (2003)
Fine root biomass	0.61*needle biomass	0.26*needle biomass	Berggren et al. (2008)

25 Muukkonen, P. & Mäkipää, R. 2006. 26

Peltoniemi M, Mäkipää R,et al.

27 Skogsstatistisk årsbok, Swedish Statistical Yearbook of Forestry. 2001-2010.

28 Claesson S et.al.. 2015.

Table 5. Turnover rates [years] for ground vegetation (Peltoniemi et al. 2004).

Ground vegetation class	Turnover rate [year]
Herbs and grasses (above)	1.00
Herbs and grasses (below)	0.33
Dwarf Shrubs (above)	0.25
Dwarf Shrubs (below)	0.33
Mosses	0.33
Lichens	0.10
Below ground biomass factor	2.00

3.2.4 Organic soils

Emissions from drained organic soils are calculated according to the Swedish greenhouse gas reporting to the UNFCCC. The area per nutrient category and climate zone is multiplied with the corresponding emission factor (table 6).

Dead wood and Litter on organic soils have been estimated based on results of Dead wood from the Heureka RegVis simulations and the production of litter using simple decay of organic material (4.6% annually for stumps and 15% annually for harvest residues).

Table 6 Emission factors for drained organic soils.

Emission factors		Carbon [ton ha^{-1}]	CH_4 [kg ha^{-1}]	CH_4 (ditches) [kg ha^{-1}]	N [kg ha^{-1}]	DOC [ton ha^{-1}]
Boreal	Nutrient poor (281 kha)	0.25	7	217*	0.22	0.12
	Nutrient rich (321 kha)	0.93	2	217*	3.2	0.12
Temperate	Nutrient poor (63 kha)	2.6	2.5	217*	2.8	0.12
	Nutrient rich (278 kha)	2.6	2.5	217*	2.8	0.12

*Fraction of ditches are set to 2.5 %

3.2.5 Harvested wood products

Emissions from the carbon pool Harvested wood products was calculated using the same methodology as in the national greenhouse gas reporting[29]. Separate calculations were made for three product categories; sawn wood,

29 National Inventory Report Sweden 2018.

wood based panels and paper products. Products from domestic forests were included while products from non-domestic forests were excluded following *the production approach*. Each year an inflow of carbon in new products was added to an existing pool of products in use, and at the same time a fraction of the pool was assumed to leave the pool as depleted products. The outflow was calculated using different half-life's for the different product categories. The annual difference between in- and outflow was translated to emissions or uptake of CO_2. In the projections, a carbon pool built by historical data was set for each product category for the start year 2010. Input data was harvested volumes of saw logs and pulpwood from the simulations of the forest development using the Heureka-system. The round wood was then allocated to the different product categories corresponding to the reference period 2000-2009.

3.2.6 Other emissions

Emissions of greenhouse gases from other sources than the carbon pool changes are estimated according to the methods used in the annual reporting to the EU and UNFCCC[30]

Direct N_2O emissions from N fertilization are based on the average reported emissions from N-fertilization of forest land for the period 2000-2009.

Emissions from N mineralization are based on the average reported emissions for the period 2000-2009.

Emissions of CO_2, N_2O, CH_4 and DOC drained organic soils are calculated as described above for organic soils.

Emissions from biomass burning (CO_2, N_2O, CH_4) are based on the average of reported emissions for the period 2000-2009. In the reporting to the EU and the UNFCCC, CO_2 is included in the carbon stock change estimates on the permanent sample plots of the NFI. Since the Heureka system does not include burning, the emissions of CO_2 are calculated separately in conjunction with the estimates of N_2O and CH_4.

3.3 Documentation of data sources as applied for estimating the FRL

Data from the National Forest Inventory (NFI) was used in the simulations of the forest development[31]. The NFI consists of a permanent and a

[30] National Inventory Report Sweden 2018.

[31] Fridman et al. 2014.

temporary sample and since the national reporting of greenhouse gas emissions is based on the permanent sample, only the permanent sample was used in the construction of the reference level. The permanent sample consists of about 30 000 circular plots of 10 m radius arranged along the sides of so called tracts, which are systematically distributed over all kinds of land (Figure 14). One fifth of the sample is measured each year and consequently, five years measurements are needed to re-inventory the whole sample. In this case measurements from 2008-2012 was used and the start year were set to 2010. To harmonize with the national reporting of greenhouse gas emissions all plots were used in the simulations irrespective of land use class.

