Ministry of Agriculture and Forestry
Natural Resources Institute Finland

National Forestry Accounting Plan for Finland

Submission of updated National Forestry Accounting Plan including forest reference level (2021 – 2025) for Finland (20 December 2019)

Table of Contents

Chapter 1: General introduction 4

1.1: General description of the forest reference level for Finland 4

1.2: Consideration to the criteria as set in Annex IV to the LULUCF Regulation 5

Chapter 2: Preamble for the forest reference level 10

2.1: Carbon pools and greenhouse gases included in the forest reference level 10

2.2: Demonstration of consistency between the carbon pools and areas included in the forest reference level 10

2.2.1 Living biomass 10

2.2.2 Dead wood 10

2.2.3 Litter 10

2.2.4 Soil carbon 11

2.2.5 Harvested wood products 11

2.2.6 Areas 11

2.3: Description of the long-term forest strategy 12

2.3.1: Overall description of the forests and forest management in Finland and the adopted national policies 12

2.3.2: Description of forest carbon sinks and harvesting rates under different policy scenarios 19

Chapter 3: Description of the modelling approach 21

3.1: Description of the general approach as applied for estimating the forest reference level 21

3.1.1 Models used for FRL estimation 22

3.1.2 MELA forestry model 25

3.1.3 The model framework for the changes in carbon stocks 28

3.2: Documentation of data sources as applied for estimating the forest reference level 29

3.2.1: Documentation of stratification of the managed forest land (Step 1) 29

3.2.2: Documentation of the forest management practices (FMP's) in 2000–2009 (Step 2) 32

3.2.3: Documentation of the use of forest management practices 2000–2009 as applied in the estimation of the forest reference level 35

3.3: Detailed description of the modelling framework as applied in the estimation of the forest reference level 37

3.3.1 Biomass 38

3.3.2 Litter, dead wood and soil carbon 38

3.3.3 Litter input 39

3.3.4 Mineral soils 39

3.3.5 Organic soils 39

3.3.6 Non-CO_2 emissions from organic soils 40
3.3.7 Harvested wood products 41
3.3.8 Other emissions sources 41
Chapter 4: Forest reference level 42
4.1: Detailed description of forest reference level 42
4.2: Consistency between the forest reference level and the latest national inventory report 46
4.3 Ex-post calibration for developing forest reference level 48
4.4 Forest reference level for Finland 48
4.5 Technical corrections planned for forest reference level 49
References 50
Appendix 1. MELA model 55
Appendix 2. Restrictions for wood production in MELA model 62
Appendix 3 Uncertainty of GHG inventory for period 2000 – 2013 63
Appendix 4. Year 2009 in Finnish forest sector. 69
Appendix 5. Modification of natural mortality- and wastewood statistics and GHG inventory 73
Appendix 6. Development of area and stem volume estimates based on NFI data and MELA prediction for 2000 – 2051 75

Chapter 1: General introduction

1.1: General description of the forest reference level for Finland

The forest reference level (FRL) for Finland for the period from 2021 to 2025 is -21.16 Mt CO_2 eq. /yr assuming instant oxidation for harvested wood products (HWP). The value is -27.64 Mt CO_2 eq./yr with carbon stock change from harvested wood products (HWP) applying the first order decay functions. The values are annual averages of the projected managed forest land and harvested wood products emissions and removals for the period 2021-2025 after ex-post calibration (Table 1.)

Table 1. Forest reference level of Finland after ex-post calibration.

Emissions and removals	2021-2025 (Mt CO_2 eq. yr^{-1})
FRL without HWP	-21.16
FRL with HWP	-27.64

The FRL was prepared in accordance with the LULUCF Regulation (2018/841) and it has been constructed from the projected emissions and removals in managed forest land as an average of five years (2021-2025). The projections of carbon stock changes in living biomass, soils and those of harvested wood products based on continuation of the forest management practices in 2000–2009, forest act and projections of the forest resources in 2010-2061.

MELA forestry model (Hirvelä et al. 2017) was used to project future development of growing stock of forests based on the national forest inventory data and country specific growth models (Hynynen et al. 2002) which have been validated with independent test data (Hynynen et al. 2002, Haara and Leskinen 2009) (see also Appendix 1). The outputs of the model were employed to calculate the projections of carbon stock changes, thus converted to emissions and removals.

Projections of emissions from N-fertilization and controlled burning were estimated based on the emissions as reported in the greenhouse gas (GHG) inventory from period of 2000-2009 (Statistics Finland 2019, hereafter referred to as NIR 2019). For the projection of carbon stock changes in harvested wood products the output data from MELA modelling, GHG inventory activity data on production volumes in 2000-2009 and statistics on energy use of wood were used.

The Finnish FRL is consistent with the methodology described in the NIR 2019. Starting year of the projection for forest development is 2011 and the forest area applied refers to the forest land remaining forest land as reported in the NIR 2019 for the year 2010. Forest land area is assumed to be constant during the projection. In the UNFCCC reporting, Finland applies a slightly different forest land definition than is in Annex II to the LULUCF Regulation. The reported forest land area was used for the FRL construction to ensure comparability between the FRL and the GHG inventory (see Section 2.2.6). Zero effect of the natural disturbances is applied.

1.2: Consideration to the criteria as set in Annex IV to the LULUCF Regulation

Each criterion as set in the Annex IV is considered below, see also Table 2.

(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;

> The FRL for Finland (2021-2025) is based on projections on development of forests and demonstrate enhancement of carbon stocks in forests under assumption that forest management continues as described for 2000-2009. Simultaneously forests that are managed according to principles of sustainable forest management provide raw materials for forest industries allowing substitution of non-renewable materials and fossil fuels. Projection shows an increase of carbon stocks of forests from 2021 to 2050, and thus, to enable Finland to meet the goal of achieving balances between anthropogenic emissions and removals latest by the second half of the century.

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

> The method for calculation of the reference level is based on projecting either carbon stock changes or fluxes of greenhouse gases. Mere presence of carbon stocks does not affect the results.

(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;

All changes in carbon stocks and with other GHG emissions on forest land remaining forest land will be accounted against the FRL. In the GHG Inventory, tree biomass removed from living biomass pool is calculated as carbon losses immediately in the harvest year. Tree biomass components left on forest during harvests are allocated to litter and dead wood pools and biomass used for energy is calculated as instantaneous oxidation, while harvested wood is allocated into HWP pool. The same approach was applied to construct the FRL. The ratio of harvested volume for energy use to total harvested volume is based on the statistics on the actual harvest volumes in 2000-2009. Thus, the possible change in the ratio during the period from 2021 to 2025 will be properly accounted for. This calculation method ensures that all biomass use is taken into account by the GHG inventory and thereafter compared against the FRL.

(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, the FRL is given with and without HWP. For the FRL with HWP, the production approach applying the first-order decay function and default half-life values are used. For the FRL without HWP, the instantaneous oxidation is assumed meaning that there is no change in the HWP pool.

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

A constant ratio between solid and energy wood use was calculated to be consistent with the criteria (e) by dividing the sum of the primary forest energy wood (stem wood, cutting residues and stumps chipped for the energy) and households' fuelwood usage with the industrial wood using the quantities compiled in Finland in 2000–2009 as documented in Chapter 3 in this NFAP based on domestic biomass.

(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 managed forest land in Finland includes all forests. In setting the FRL no forest harvesting was allowed in conservation areas to safeguard the biodiversity. In forest available for wood supply, forest and nature conservation legislation and a number of other policies (see chapter 2.3.1) provide high quality requirements for the use and management of forests to contributing EU and national biodiversity targets as well as to implementing sustainable use of natural resource, and thus, to contribute to implementation of the EU Forest Strategy. With MELA coupled with National forest inventory (NFI) data it was also possible to take into account also known restrictions (areas where no harvests or no clear-cuts are allowed due to the owners decision or other legally unbinding reasons) when the FRL was estimated for Finland. The Best Practices for Sustainable Forest Management guidelines (Tapio 2006) operationalise forest and nature conservation legislation and provide additional guidance for forest owners for ecologically, economically and socially sustainable use of forest, as set out in adopted national policies. The Best Practices for Sustainable Forest Management is based on and consistent with principles of sustainable forest management as agreed in the Forest Europe process, EU forest strategy and national forest policies. During the estimation of the FLR, the best practises according to sustainable forest management guidelines (Tapio 2006) and forest act (224/1997) (MMM 1997) were used to constrain the harvest options simulated with MELA model. A number of measures for maintaining and enhancing the biodiversity of production forests have been defined and are being promoted (see chapter 2.3.1).

(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 is consistent with Finnish reporting under Regulation (EU) No 525/2013 as both report accounted forest land and all carbon pools (biomass, dead wood, litter, soil carbon), and also non-CO_2 emissions, like those from drained organic soil, nitrogen fertilization and from controlled burning. The same methodologies are used both for projections reported under Regulation (EU) No 525/2013 and for the FRL. In both, the MELA results on the development of forest resources are the basis for the estimation of biomass changes, and consequent changes in carbon dioxide and other emissions as in the GHG inventory. For the FRL, estimation of biomass change is based on the same data as in the GHG inventory while in the projections reported under Regulation (EU) No 525/2013 estimation is based on the tree level biomass functions that take into account the projected change in the size distribution of trees. In the most recent long-term strategy consistency has been further improved. Consequently, the new scenarios (Koljonen et a. 2020), are also based on the most recent NFI data, and therefore differ from those reported under Regulation (EU) 525/2013.

(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.

The FRL for Finnish forests is based on National Forest Inventory data, MELA model, Yasso07 soil model, HWP model and emission factors. The applied methodology is consistent with the methodology used in the national GHG inventory for Finland (NIR 2019). The produced reference levels have been ex-post calibrated with GHG inventory data by comparing to historical data from MELA predictions with reported GHG inventory data. For ex-post calibration the period from 2006 to 2011 was used due to the availability of NFI 9 data (See section 4.3).

Table 2. Equivalence table for the NFAP for Finland.

Item	Elements of the national forestry accounting plan according to Annex IV B.	Chapter
(a)	A general description of the determination of the forest reference level.	3.1
(a)	Description of how the criteria in LULUCF Regulation were taken into account.	3.2.2
(b)	Identification of the carbon pools and greenhouse gases which have been included in the forest reference level.	2.1, 2.2
(b)	Reasons for omitting a carbon pool from the forest reference level determination.	2.1, 2.2
(b)	Demonstration of the consistency between the carbon pools included in the forest reference level.	4.2, 4.3
(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.	3.1, Appendix 1
(c)	A description of documentary information on sustainable forest management practices and intensity.	3.2
(c)	A description of adopted national policies.	2.3.1
(d)	Information on how harvesting rates are expected to develop under different policy scenarios.	2.3.2
(e)	A description of how the following element was considered in the determination of the forest reference level:	
(i)	The area under forest management	3.2
(ii)	Emissions and removals from forests and harvested wood products as shown in greenhouse gas inventories and relevant historical data	4.1, 4.2
(iii)	Forest characteristics, including: - dynamic age-related forest characteristics - increments - forest management guidelines	3.2.2
(iv)	Historical and future harvesting rates disaggregated between energy and non-energy uses	3.2.3

Chapter 2: Preamble for the forest reference level

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

The estimates of carbon stock changes in tree biomass include above-ground and below-ground biomass. The estimates for carbon stock change in Litter, Deadwood and soil organic matter are given as an aggregate estimate. Also N_2O and CH_4 emissions from drained organic forest soils were included following the methodology of the GHG inventory of Finland. Liming on forest lands do not occur in Finland, therefore the emissions were not estimated. Emissions (CH_4 and N_2O) from biomass burning cover emissions from controlled burnings of slashes on clear cut sites. Also direct emissions from N fertilization were taken into account. Carbon stock changes in HWP were estimated separately for the three product categories sawn wood, wood-based panels and paper and paperboard.

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

2.2.1 Living biomass

Living biomass has been defined as the dry weight of living trees with a height of at least 1.35 m and both above-ground and below-ground biomasses are reported. Tree biomass includes stem wood, stem bark, living and dead branches, needles/foliage, stumps, and roots down to a minimum diameter of one cm. The understory vegetation is not included into biomass pool reporting but it is taken into account as a litter input to soils.

2.2.2 Dead wood

This carbon pool includes tree stems that are left in the forest to decay. This pool originates from the natural mortality of the trees and from harvesting residue. The trees with minimum diameter of 10 cm are measured and reported in dead wood pool. On mineral and drained organic soils, the dead wood carbon pool is reported as a combined with Litter and Soil organic matter pools. This is because the modelling framework is currently able to estimate reliably changes of only aggregated pools.

2.2.3 Litter

This carbon pool includes both above-ground and below-ground litter, which originates from trees and ground vegetation. Litter consists of dead foliage, leaves, branches, bark, coarse roots, stumps and fine roots. On mineral and drained organic soils, the Litter carbon pool is reported as combined with Dead wood and Soil organic matter pools.

2.2.4 Soil carbon

Soil organic matter (SOM) originates from the decomposed litter that has accumulated in soils. On mineral soils, Dead wood, Litter and Soil organic matter pools are reported as aggregated values. They are calculated using the soil carbon model Yasso07 (Tuomi 2011a, b). Yasso07 estimates soil carbon stocks and their changes to a depth of one metre. On drained organic forest soils, the carbon stock changes of SOM, Dead wood and Litter are estimated based on the below-ground litter input and peat decomposition flux. The above-ground pools of Dead wood and Litter are assumed to be in a steady state on drained organic forest soils.

The possibility to report deadwood separately in the GHG inventory will be studied and a technical correction will be considered.

Soil is considered organic if the soil type is peat. Finland is a relatively flat and humid country, where the conditions have been favourable for peat accumulation. Peatlands are defined in the same way as in the Finnish GHG inventory (NIR 2019) and as in Finnish NFI; a site is classified as peatland if the organic layer is peat or if more than 75% of the ground vegetation consists of peatland vegetation. Otherwise, the soil is considered mineral.

2.2.5 Harvested wood products

Carbon stock changes in harvested wood products (HWP) include HWP originating from domestic forests, produced domestically and consumed domestically or exported. Imported timber and harvested wood products were excluded. It was assumed that all HWP originated from managed forest land. Calculations were done in three product categories (sawn wood, wood-based panels, paper and paperboard). HWP in solid waste disposal sites and HWP harvested for energy purposes were accounted for on the basis of instantaneous oxidation.

2.2.6 Areas

Currently, Finland uses a different definition of forest for reporting to the UNFCCC and under Regulation 2018/841. The difference between definitions of forest areas (Table 3) is due to the criterion on minimum area of forest patch, which for the reporting to the UNFCCC is determined as in the NFI field measurements and no exact minimum area is given. For FRL the area of Forest land remaining Forest land reported under UNFCCC was used in order to ensure comparability between FRL and GHG inventory results.

MELA modeling has been done with the FAO forest area based on the 11th national forest inventory (NFI11) data, while GHG forest area is always derived from the NFI10 data and observed changes in land use thereafter. This creates a very small inconsistency of 1-2 %. Even though the difference in area is small the GHG exchange results for Finnish forests based on MELA modeling were downscaled to exactly match with the GHG inventory area from year 2010.

Table 3. Areas of forest land according to different definitions

	Area of 2010 (ha)	Minimum area (ha)	Tree crown cover (%)	Tree height (m)
MELA (FAO)	22 043 800	0.5	10	5
UNFCCC FL rem FL	21 780 765	guidance of 0.25, not exact	10	5
Regulation 2018/841 managed forest land	21 756 226	0.5	10	5

Land-use changes to and from managed forest land have not been taken into account, thus the area remains constant. The losses in area of managed forest land due to deforestation and increase in the area due to inclusion of afforested land 20 years after the date of conversion will be taken into account as a technical correction, as proposed by the guidelines (Forsell et al. 2018, chapter 2.5.3).

2.3: Description of the long-term forest strategy

2.3.1: Overall description of the forests and forest management in Finland and the adopted national policies

Overall description of forests

Forests cover 73 % of the land area of Finland. A total of 20.3 million hectares is available for wood production, of which 61% is privately owned. The growing stock is 2.4 billion m^3. Of the growing stock, 90% is located on forest land available for wood production. The mean volume of the growing stock on forest land is 118 m^3/ha. The mean volume is 143 m^3/ha in Southern Finland and 87 m^3/ha in Northern Finland.

The annual increment of growing stock on forest land and poorly productive forest land totals 107 million m^3 according to 2018 National forest inventory results. Mean growth of the growing stock per hectare is 4.7 m^3. The annual mean increment is 6.7 m^3/ha in Southern Finland and 2.7 m^3/ha in Northern Finland.

Almost half of the volume of the timber stock consists of pine (*Pinus sylvestris*). The other most common species are spruce (*Picea abies*), downy birch (*Betula pubescens*) and silver birch (*Betula pendula*). These species make for 97 percent of total timber volume in Finland. The majority of Finnish forests are mixed, which means that they consist of more than one species. In all, Finland has about thirty indigenous tree species.

There are approximately 350 000 family forest holdings owning at least two hectares of forest land. Family forest owners who own over 60% of the forest land, sell the forest industries 80 per cent of the Finnish timber utilized by the companies. The state-owned forests are managed by Metsähallitus and they cover a quarter of the forest land, while forest companies own close to 10% of the forest land.

Overall description of forest management

Finnish forestry is based on sustainable forest management and multiple use of forests, taking all dimension of sustainability into consideration.

Forest management aims to promote the growth of valuable stands and improve the quality of roundwood. In addition to wood production, forest management focuses on the preservation of natural values, landscape management, wildlife management and recreational needs. Climate change mitigation and adaptation has become significant objectives to be integrated both in both forest policy and management.

The minimum requirements for forest management is set in the forest and nature conservation legislation (see Adopted Policies). Some forest owners value profitable and efficient wood production while others nature values or recreation. Most forest owners have multiple goals and combine different ways of forest use. Since the forest owners have heterogeneous values and preferences, the amendments to the Forest Act (2013) increased the diversity and freedom of choice of forest owners to manage his/her forest reflecting better his/her objectives.

The Best Practices for Sustainable Forest Management has been a key instrument to operationalize legislation and to promote sustainable forest management in practice (Tapio 2006). The Best Practices aim to support the forest owners in his/her decision making and ensure that forests, also privately owned, are managed according to the best information available. The Best Practices for Sustainable Forest Management is prepared in wide cooperation of private forest owners, forestry experts and forest, energy and environmental researchers. They are completed with several detailed guide books on specific topics such as protection of waters, peatland forestry, biodiversity and climate change adaptation. The follow-up illustrates that the Best Practices are widely followed and applied among forest practitioners. The sustainability of forest management is assessed and monitored on the basis of the Pan-European Criteria and Indicators for Sustainable Forest Management.

In Finland forestry generally involves the management of forest stands with even-aged structure. Stands are managed according to a regeneration cycle extending from planting or natural regeneration to the final harvesting phase. The forest management measures, including fellings and their timing and forest regeneration methods, depend on the growing conditions of each site.

The length of the regeneration cycle can be between 50 and 120 years, depending on the tree species, the location of a stand as well as forest owner’s objectives. After final felling the forest owner is obliged in due time to regenerate the forest, which is also the case if the stand remaining after intermediate felling does not meet the requirements set by the law. Forests may be regenerated naturally, by leaving a few selected seed trees during final harvesting, or artificially, by sowing seeds or planting seedlings grown in tree nurseries.

Commercially managed even-aged forests are typically thinned periodically from two to three times during the rotation period, with some 25−30% of the trees removed during thinning. The demand for wood for bioenergy has created new markets for the trees too small for industrial use cut during thinnings, and for logging residues such as branches which were earlier commonly left in the forest.

Continuous-cover silviculture (uneven-aged forestry) methods were made available in the revision of the Forest Act (2013). In this method forest regeneration is performed by light selection felling or small scale group selection system. The aim is a forest stand with a diverse age structure and to maintain forest cover. The share of this method is still low but increasing.