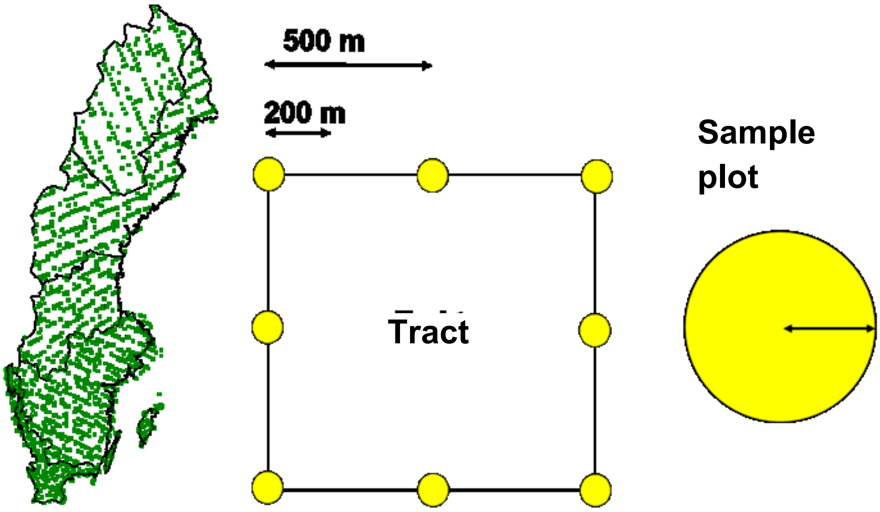


Figure 14. Illustration of the systematic grid of permanent clusters of sample plots for the NFI (one year grid, see text), example of a clusters (tract) with circular plots along the sides and a circular plot.

A separate database is used in the national reporting of greenhouse gas emissions. It differs from the ordinary NFI-database in that it contains permanent plots only, and that borders between land-use classes within plots have been harmonized between the measurements. In the NFI, when occurring, the delineation of plots into more than one land use category suffers from observation (judgement) errors. Such errors have been removed in the database used for the national carbon reporting by studying the registered delineations over time and by using auxiliary information as aerial photos. This is to avoid artificial land use conversions. Land use and changes in land-use are important parts of the national reporting of greenhouse gas emissions and therefore these variations have been adjusted and harmonized. To harmonize with the national reporting of greenhouse gas emissions this database was also used in the simulation of the forest reference level.

3.4 Documentation of stratification of the managed forest land

3.4.1 Areas

The NFI classifies land use for each plot and each plot is assumed to represent a certain area. Within the land use class forest land, the NFI differs between productive forest, where the forest growth potential exceeds 1 m^3 ha^{-1} and year, and low-productive forests. The productive forests are subdivided into productive forest land managed for wood supply and productive forest land for nature conservation. Management practices do only occur in productive forest land managed for wood supply. Productive forests that is not protected is denoted as forest available for wood supply.

Two categories of set-aside areas are reported; formally protected areas such as national parks and nature reserves, and informally protected areas such as retained patches at final felling's and voluntarily set aside areas. In the latest large-scale forest forecast study made in Sweden, NFI-plots were marked as set-aside areas of the different categories and these markings were used also in this case (Claesson et al. 2015).

Non-forest land covers several land-use classes, such as grassland, cropland, wetland, etc. Trees also occur on these land-use classes which results in some emissions or uptake of CO_2. These emissions or uptakes are not included in the forest reference level.

Organic soils are equal to NFI-plots covered by more than 50 % peat. The soil is considered as peat if the depth of the peat exceeds 30 cm.

3.4.2 Initial conditions 2010

In tables 7 to 11, the initial conditions representing 2010 are presented. The NFI-data 2008-2012 have been aggregated into four regions for the calculation of the FRL denoted Norra Norrland (N.N.), Södra Norrland (S.N.), Svealand (Svea) and Götaland (Göta), see figure 15. Areas (table 7), standing volume (table 8), growth (table 9) are presented by region, forest type and species.