The biodiversity of forests is promoted by maintaining the characteristics of the valuable habitats, both in even and uneven-aged forests. The most commonly used methods of nature management in commercial forests include leaving retention trees in final fellings and preserving key habitats, such as the habitats of special importance for biological diversity that are defined in the Forest Act. These habitats of special importance are usually in their virgin state or slightly modified and they are small in size. Forest management practices have to be carried out in a way that the special features of these habitats are maintained. A special feature of natural boreal forest is the occurrence of fire and the organisms living in burned wood.

Forest policy framework

The sustainable management of forests in Finland is based on legislation and good practices. The means for steering the use of forests include legislation, Finland’s National Forest Strategy 2025 (NFS), financing and public forestry extension organisations. Forest legislation is the most important means of forest policy for ensuring sustainable forestry. The key acts include the Forest Act and the Act on the Financing of Sustainable Forestry. There is also legislation dealing with the prevention of forest damage and the trade in forest reproductive material, timber measurement, jointly owned forests and organisations in the forestry sector. Acts on timber measurement and jointly owned forests, as well as on some forest organisations have recently been updated.

Public funding for forestry is based on the Act on the Financing of Sustainable Forestry (34/2015). Environmental aid may be granted for additional costs and income losses due to preservation and management of habitats of special value. The State also finances forest nature management projects. The works to be designed and implemented in these projects are defined in further detail in the legislation. Most of the forest nature management projects have special regional importance. Apart from habitats of special value, the projects may concern landscape management, preventing damage to waters and the restoration of ditched areas.

The purpose of the Forest Damages Prevention Act (228/16) is to ensure good forest health by preventing insect damages, in particular. The act includes regulations for removal of conifers from a felling site or immediate storages to prevent mass occurrence of insects, for preventing extensive forest damages, for prevention of root rot in conifer stands, and for monitoring and organising of the control (governance).

The national strategy and action plan for the conservation and sustainable use of biodiversity, entitled “Saving Nature for People”, was approved by a government resolution in December 2012. The strategy’s five objectives focus on the mainstreaming of environmental issues across society, the introduction of new participants in the work to advance environmental causes, a decision-making process based on robust research data, and Finland's responsibility, as a member of the international community, for the global environment. As forests are the most abundant ecosystem in Finland, a considerable weight in the strategy and in the action plan is set to safeguard the biodiversity of forest ecosystems.

The Nature Conservation Act aims at maintaining biological diversity; conserving the beauty and scenic values of nature; promoting the sustainable use of natural resources and the natural environment, promoting awareness and general interest in nature as well as scientific research. The Nature Conservation acts includes regulations on nature conservation planning, nature reserves and natural monuments, conservation of natural habitats, landscape conservation, protection of species and special provisions on the European Community Natura 2000 network. High-value old-growth forests, herb-rich forests and eskers are protected also under national conservation programmes.

With regard to contributing to the conservation of biodiversity and the sustainable use of natural resources, the most important instruments are Section 10 of the Forest Act (on preserving diversity and habitats of special importance) and the policies and measures outlined in the Forest Biodiversity Programme for Southern Finland 2014 to 2025 (the METSO programme). Both are integral parts of the range of instruments in the National Forest Strategy to protect biological diversity in the future. The METSO programme is being implemented jointly by the Ministry of Agriculture and Forestry and the Ministry of the Environment. METSO targets both private and state-owned land. It covers the protection and commercial use of forests. The aim is to halt the decline in forest habitats and species and to establish stable and favourable conditions for forest biodiversity in southern Finland. A Government decision-in-principle in 2014 sets goals for METSO up to 2025 that 96,000 ha of private and 13,000 ha state-owned forests will be conserved on permanent or temporary basis.

According to Korhonen et al. (2016), an increased level of harvest would be possible without endangering the biodiversity of commercial forests, if the following key measures were further strengthened: increasing the amount of deadwood, increasing the diameter of retention trees, increasing the share of broadleaved trees in mixed forests, increasing the intensity of prescribed burning, and avoiding harvest in habitats important for biodiversity. In addition, sufficient quantity and quality of conservation of old growth forest in Southern Finland needs to be ensured, for example, by a steady increase in the area of forest devoted for the METSO programme. The Finnish Government is working towards mainstreaming these and other improved forest management practices to wider use through a number of initiatives.

Finland’s National Forest Strategy (NFS) was adopted by the Government in February 2015 and operationalising Government policy, specifies the main objectives for forest policy and forest-based business and activities until 2025. The vision is includes three strategic objectives: 1) Finland is a competitive operating environment for forest-based businesses, 2) Forest-based businesses and activities and their structures are renewed and diversified, and 3) Forests are in active, economically, ecologically and socially sustainable, and diverse use.

The strategy is implemented by eleven key projects. According to the NFS, climate change mitigation and adaptation in forests are supported by diversifying forest management. Forests' viability, i.e. growth and resilience will be maintained and enhanced through active forest management. Over the long term, forest management techniques must be adapted to new and changing climate conditions. Timely and careful forest management can improve the growth but also the resistance of growing stock to damage while safeguarding the ecosystem services of forests and producing wood biomass sustainably. Forests as a carbon sink have been a significant means of mitigating climate change in Finland.

The NFS is implemented and monitored in broad cooperation between the public and private sectors. The Ministry of Agriculture and Forestry, supported by the Forest Council, has the overall responsibility for the programme. The Forest Council includes representatives from different administrative sectors, industries, NGOs and specialist organisations.

The revised National Forest Strategy published in 2019 builds on the Government Report on Forest Policy 2050, which marks out the long-term use and management of Finland's forests. The forest policy report was prepared by the Ministry of Agriculture and Forestry in broad-based cooperation with other relevant ministries and stakeholders. The aim of forest policy is to promote the management of forests as a multiple source well-being and promote the sustainable growth by forest bioeconomy.

The objective of the Finnish Bioeconomy Strategy is to generate new economic growth and new jobs from an increase in the bioeconomy business and from high added value products and services, as well as to reduce dependence on fossil natural resources, while securing the operating conditions for natural ecosystems. Finland is committed to reaching United Nation's Sustainable Development Goals (SDGs) both domestically and in its international cooperation. Forests are important in reaching the all aspects of sustainability, i.e. in social, ecological economic and cultural dimensions.

Climate and energy policy framework

The legislative basis for Finland's climate action framework is in the Climate Act (2015). It stipulates that the Government approves long-term and medium-term strategic mitigation plans and at least every ten years a national plan on adaptation. The first Medium-term Climate Change Policy Plan was finalised during 2017. Alongside the National Energy and Climate Strategy for 2030, adopted at the end of 2016, the plan implements the climate policy objectives of the Government Programme as well as EU obligations.

The Government Programme (10 December 2019) sets a target for achieving carbon neutrality in Finland by 2035. Finland will submit the renewed National Energy and Climate Plan and the Long Term Strategy by the end of 2019 as prescribed in the Governance Regulation of Energy Union.

The Government of Finland is preparing a wide range of additional measures in the land sector to reduce emissions and to enhance removals by sinks. This involves developing guidance instruments and incentives for maintaining and strengthening the carbon sinks and storage of forests and soil and for safeguarding the management, growth capacity and health of forests. The measures include, for example, implementing a pilot for carbon sequestration and storage markets, promoting the use of diverse forestry and forest management methods, assessing and – when necessary – updating the forest management guidance, and supporting the research and development of long-lived wood products and diverse uses of industry side streams. Due to the early stage of the plan, the impact of such additional measures on the forest land sink cannot yet be estimated.

Forest biomass will be crucial for Finland as a source of renewable energy. The objective is that the majority of forest-based energy will continue to be produced on market terms from the side streams of other wood use. There is also wood material produced in forestry management operations and timber harvesting that is not suitable as raw material for wood processing. This forest biomass can be used to replace imported fossil fuels in heating, CHP production and transport.

The National Energy and Climate Strategy also highlights the importance of the sustainable management and use of forests, including forest conservation, in achieving the climate and energy targets, highlighting the importance of (i) implementing the measures of the National Forest Strategy, (ii) maintaining a good forest health, and (iii) reinforcing the growth and carbon capture capacity of the forests over the long term. The role of promoting wood construction is recognised in the strategy as a long term storage of carbon.

The national adaptation policy framework is described in the National Climate Change Adaptation Plan 2022 adopted in 2014. Its aim is that the Finnish society has the capacity to manage the risks associated with climate change and adapt to changes in the climate. The revised adaptation policy document was based on the experiences, follow-up and evaluation of the previous National Adaptation Strategy to Climate Change as well as the latest scientific research and best practices.

2.3.2: Description of forest carbon sinks and harvesting rates under different policy scenarios

Figure 1 shows the implications of three long-term scenarios on the projected net carbon sink for forest land, with varying harvest levels (see Table 4). The results are presented for Forest land including harvested wood products. The 'WEM' (with existing measures) scenario depicts a business as usual development with stagnating wood-based pulp production. The 'Growth' scenario assumes a slightly declining trend in the use of wood of the forest industry in 2030-2050. The 'Save' scenario assumes one additional large scale pulp mill (with an annual capacity of 800 kt) on top of the WEM scenario, as well as major growth in the relative share of new wood-based products.

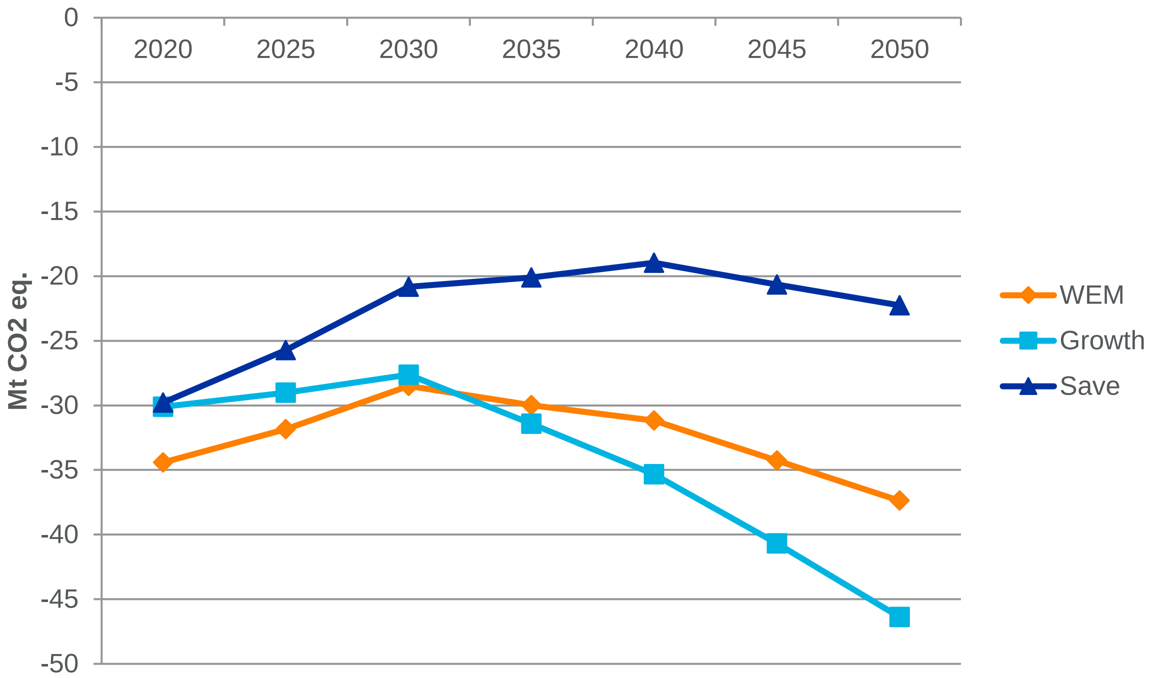


Figure 1. Forest land including HWP according to scenarios prepared for the long-term strategy, with the stock-change methodology applied for biomass carbon stock change estimation (Koljonen et al. 2020).

According to the comprehensive scenario projections, Finland could achieve the Government's objective of carbon neutrality by 2035, when maintaining a sufficient forest carbon net sink and reducing significantly emissions through a range of additional measures in all sectors. However, these additional measures are not yet implemented. According to scenario projections, Finland would achieve carbon neutrality by 2050 in all scenarios. All of the scenarios portray increasing sinks after the projected temporary decline from 2030 or at the latest from 2040 onwards, with the total level of harvest being around 80 Mm^3 during 2030-2050 in the WEM scenario (compared to 78.2 Mm^3 in 2018).

The estimated size of the forest carbon sink becomes the more uncertain, the longer the time horizon. The size of the forest carbon sink is to a significant extent determined by the allocation and rate of harvest, which is mainly influenced by the global demand for e.g. housing and packaging, the preferences of forest owners and the competitiveness of the forest industry. Moreover, the impact of climate change on the size of the forest carbon sink remains equivocal, since a significant rise on temperature may increase the likelihood of forest disturbances, besides possibly enhancing growth.

Table 4. Roundwood removals associated with the scenarios in Fig. 1.

WEM	**2015-24**	**2025-34**	**2035-44**	**2045-54**
Roundwood removals, Mm^3/a	72.0	79.9	81.2	80.7
Industrial roundwood removals, Mm^3/a	61.7	67.9	69.2	69.2
GROWTH	**2015-24**	**2025-34**	**2035-44**	**2045-54**
Roundwood removals, Mm^3/a	75.5	81.8	79.6	77.9
Industrial roundwood removals, Mm^3/a	67.2	70.5	68.4	67.5
SAVE	**2015-24**	**2025-34**	**2035-44**	**2045-54**
Roundwood removals, Mm^3/a	75.8	86.7	91.6	92.2
Industrial roundwood removals, Mm^3/a	68.5	75.1	80.1	82.2

The scenarios prepared for the long-term strategy are calculated applying the stock-change methodology. The FRL is calculated with gains-losses methodology applying the biomass conversion and expansion factors (BCEFs) from the GHG inventory. The WEM scenario is presented here (Figure 2.) with both methodologies to provide a comparison of the difference in results between methodologies.

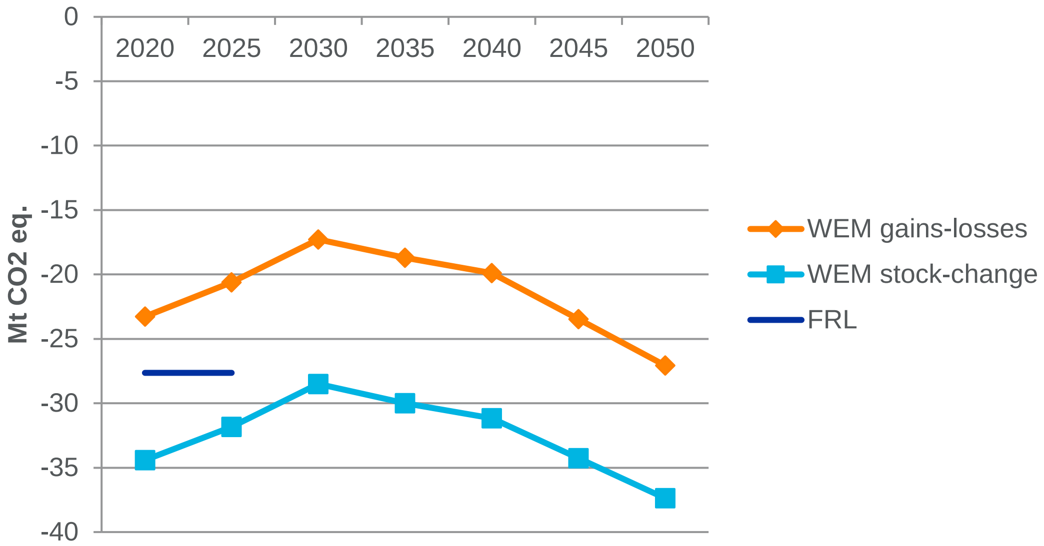


Figure 2. Comparison of Forest land including HWP with stock-change methodology and gains-losses methodology (with BCEFs from GHG inventory) applied for biomass carbon stock change estimation (Koljonen et al. 2020), together with the FRL.

Chapter 3: Description of the modelling approach

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

Our general approach was as follows:

1) Estimation of forest management practices in the reference period is based on Tapio (2006) guidelines and forest act 224/1997 that correspond well with the forest management practice during 2000-2009. For this purpose we used official forestry statistics of Finland (stat.luke.fi) on the area of intermediate fellings (thinnings) and final fellings during 2000-2009 and NFI10 (2004-2008) to derive the total area of thinning stands and mature stands.
2) We used NFI11 (2009-2013, mid-year 2011) as a primary data source for the future projections. These data were first updated to year 2015 with best available data, being here official forestry statistics on the area and removals of thinnings and final fellings and forest development models (increment, mortality, harvesting). MELA forestry model was applied for this step.
3) We simulated the development of forests for time steps 2016-2020, 2021-2025, 2026-2030, 2031-2040, 2041-2050, 2050-2060 using the MELA forestry model and the forest management practices of the reference period. The simulation produced increment,

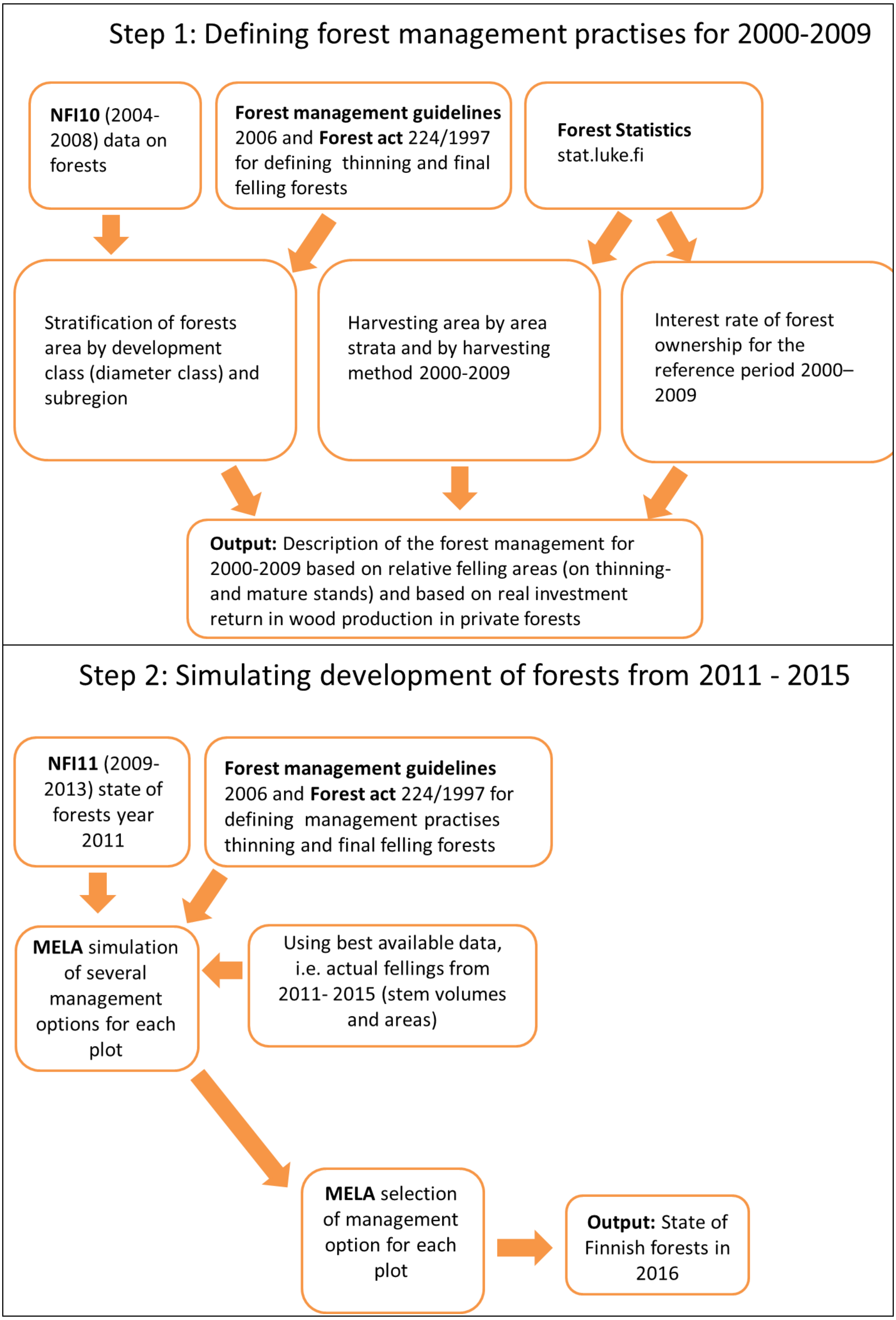
mortality, and removal estimates for the mentioned time steps. We converted these estimates to GHG removal estimates by using Yasso07 soil carbon model and emission factors for drained peatland forest soils. In addition, also CH_4 and N_2O emissions from soils, prescribed burning and fertilization were estimated with methodology of the GHG inventory.