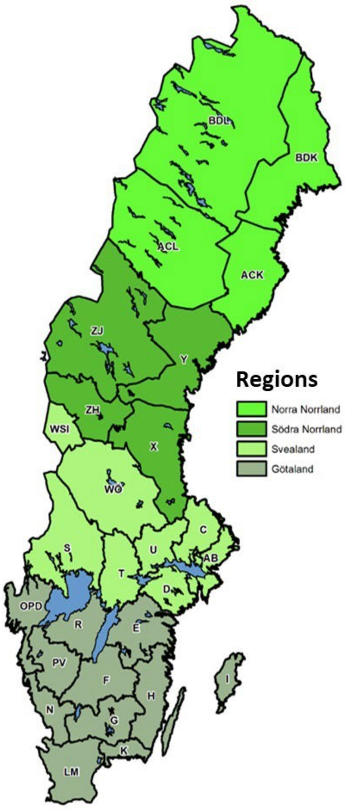


Figure 15. Regions used in the FRL-calculation.

Table 7. Initial areas [kha] representing 2010 for different forest types by region.

Forest type	**N.N**	**S.N**	**Svea**	**Göta**	**Total**
Productive forest land	7 143	5 867	5 380	5 021	**23 411**
Voluntary set-aside areas	*556*	*333*	*258*	*198*	***1 345***
Formally protected areas	*413*	*113*	*146*	*109*	***780***
Production land incl. TR	*6 173*	*5 421*	*4 976*	*4 714*	***21 286***
Low-productive forest land	1 964	1 035	638	400	**4 037**
All forests	**9 107**	**6 902**	**6 018**	**5 420**	**27 447**

Table 8. Initial volume [1000 m3sk] representing 2010 for different forest types and species by region.

Type	Region	Pine	Spruce	Contorta	Larch	Birch	Aspen	Other broadl.	Other	Total volume
Low-productive forest	NN	29 805	22 720	0	0	16 734	25	0	247	69 531
	SN	17 529	16 574	37	0	9 244	97	0	352	43 832
	SVEA	23 073	3 579	0	0	3 545	230	189	554	31 170
	GÖTA	16 512	2 127	0	0	2 772	448	1 388	583	23 830
	ALL	**86 919**	**44 999**	**37**	**0**	**32 294**	**799**	**1 577**	**1 736**	**168 362**
Production land incl. TR	NN	293 219	154 501	9 554	0	83 328	3 001	0	3 610	547 212
	SN	263 814	281 675	21 639	184	85 539	6 878	139	14 082	673 950
	SVEA	300 760	296 260	2 379	426	73 940	15 292	5 014	15 279	709 350
	GÖTA	231 704	386 773	8	815	80 762	11 282	45 024	21 799	778 167
	ALL	**1 089 497**	**1 119 210**	**33 580**	**1 425**	**323 569**	**36 453**	**50 177**	**54 770**	**2 708 681**
Reserves and voluntary set-asides areas	NN	46 305	52 505	0	29	16 608	594	0	873	116 913
	SN	22 330	43 965	0	0	8 480	785	0	1 013	76 573
	SVEA	34 226	33 192	0	0	6 808	1 675	1 986	1 720	79 608
	GÖTA	20 944	14 680	0	17	6 537	1 449	14 678	2 253	60 558
	ALL	**123 805**	**144 342**	**0**	**46**	**38 433**	**4 503**	**16 664**	**5 859**	**333 652**
All managed forest land	NN	369 329	229 725	9 554	29	116 670	3 619	0	4 730	733 656
	SN	303 672	342 215	21 676	184	103 262	7 760	139	15 447	794 355
	SVEA	358 060	333 031	2 379	426	84 293	17 196	7 189	17 553	820 128
	GÖTA	269 160	403 580	8	832	90 071	13 179	61 090	24 635	862 555
	ALL	**1 300 221**	**1 308 551**	**33 617**	**1 471**	**394 296**	**41 755**	**68 419**	**62 365**	**3 210 695**

Table 9. Net annual increment [1000 m3sk] for the first simulated period 2010-2015.