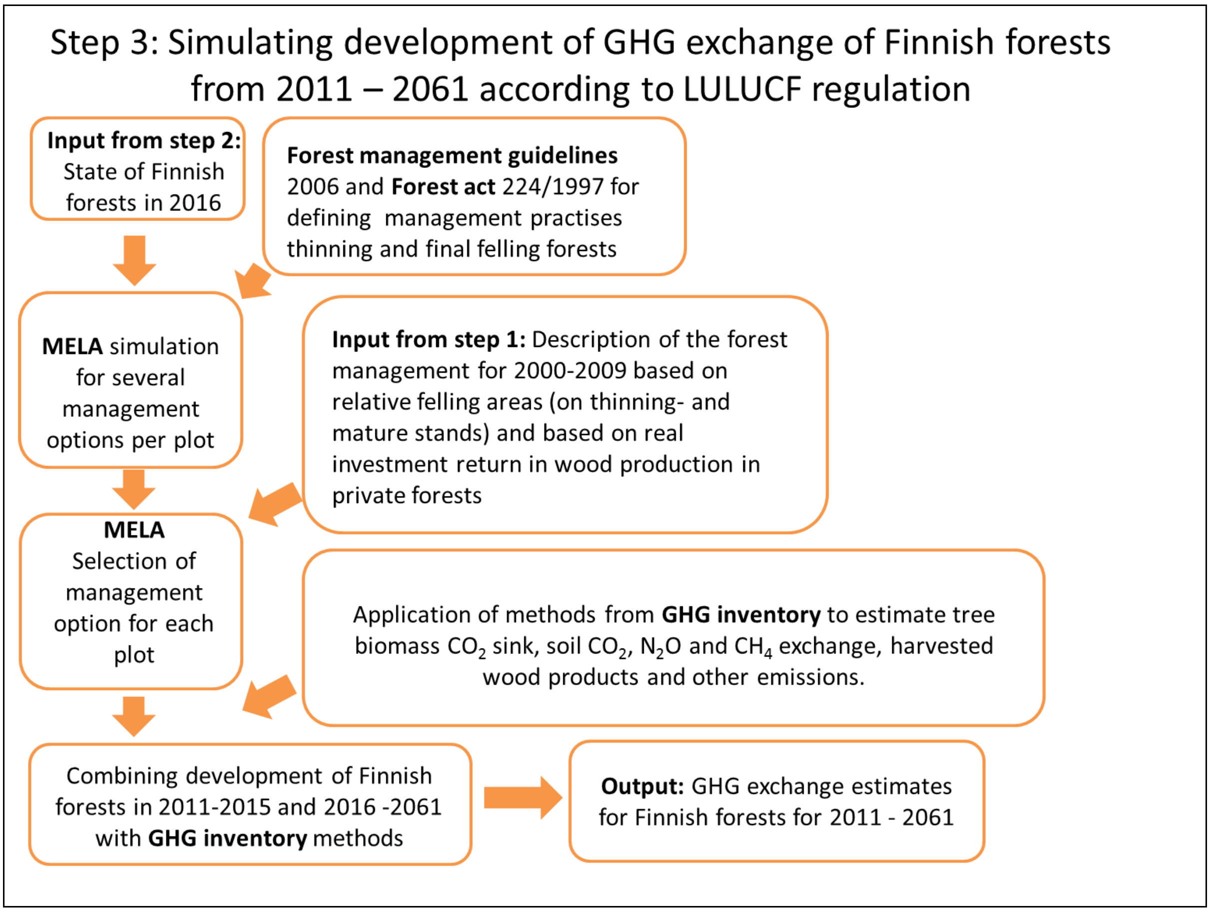
4) We used the MELA model with NFI9 data (1996-2003) to estimate the GHG emissions for the 2006 to 2010. These estimates were compared with the GHG statistics for the same years and ex-post calibration factor was derived from the ratio.

This general approach is in more details described in the next sub-chapters.

3.1.1 Models used for FRL estimation

The MELA forestry model (Hirvelä et al. 2017) was used to predict the development of the Finnish forests biomass according to the forest management practices which were prevailing during the years 2000–2009. Further, for evaluating the soil carbon development the Yasso07 model (Tuomi et al. 2011a) for mineral soils and emission factors for organic soils were used (NIR 2019). The methodology applied with these models followed the step-wise approach as described in the guidance provided by EC (Forsell et al. 2018) for calculating the Forest Reference Level (Figure 3). For harvested wood products, a production approach with first-order decay function and default half-life values were applied (NIR 2019).


Step 1: Defining forest management practises for 2000-2009
NFI10 (2004-2008) data on forests
Forest management guidelines 2006 and Forest act 224/1997 for defining thinning and final felling forests
Forest Statistics stat.luke.fi
Stratification of forests area by development class (diameter class) and subregion
Harvesting area by area strata and by harvesting method 2000-2009
Interest rate of forest ownership for the reference period 2000–2009
Output: Description of the forest management for 2000-2009 based on relative felling areas (on thinning- and mature stands) and based on real investment return in wood production in private forests
Step 2: Simulating development of forests from 2011 - 2015
NFI11 (2009-2013) state of forests year 2011
Forest management guidelines 2006 and Forest act 224/1997 for defining management practises thinning and final felling forests
MELA simulation of several management options for each plot
Using best available data, i.e. actual fellings from 2011- 2015 (stem volumes and areas)
MELA selection of management option for each plot
Output: State of Finnish forests in 2016



Step 3: Simulating development of GHG exchange of Finnish forests from 2011 – 2061 according to LULUCF regulation
Input from step 2: State of Finnish forests in 2016
Forest management guidelines 2006 and Forest act 224/1997 for defining management practises thinning and final felling forests
MELA simulation for several management options per plot
Input from step 1: Description of the forest management for 2000-2009 based on relative felling areas (on thinning- and mature stands) and based on real investment return in wood production in private forests
MELA Selection of management option for each plot
Application of methods from GHG inventory to estimate tree biomass CO_2 sink, soil CO_2, N_2O and CH_4 exchange, harvested wood products and other emissions.
Combining development of Finnish forests in 2011-2015 and 2016 -2061 with GHG inventory methods
Output: GHG exchange estimates for Finnish forests for 2011 - 2061

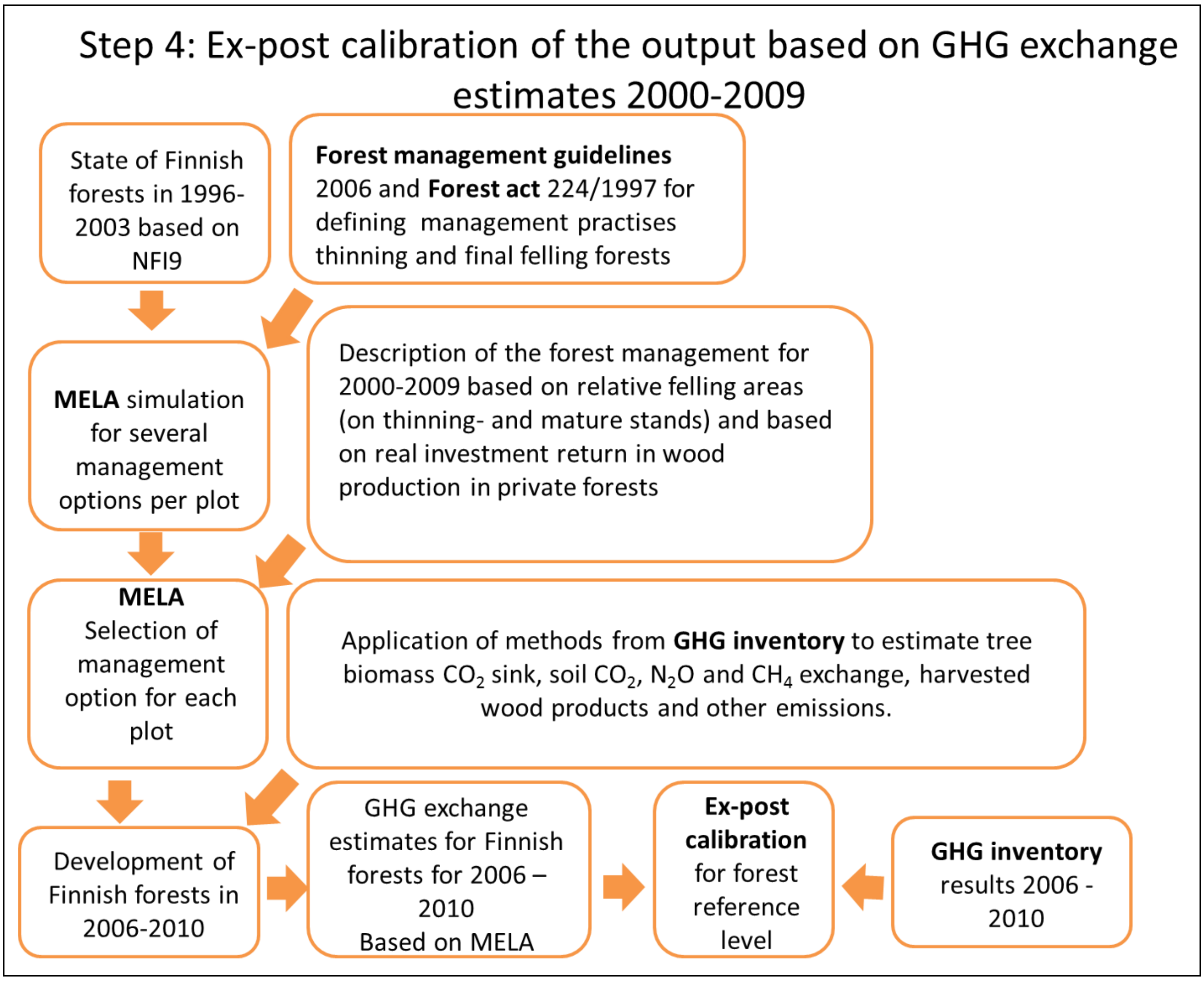


Figure 3. Illustration of forest reference level estimation for Finnish forests by four steps.