Type	Region	Pine	Spruce	Contorta	Larch	Birch	Aspen	Othe broad leaved	Other.	All
Low-productive forest	NN	589	234	0	0	151	0	0	4	978
	SN	291	202	1	0	74	1	0	6	574
	SVEA	388	70	0	0	41	4	3	14	520
	GÖTA	325	66	0	0	61	10	35	22	518
	ALL	**1**	**571**	**1**	**0**	**327**	**14**	**38**	**47**	**2 591**
Production land incl. TR	NN	9	3 819	1 002	0	2 719	118	0	115	17361
	SN	8	8 046	1 780	9	3 631	244	0	621	22846
	SVEA	10	11 391	214	8	3 438	538	68	620	26371
	GÖTA	6	16 720	1	41	3 657	444	827	957	29354
	ALL	**34**	**39 975**	**2 996**	**58**	**13 446**	**1 345**	**895**	**2 313**	**95933**
Reserves and voluntary set-asides areas	NN	759	739	0	1	193	5	0	5	1 702
	SN	343	629	0	0	172	14	0	42	1 201
	SVEA	472	557	0	0	153	44	19	50	1 295
	GÖTA	356	446	0	2	199	43	295	77	1 418
	ALL	**1**	**2 372**	**0**	**2**	**717**	**106**	**314**	**174**	**5 616**
All managed forest land	NN	10	4 792	1 002	1	3 063	123	0	124	20042
	SN	9	8 877	1 780	9	3 878	259	0	669	24622
	SVEA	10	12 018	214	8	3 633	586	90	684	28187
	GÖTA	7	17 232	1	42	3 917	497	1 157	1 056	31290
	ALL	**38**	**42 919**	**2 997**	**60**	**14 490**	**1 465**	**1 247**	**2 534**	**104 140**

3.5 Documentation of sustainable forest management practices as applied in the estimation of the forest reference level

Information on silvicultural activities in Sweden are based on questionnaire surveys. Until 2014, the Swedish Forest Agency annually conducted a survey of nearly all corporate forest holdings and of other large forest holdings and a sample of private forest owners of different size. Detailed information can be found in the statistical yearbooks produced by the Swedish Forest Agency [32]. The information from these surveys as well as observations from the NFI (representing 2000-2006) forms the basis for the settings in the simulation of the FRL (table 10).

The statistics from the Swedish Forest Agency include annual information on:

[32] Swedish Statistical Yearbook of Forestry. 2001-2010.

- Pre-commercial thinning of young forests (320 kha in average 2000-2009)
- Soil scarification (160 kha in average 2000-2009)
- Planted area (157 kha in average 2000-2009)
- Fertilized area (33 kha in average 2000-2009)

Table 10. Settings for the simulations in Heureka RegVis. The numbers represent the share in % of the total area in each class or domain. The settings are specific for each region (N.N., S.N., Svealand, Götaland).

N Norrland (N.N.)

Regeneration method	**Dry**	**Mesic**	**Moist**
Plantation	34	73	86
Sowing	9	7	3
Seed trees	54	18	9
Extensive	3	2	2

Soil scarification	**Dry**	**Mesic**	**Moist**
Plant./Sow	94	97	100
	3	2	0
	3	1	0
Seed trees	66	75	49
	0	0	0
	34	24	33

Regeneration species	**Dry**	**< 22**	**22-26**	**> 26**	**Moist**
Pine	93	76	73	62	47
Spruce	5	21	24	35	51
Birch	0	1	2	2	2
Contorta	3	3	2	1	0

S Norrland (S.N.)

Regeneration method	**Dry**	**Mesic**	**Moist**
Plantation	49	77	84
Sowing	1	4	0
Seed trees	49	17	12
Extensive	0	2	4

Soil scarification	**Dry**	**Mesic**	**Moist**
Plant./Sow	94	99	91
	0	0	0
	6	1	9
Seed trees	78	78	48
	0	0	0
	22	22	35

Regeneration species	**Dry**	**< 22**	**22-26**	**> 26**	**Moist**
Pine	72	56	41	19	27
Spruce	24	39	55	79	65
Birch	0	1	1	0	5
Contorta	4	5	3	1	2

Table 10. Cont.

Svealand					
Regeneration method	**Dry**	**Mesic**	**Moist**		
Plantation	39	70	70		
Sowing	2	3	1		
Seed trees	59	23	21		
Extensive	0	4	8		
Soil scarification	**Dry**	**Mesic**	**Moist**		
Plant./Sow	70	87	80		
	1	0	0		
	30	13	20		
Seed trees	62	72	36		
	0	0	0		
	38	28	44		
Regeneration species	**Dry**	**< 22**	**22-26**	**> 26**	**Moist**
Pine	49	74	24	1	17
Spruce	50	25	75	97	77
Birch	0	1	1	1	6
Contorta	1	1	0	0	0