3.1.2 MELA forestry model

MELA forestry model (see Appendix 1) consists of 1) a forest stand simulator based on individual tree growth and development models (Hynynen et al. 2002), and 2) an optimization package (Lappi 1992) based on linear programming (LP). MELA simulates several management schedules (options) for each management unit over the chosen calculation period according to the given simulation instructions. Management schedules differ from each other, for example, in timing of management activities. The simulation instruction includes the Tapio (2006) forest management guidelines and Forest Act 224/1997 defining minimum diameters for final fellings by geographic region and tree species (MMM 1997). For some regions and tree species, the diameter thresholds for final felling defined in the Forest Act 224/1997 are slightly (1-3 cm) higher than in the Tapio (2006) forest management guidelines. In such a case, the Forest Act thresholds were applied for those classes. The simulation of the management schedules for each management unit consists of states and events. The events are i) natural processes (ingrowth, growth and mortality of trees) and ii) management activities (fellings and other silvicultural treatments).

MELA model estimates for individual tree growth were re-parametrized first with growth indices (see e.g. Henttonen 1984, 1990) to the average level of diameter increment for years 1984–2013 (Korhonen et al. 2007) of which the mean year is 1999. The growth indices are used both to remove the year-to-year variation in weather conditions and to adjust the mean growth prediction to the average level of period 1984 – 2013. The estimate of volume growth obtained was still adjusted to match with measured NFI11 growth level using the realized weather and CO_2 concentration data by the year 2017 and transformation functions (Matala et al 2005, for details see Aakkula et al. 2019 pages 14-15).

This has been implemented by estimating mean 30 year (1970-1999) temperatures and CO_2 concentrations for preceding mean year of the calibration period (1999). Corresponding mean values were estimated also for year 2017 from period 1988-2017. The differences between means were given as an input for MELA program. In Southern Finland mean temperature change between those mean years was ca. 0.89 degrees and in Northern Finland that was 0.99 degrees, while CO_2 change was 41.2 ppm in Finland.

These two values were used to predict the change in the growth rate as a function of the increase in mean temperature and CO_2 concentration linearly between 1999, 2010 and 2017. After 2017 modified growth rate from 2017 was used for following years. This procedure ensured that MELA model was able to agree with latest NFI increment data and with GHG inventory (see ch 4.2 and Appendix 1).

Key assumptions used in the MELA calculations:

- The starting year for MELA simulation was 2011 as that is the mean year of NFI11 data. Therefore, initial state of forest area, volume of growing stock and increment of growing stock were based on NFI11 data measured 2009–2013.

- NFI sample plots were classified into two categories: forests available for wood supply including also forests available for restricted wood supply and protected (conservation) forests.

- According to the forest management guidelines (Tapio 2006), Finland was stratified further into three regions (chapter 3.2.1).

- For the forests available for wood supply, forest management activities were simulated according to the Forest Management Guidelines (FMP) (Tapio, 2006) and taking into account forest act 224 from 1997 (MMM 1997), which were prevailing and applied in reference period 2000-2009. For the forests available for restricted wood supply only intermediate fellings (thinnings) of industrial wood were allowed, i.e. final fellings or harvest for energy wood were not carried out in these areas.

The guidelines and the act 224 define only the minimum values when and how the management activities can be carried out, for example, the minimum basal area requirements before and after intermediate fellings and the minimum diameters for final fellings. For each intermediate and final felling activity also a no-treatment alternative was also simulated and thus these felling activities were also postponed and simulated as alternative management schedules in the subsequent sub-periods.

- For the protected forest land and for all poorly productive forest land there were no silvicultural operations and only ingrowth, growth and mortality of trees were simulated.

- The time period to which the development of forests was predicted reached from 2011 up to the year 2061, i.e. 50 years and for the MELA this period was divided into the time steps of 5+5+5+5+10+10+10 years.

- Besides the natural processes, the fellings define the development of forest resources in MELA model. During years 2011–2015 the best available data included information from the fellings carried out. Therefore removals and felling areas from these years were applied as an input to MELA model (Figure 3, step 2) when simulating development of forests from 2011 to 2015.

- From 2016 onwards the fellings were based on MELA optimization with FRL defined area constraints (Figure 3, step 3) derived from the sustainable forest management practises from 2000 to 2009 (chapter 3.2.2). The silvicultural treatments were made based on the 2000–2009 prevailing Forest Management Guidelines (Tapio 2006) and also based on Forest act 224 from 1997, as described earlier (MMM 1997). However prescribed burning, fertilization or pruning were not included in the management alternatives.

- The delivery prices (= average stumpage prices plus average procurement costs to the roadside) were used to calculate the gross revenues from different treatment and development options in MELA. The net revenues were received as the difference of gross revenues and logging and silvicultural costs.

- The development path of Finnish forests from 2016 onwards thus also including the Reference Period from 2021 to 2025 and subsequent periods was operationalized by MELA and as a linear programming (LP) task in order to reflect the FMP’s from the reference period of 2000–2009. The calculation task was formulated by utilizing 3.5% discount rate to maximize the net present value of the total forest land area while requiring non-declining industrial roundwood removals between the successive periods during 2016–2061 (see chapter 3.2.2, table 8). Non-declining industrial roundwood removals in the context of MELA modelling is a sustainability measure which refers to future harvesting possibilities. This measure ensures that the long-term cutting possibilities are kept at least at the same level as they are now. The total cutting potential was according to the forest act 224/1997 and the forest management guidelines (Tapio 2006) considerable higher than current loggings, being more than 100 mill m^3 per year.

- For the energy wood removals during 2016–2061 the ratio between domestic solid and energy wood use in 2000–2009 was used as a LP constraint (see chapter 3.22. table 9).

- Biodiversity aspects on managed forest land has been taken into account by MELA

  - By leaving 5 m^3 retention trees per hectare
  - Dead wood is not harvested
  - No final fellings on forest land available for restricted wood supply (more information in Appendix 2)
  - No fellings on any low productive forest lands (scrub land)

3.1.3 The model framework for the changes in carbon stocks

The development of forest resources were projected using MELA forestry model as explained in the previous section. The changes in carbon stocks of biomass, Deadwood, Litter and SOM (Figure 3) were evaluated using biomass expansion factors from GHG inventory and stem wood volumes from MELA, soil carbon model Yasso07 (NIR 2019 Appendix_6e, Tuomi et al., 2011a,b) for mineral soils and a method based on emission factors for organic soils (NIR 2019 Appendix_6f, Sievänen et al. 2013). All components of this model framework are compatible with those in the greenhouse gas inventory system (NIR 2019). The greenhouse gas inventory uses measurements of NFI to calculate changes of carbon stock in biomass and amount of litter production. This model framework uses input from MELA simulation instead of NFI measurements; otherwise the calculations are practically the same as in the greenhouse gas inventory.

MELA projects the development of forest resources and calculates amount of carbon in growing stock, litter from living trees, harvesting residues and unrecovered natural mortality. Here, in this project stem volume estimates for increment, natural mortality and loggings were used with biomass expansion factors from GHG inventory in order to derive carbon stock change estimates for forest biomass. The litter input is used in Yasso07 (NIR 2019 Appendix_6e, Tuomi et al. 2011a, b) to calculate carbon changes of the aggregated pool of deadwood, Dead wood, Litter and SOM on mineral soils. A method based on emission factors was used for Dead wood, Litter and SOM on organic soils (NIR 2019 Appendix_6f, Sievänen et al. 2013). Change in biomass of understory vegetation is not considered but its litter input is included (NIR 2019, Table 6.4-3).

3.2: Documentation of data sources as applied for estimating the forest reference level

3.2.1: Documentation of stratification of the managed forest land (Step 1)

The data on NFI11 was used for calculating the FRL for the period from 2021 to 2025. The NFI11 was carried out in 2009–2013 so that measurements (~20 %) were made through whole country in each year. The sampling design of NFI11 followed the design of NFI10 (Korhonen 2016), i.e., systematic cluster sampling was applied. The results of NFI11 and the parameters of cluster sampling – the distance between clusters, the shape of a cluster, the number of field plots in a cluster and the distance between plots within a cluster – varied in different parts of the country according to spatial variation of forests and density of road network can be found out in Korhonen (2016, 2017). Details of the field measurements are described in the field manual (in Finnish) and in it's appendices (in Finnish). The main results of NFI11 are presented also in the Luke's web pages (https://stat.luke.fi/en/metsa) by the Luke's Statistical Services.

The calculation data for managed forest land consists of the NFI11 sample plots defined as forest according to the definition by FAO. The management units were classified further into two categories according to restrictions concerning wood production:

1. no restrictions for wood supply or partially restricted wood supply

2. no wood supply allowed (protected forests)

The forest management guidelines applied in 2000–2009 (ch. 3.2.2) have been defined separately for the Southern, Central and Northern Finland therefore the forest management was defined by these regions for FRL estimation, see below (Figure 4, Table 5 and Table 6):

1) Southern Finland: provinces of Åland, Uusimaa, Varsinais-Suomi, Satakunta, Kanta-Häme, Pirkanmaa, Etelä-Savo, Kymenlaakso and South Karelia.