Götaland					
Regeneration method	**Dry**	**Mesic**	**Moist**		
Plantation	51	84	53		
Sowing	3	0	0		
Seed trees	41	12	40		
Extensive	4	4	7		
Soil scarification	**Dry**	**Mesic**	**Moist**		
Plant./Sow	66	79	72		
	0	0	0		
	34	21	28		
Seed trees	72	43	14		
	0	0	0		
	20	57	86		
Regeneration species	**Dry**	**< 22**	**22-26**	**> 26**	**Moist**
Pine	20	26	16	4	4
Spruce	78	67	80	93	93
Birch	2	2	4	4	3
Contorta	0	0	0	0	0

4. Forest reference level

4.1 Forest reference level and detailed description of the development of the carbon pools

The FRL for Sweden amounts to -30 556 kt CO_2-equivalents for the period 2021-2025.

In table 11 the results for the FRL are shown by carbon pool and other included emissions.

Figure 16 illustrate that the standing volume of timber is steadily increasing while maintaining a high sustainable harvest.

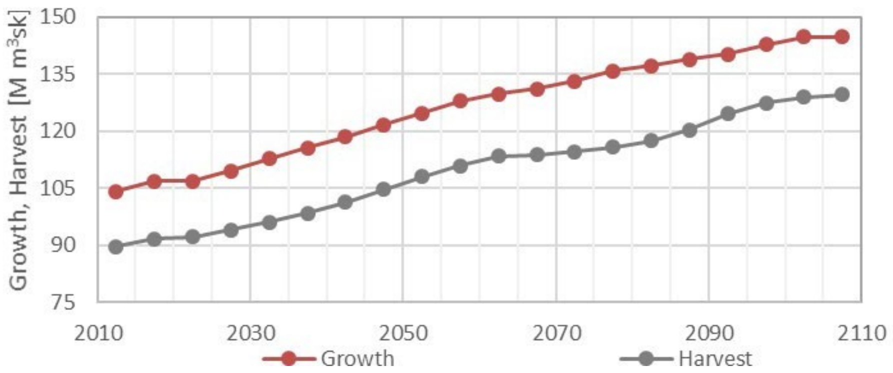
In table 12 the net growth and harvest for different types of forest land are presented for the periods simulated for the FRL (2010-2030).

Table 11. Average annual carbon stock changes, other emissions and the resulting FRL for Sweden 2021-2025.

[kt CO_2-equivalents]		**2021-2025**
Living biomass	Managed forest land, total	-17 570
	Production land incl tree retention TR (ca 21100 kha)	*-6 533*
	Forests set-aside for nature conservation (ca 2100 kha)	*-7 396*
	Low-productive forest land (ca 4000 kha)	*-3 641*
Mineral soils	Dead wood	-2 083
	Litter, Soil	-11 613
Organic soils	Dead wood	-271
	Litter, Soil (CO_2+DOC from drained soils)	5 191
	Drained organic soils (N_2O, CH_4)	1 189
HWP	Total	-5 495
	Sawn wood	*-4 561*
	Wood panels	*112*
	Paper and paper board	*-1 046*
Fertilisation (N_2O)		23
Mineralization (N_2O)		0
Indirect emissions (N_2O)		4
Biomass burning (CO_2, N_2O, CH_4)		69
TOTAL WITHOUT HWP		**-25 061**
TOTAL WITH HWP		**-30 556**

Table 12. Annual simulated harvest and growth in five year periods from 2010.

		2010-2015	2015-2020	2020-2025	2025-2030
Harvest [M m³sk]	Production land incl. TR	87	90	91	91
	Reserves and voluntary set-asides areas	0	0	0	0
	Low-productive forest land	0	0	0	0
Growth [M m³sk]	Production land incl. TR	96	98	98	101
	Reserves and voluntary set-asides areas	5,6	5,8	5,9	6,1
	Low-productive forest land	2.7	2.7	2.6	2.6
	All managed forest land	**105**	**107**	**107**	**110**
Relative harvest	All managed forest land	0.83	0.84	0.85	0.83
Other harvest activities [M m³sk]	Pre-commercial thinning	4.6	3.7	1.4	3.9
	Deforestation (also included in harvest on forest	1.6	1.4	1.5	1.8
	Other land use*	0	0	0	0
Total harvest [M		**92**	**94**	**92**	**95**