2) Central Finland: provinces of Ostrobothnia, South Ostrobothnia, Central Ostrobothnia, Central Finland, Pohjois-Savo and North Karelia.

3) Northern Finland: provinces of North Ostrobothnia, Kainuu and Lapland

In the Finnish greenhouse gas inventory (e.g. NIR 2019) the calculations are made for South Finland and North Finland. Therefore for the sake of consistency, also in this report the results are presented for these two regions. The initial stratification into Southern, Central and Northern Finland is equivalent to NIR (2019) results in such a way that South Finland is composed of Southern and Central Finland and North Finland is same as Northern Finland.

Figure 4: Stratification of Finland for NFAP based on applied Forest Management Guidelines (Tapio 2006)

Table 5. Area by management categories in NFI11, according to FAO forest definitions (million hectares).

Management category	Area, mill. ha			%
	Forest land	Scrub land(*	Total	
Land available for wood supply	18.39	0.83	19.22	87.2
- Southern Finland	5.05	0.12	5.17	96.7
- Central Finland	5.73	0.10	5.83	96.6
- Northern Finland	7.60	0.61	8.21	77.1
No wood supply allowed	1.84	1.38	3.23	12.8
- Southern Finland	0.16	0.02	0.18	3.3
- Central Finland	0.17	0.03	0.21	3.4
- Northern Finland	1.51	0.93	2.44	22.9
Total	20.23	1.81	22.04	
- Southern Finland	5.21	0.14	5.34	
- Central Finland	5.91	0.14	6.04	
- Northern Finland	9.11	1.54	10.66	

*) Scrub land (poorly productive forest land) belongs either in category of wood supply allowed or in no wood supply allowed. However, there are no human events on scrub land.

Table 6. Volume by management categories in NFI11, according to national forest definitions (million cubic meters).

Management category	**Volume, mill. m³**			%
	Forest land	Scrub land(*	Total	
Land available for wood supply	2094.5	28.0	2122.5	90.1
- Southern Finland	766.2	6.1	772.3	96.0
- Central Finland	725.3	3.4	728.7	96.0
- Northern Finland	603.0	18.5	621.5	78.4
No wood supply allowed	200.1	33.6	233.7	9.9
- Southern Finland	31.3	0.7	32.0	4.0
- Central Finland	29.2	1.2	30.4	4.0
- Northern Finland	139.6	31.7	171.3	21.6
Total	2294.6	61.6	2356.2	
- Southern Finland	797.5	6.8	804.3	
- Central Finland	754.5	4.6	759.1	
- Northern Finland	742.6	50.2	792.8	

*) Scrub land (poorly productive forest land) belongs either in category of wood supply allowed or in no wood supply allowed. However, there are no human events on scrub land.

3.2.2: Documentation of the forest management practices (FMP's) in 2000–2009 (Step 2)

Figure 3 describes the steps in estimation of forest management practices of the reference period:

1. We calculated the area of thinning stand forests and mature forests on forest available for wood supply using the NFI10 data. Further stratification was by sub-regions Southern Finland, Central Finland, Northern Finland.

2. We took the area of intermediate fellings (thinnings) and final fellings from the official forestry statistics

3. The forest management practice during 2000-2009 was described as the percentage of thinning areas from the total area of thinning stands and as the percentage of the areas of final fellings from the total area of mature stands by the three sub-regions.

The forest management in Finland was based in 2000-2009 on the system of periodic cover silviculture (even-aged management). A rotation period began with regeneration of a new stand and ended in the final felling. The management actions in forest stands were based on the guidelines for Good Management Practices (Tapio 2006) and those from forest act 224 (MMM 1997) that had been defined separately for the Southern, Central and Northern Finland (see Appendix 1 for diameter limits applied). In addition, there were supplementary guidelines for Northern Finland (Keskimölö et al. 2007) and for peatlands (Ruotsalainen 2007). The guidelines comprised recommendations for stand-wise management actions, e.g. concerning fellings: regeneration criteria of a stand (age or diameter) and the intensity of thinnings (the amount of felling based on basal area or number of trees). Further the guidelines included instructions for choosing regeneration method (artificial or natural), soil treatment measure, tree species for cultivation and young stand treatments.

Table 7. Forest land available for wood supply delineated into the seedling stands, thinning stands and mature stands according to the mean diameter of the dominant tree species of the sample plot based on NFI10 data, according to FAO forest definition (Korhonen et al 2013).

	Seedling stands	Thinning stands	Mature stands	Total
- Southern*	1172	2862	993	5027
- Central*	1462	3682	633	5777
- Northern*	1871	5120	792	7783
Finland	4505	11664	2418	18586

*For estimating GHG emission and sinks these areas were aggregated into South- and North Finland, by summing regions of Southern and Central to be South Finland, as in (NIR 2019).

The development class distribution and existing forest management guidelines define the measures that forest managers are able to use as management options. Regeneration measures are mainly obligatory as the consequences of final fellings. For defining the forest management practice applied 2000–2009, the documented (https://stat.luke.fi/en/metsa) areas from 2000–2009 by intermediate fellings (thinnings) and final fellings were used (Table 7 and Table 8). These areas were used for determining relative areas (ratio of area of realised operations to the potential area) for thinnings and for final fellings in order to define quantitative aspects of sustainable forest management for the projection as documented in chapter 3.2.3. The relative areas (rather than fixed hectare area) were used in order to reflect the dynamic changes in the age related forest characteristics.

Table 8. Average annual felling areas in 2000–2009 in Finland, 1000 ha/y

Fellings, 1000 ha/y	Southern Finland	Central Finland	Northern Finland	Total
Thinnings	128.7	127.0	97.0	352.8
Final fellings	58.0	54.2	56.2	168.3
Total	186.7	181.2	153.2	521.1

The discount rate that is used in the net present value calculation of MELA is a significant factor affecting the projections (Lehtonen et al. 2019) (see also Assumptions in short used in the MELA calculations in Section 3.1.2 Models and Section 3.2.3 Documentation of the use of forest management practices 2000–2009 as applied in the estimation of the forest reference level). Employment of discount rate in MELA modelling is related to finance, in which risk and return are fundamental concepts. Their interdependency is traditionally described by the Capital Market Line (CML) that shows the relation between the volatility of investment and the expected return (see, e.g., Sharpe 1964). Using the CML, it is possible to infer an interest rate for forest ownership that is consistent with the behavior of the finance market with respect to the risk (volatility) difference between forest returns and stock market returns. To be able to derive the interest rate for forest ownership, it is necessary to have values for the stock market risk premium (equity premium), the risk-free rate, and the standard deviations of returns in forest ownership and the stock market. The equity premium varies over time and across stock markets, and among companies. Therefore, the literature presents a large number of possible values. Based on international (Fama and French 2012, KPGM 2018) and domestic (Kallunki and Niemelä 2004) sources, we chose the equity premium to be 4.5% in our calculation.

The reference period of 2000–2009 has 10 years, which is an overly short time period for inferring statistical values for investment markets. To estimate the volatility of returns in forest ownership and the stock market, we used the period of 1986–2010, as reported in Uotila (2011), based on the approach developed by Penttinen and Lausti (2004). This yielded us volatilities of 9.9% and 36.8% for forestry and stock markets, respectively. The risk-free rate was taken to be the Finnish treasury rate, which for the same period was on average 2.6% (real rate). Applying the CML, these parameter values result in a required rate of return of 3.8% (= 2.6 + 4.5*(9.9/36.8)). For the computations of forest owners' decisions, we used a rate of 3.5% (real rate). Simultaneously, real return of assets in wood production for private forest owners calculated with constant stumpage prices was 3.58% for period of 2000-2009 (Uotila 2011 and stat.luke.fi).

3.2.3: Documentation of the use of forest management practices 2000–2009 as applied in the estimation of the forest reference level

The realized relative thinning and final felling areas during the years 2000–2009 (Table 9) were applied as constraints in MELA calculations. These constraints were applied since 2016 onwards (Table 9 and Table 11). This approach was adopted on the basis of the guidance document by Forsell et al. (2018), and it is expected to accurately reflect the forest management of the reference period. The percentages were applied in the MELA calculations according to equations [1] and [2]:

$\text{Thinning area}_t < \text{tha\%}_{(2000\text{-}2009)} * \text{Area of young and advanced thinning stands}_{tb}$ [1]

$\text{Final felling area}_t < \text{ffa\%}_{(2000\text{-}2009)} * \text{Area of mature stands}_{tb}$ [2]

t = period, t >1, tb = in the beginning of period t

Table 9. Felling areas in 2000–2009 as a per cent of corresponding phases of the stands based on themean diameters of dominant trees of the NFI10, %

	1000ha/year		1000 ha			% per year
Region	Thinning	Final felling	Thinning stands	Mature stands	Share of thinnings	Share of final felling
	area	area	area	area	tha%	ffa%
Southern Finland	128.7	58.0	2861.9	993.2	**4.5**	**5.8**
Central Finland	127.0	54.2	3682.1	632.6	**3.4**	**8.6**
Northern Finland	97.0	56.2	5120.3	791.7	**1.9**	**7.1**
Finland	352.8	168.3	11664.3	2417.5	3.0	7.0

In order to calculate domestic energy wood removals for the periods starting from 2016 and fulfilling the condition of Annex IVA (e) the ratio of removals of energy wood (forest chips and household's fuelwood) to industrial wood were calculated based on statistics of 2000–2009 (https://stat.luke.fi/en/metsa) (Table 10). These ratios were used as constraints in MELA calculation as defined in equation [3].