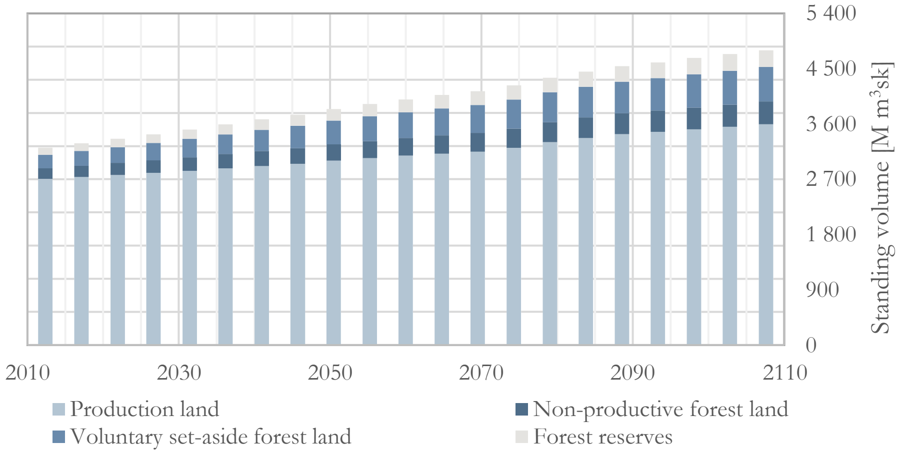


Figure 16. Simulated timber volumes, net increment and harvest 2010-2110 for managed forest land.

Table 13. Areas for managed forest land in the FRL for Sweden 2010-2030.

Areas [kha]	2010	2015	2020	2025	2030
Productive forest land (total)	23 355	23 299	23 240	23 183	23 127
Production land incl. tree retention (TR)	21 230	21 174	21 115	21 058	21 002
Productive forest land set-aside for nature conservation	2 125	2 125	2 125	2 125	2 125
Voluntarily set-aside	*1 345*	*1 345*	*1 345*	*1 345*	*1 345*
Forest reserves	*780*	*780*	*780*	*780*	*780*
Low-productive forest land	4 037	4 030	4 024	4 018	4 009
All managed forest land	**27 392**	**27 329**	**27 264**	**27 201**	**27 136**

4.2 Consistency between the forest reference level and the latest national inventory report

The same carbon pools and other greenhouse gas emissions are included in the FRL in the same way the carbon pools and emissions is reported to the EU and the UNFCCC[33].

The same methodology is used for carbon pools and other emissions in the FRL as is used in the greenhouse gas inventory. See the description of methods for details.

Due to small differences in the definitions of land use categories and accounting categories respectively the results are not 100 % comparable. The initial state (2010) of the FRL is based on the same sample units as the Swedish reporting to the EU and the UNFCCC. Due to slightly different rules for land use change the initial state in 2010 is not exactly the same. E.g. basing the FRL on the average management 2000-2009, makes the different approaches less comparable after 2010.

Otherwise, the same methodologies are used for carbon pools and other emissions in the FRL as is used in the greenhouse gas inventory. See the description of methods for details.

[33] National Inventory Report Sweden 2018.

When the first annual reporting according to the LULUCF regulation is made in 2022, the FRL and the national inventory report will be fully consistent.

4.3 Calculated carbon pools and greenhouse gases for the forest reference level

The forest reference level for Sweden includes changes in the carbon pools Living biomass (above and below ground), Dead wood, Litter, Soil carbon and Harvested wood products. No carbon pools have been omitted in the forest reference level for Sweden.

The forest reference level also includes emissions from forest fertilization (N_2O), from drained organic soils (CO_2, N_2O, CH_4 and DOC), mineralization (N_2O) and biomass burning (CO_2, N_2O and CH_4).

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EUROPAPARLAMENTETS OCH RÅDETS BESLUT nr 529/2013/EU av den 21 maj 2013 om bokföringsregler för utsläpp och upptag av växthusgaser till följd av verksamheter i samband med markanvändning, förändrad markanvändning och skogsbruk och om information beträffande åtgärder som rör dessa verksamheter

EUROPAPARLAMENTETS OCH RÅDETS FÖRORDNING (EU) 2018/841 av den 30 maj 2018 om inbegripande av utsläpp och upptag av växthusgaser från markanvändning, förändrad markanvändning och skogsbruk i ramen för klimat- och energipolitiken fram till 2030 och om ändring av förordning (EU) nr 525/2013 och beslut nr 529/2013/EU.

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