Table 10. Removals of energy wood (forest chips + households' fuelwood) and industrial roundwood in 2000-2009, 1000 m^3/year, excluding imports. (Source: https://stat.luke.fi/en/metsa)

Region	Energy wood (EW)	Industrial roundwood (RW)	EW%
	1000 m^3/y	1000 m^3/y	(=EW/RW)
Southern Finland	3665.0	22763.7	16.1
Central Finland	2783.2	19374.2	14.4
Northern Finland	1242.0	11155.8	11.1
Finland	7690.2	53293.6	14.4

$$\text{Forest energy wood removal}_t^{(*} < \text{EW\%}_{(2000\text{-}2009)} * \text{Industrial roundwood removal}_t \qquad [3]$$

*) comprise of forest chips and households' fuelwood

Table 11. Felling area per cents for thinnings and for final fellings for period of 2011-2051 based in 2000-2009 sustainable forest management and used for constraining MELA simulations. The denominations are for a) 1000 ha and b) 1000/yr and %/yr.

		2011	2016	2021	2026	2031	2041	2051
Southern Finland	(a) Thinning stands	2912.4	2852.0	2893.6	2748.4	2594.8	2548.0	2562.9
	(b) Thinning area	144.0	128.3	130.1	123.8	116.7	114.7	
	% (b/a)	4.9	4.5	4.5	4.5	4.5	4.5	
	(a) Mature stands	1042.1	1234.2	1227.4	1252.8	1253.8	1301.5	1310.3
	(b) Final fellings	54.0	71.6	71.3	72.7	72.9	75.7	
	% (b/a)	5.2	5.8	5.8	5.8	5.8	5.8	
Central Finland	(a) Thinning stands	3777.5	3736.8	3768.5	3644.7	3451.6	3142.5	3118.8
	(b) Thinning area	158.5	127.0	128.1	124.0	117.2	106.7	
	% (b/a)	4.2	3.4	3.4	3.4	3.4	3.4	
	(a) Mature stands	663.6	899.1	882.5	927.7	944.8	1004.2	1110.6
	(b) Final fellings	47.3	77.4	76.1	79.7	81.4	86.5	
	% (b/a)	7.1	8.6	8.6	8.6	8.6	8.6	
Northern Finland	(a) Thinning stands	5428.6	5425.3	5255.5	5128.3	4926.0	4477.2	4257.1
	(b) Thinning area	144.7	103.1	99.9	97.3	93.5	85.0	
	% (b/a)	2.7	1.9	1.9	1.9	1.9	1.9	
	(a) Mature stands	669.4	874.2	874.9	984.8	1141.3	1426.9	1649.3
	(b) Final fellings	52.6	62.2	62.2	69.9	81.1	101.2	
	% (b/a)	7.9	7.1	7.1	7.1	7.1	7.1	

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

The estimation of the forest reference level was done as follows (see Figure 3).

1. NFI11 data from 2011, updated to the year 2015 was used as starting point.

2. We used MELA model to simulate increment, mortality and management options for each NFI plot and for each time step. All the simulated management options were according to the Forest Management Guidelines 2006 and Forest Act 224/1997. Several management options per plot and time point were possible and no management was always an option.

3. We used MELA model to select one management option (including also the possibility of no action taken) for each plot and each time step. This selection was done with the Linear Programming tool of MELA. As constraints in the optimisation there were the thinning areas and final fellings areas that were calculated by multiplying the areas of respective development class by the percentages of thinning and final felling areas during the reference period (2000-2009) (see subchapter 3.2.2). The net present value of forests at the 3.5 % discount rate was used as the variable to maximize net revenues from forestry. Additional restriction was the non-declining industrial round wood removals between the successive periods during 2016–2061. The results of ex-post calibration with NFI9 data (see subchapter 4.2 and 4.3) proved that the use of 3.5 percent discount rate was feasible.

4. The output from the MELA simulation and optimization contained the estimates of increment, mortality and removals for each plot and time step. These estimates were summed by sub-regions, tree species groups, forest type (mineral soils, drained peatland, undrained peatland). The methods from the Finnish GHG inventory, like Yasso07 soil model were used to estimate above ground biomass CO_2 sink, soil CO_2, N_2O and CH_4 exchange, harvested wood products and other emissions.

3.3.1 Biomass

The projection of carbon stock change in tree biomass was calculated using the same method as in GHG inventory, a difference between gains (increment) and losses (drain) (NIR 2019). The increments and losses in volume obtained from MELA modelling were converted to biomass with the biomass expansion factors used currently in the GHG inventory (NIR 2019) . Calculations were made by tree species, soil type, South and North Finland, and separately for increment, natural mortality and harvesting losses. The values between mid-years were interpolated.

3.3.2 Litter, dead wood and soil carbon

The methodology of estimation of carbon stock changes in soil, litter and dead wood on mineral soils and drained organic soils is practically the same as in the GHG inventory (NIR 2019). This method combines forest inventory data, biomass models, litter turnover rates and the dynamic soil carbon model Yasso07 (Tuomi 2011a, b). See Appendix_6e the NIR 2019 for details.

Projections for dead organic matter and soils are given in Table 15 and Table 16.

3.3.3 Litter input

Litter input for period prior 2011 was the same as in the latest submission of GHG inventory, and the same practise to estimate thelitter input was applied for future projections, see NIR 2019, section 6.4.2.1. MELA forestry model provided estimates for future tree stocks starting from 2011 (Table 14). These stocks were then converted to biomass with biomass functions currently applied in the national GHG inventory (NIR 2019, Appendix_6d). The litter input to the soils from living trees was estimated with turnover rates that are applied in the GHG inventory (NIR 2019 Table 6.4-2).

Future litter input from loggings and natural mortality were also estimated based on the MELA projections. MELA system provides estimates for natural mortality and loggings (Table 14.). The biomass of natural mortality and harvesting residues were estimated with the same BEFs (NIR 2019 Appendix_6c) and biomass functions (NIR 2019 Appendix_6d) of the GHG inventory. The estimates of energy wood fractions obtained from MELA modelling were used in the soil carbon simulations. The fractionsof bioenergy were assumed to remain as it was 2016 (division into stumps, harvesting residues and stems), also regional uses were assumed to be proportional to the situation of 2016 (as that is the best available data). Litter input of ground vegetation was estimated in the same way as in the GHG inventory (NIR 2019 section 6.4.2.1.). The energy use of bioenergy was deducted from the litter input that was provided for Yasso07 model.

3.3.4 Mineral soils

Yasso07 soil carbon model was applied on mineral soils (Tuomi et al. 2011b, NIR 2019 Appendix_6e). Yasso07 calculations provide estimates of changes in carbon stocks of dead wood, litter and SOM. The initial values of carbon stocks for Yasso07 in 2011 was taken from the results of the latest GHG inventory submission (NIR 2019) in order to ensure consistency with the GHG inventory. The input of weather conditions (mean annual temperature, amount of precipitation and amplitude of monthly mean temperature) were applied as 30 years moving average as is done in the GHG inventory. For the parameter values and the model description, see section 6.4.2.1. and Appendix_6e in NIR (2019).

3.3.5 Organic soils

Changes in carbon stocks of deadwood, litter and SOM on organic soils/peatlands on drained organic soils were calculated as a difference of emissions from the soil and the below-ground litter input in the same way as in GHG inventory (NIR 2019 section 6.4.2.1. and Appendix_6e). Emissions of peat decomposition were estimated separately according to the fertility classes, thereafter below ground litter input was deducted from the organic matter decomposition flux to obtain net gas exchange for drained peatland forests. In order to upscale emissions to the national level the area of drained organic forest lands were multiplied with net emission factors by fertility classes.

Carbon stock change of above-ground dead wood pool and that of above-ground litter pool on organic soils was evaluated in the same way as on mineral soils, that is, with NFI data (NIR 2019).

3.3.6 Non-CO_2 emissions from organic soils

Finland reports non-CO_2 emissions from drained organic forest soils, those being N_2O and CH_4. Emission factors (based on Ojanen et al. 2010 and 2018) for N_2O emissions by soil fertility for drained organic forest lands have been given in (Table 12).

Table 12. N_2O emission factors for drained organic forest soils (NIR 2019).

Site type	Emission factor [g N_2O m^{-2} a^{-1}]
Herb-rich type (Rhtkg)	0.331
Vaccinium myrtillus type I (MtkgI)	0.177
Vaccinium myrtillus type II (MtkgII)	0.323
Vaccinium vitis-idaea type I (PtkgI)	0.064
Vaccinium vitis-idaea type II (PtkgII)	0.098
Dwarf shrub type (Vatkg)	0.043
Cladina type (Jätkg)	0.043

Table 13. CH_4 emission factors for drained organic forest soils (NIR 2019).

Ditch condition	Emission factor [g CH_4 m^{-2} a-^{1}]
Poor	1.16
Good	-0.28

The CH_4 emissions originate from drained land (97.5% of the area, country-specific EFs) and from ditches (2.5% of the area, default fraction and EF 217 kg CH_4 ha^{-1} for boreal/ temperate zone given the IPCC Wetlands Supplement). Country-specific emission factors for CH_4 from drained organic land by drainage class are net emission of 11.6 kg CH_4 ha^{-1} for poorly or recently drained land and net uptake of -2.8 kg CH_4 ha^{-1} for well drained land (based on Ojanen et al. 2010), see (Table 13).

3.3.7 Harvested wood products

Carbon stock changes in harvested wood products were estimated applying production approach with first-order decay function and default half-life values. Calculations were done in three product categories (sawn wood, wood panels, paper and paperboard). To remain consistent with the GHG inventory (NIR 2019) and national projections, estimation was started from the carbon stocks of GHG inventory in the end of year 2010 (as tree biomass projection starts from 2011). In the GHG inventory carbon stock of harvested wood products estimation has been started from year 1900. The result from the MELA modelling, the harvest of solid wood was used as input. A constant ratio between solid and energy use of forest biomass and between the HWP product categories was used as documented in the period from 2000 to 2009 (Box 1.). HWP in solid waste disposal sites and HWP for energy purposes were accounted for on the basis of instantaneous oxidation and imported HWP were excluded. All HWP was allocated to managed forest land.

Box 1. Demonstration that the ratio between the production amount of the HWP categories and total harvests remain constant.

	2000-2009	**2021-2025**	**Ratio of harvest to production**
Average total harvest (mill. m³)	59	77	
Average production			
-Sawnwood (mill. m³)	11	15	0.2
-Wood panels (mill. m³)	1	2	0.025
-Paper (mill. mt)	9	12	0.2

3.3.8 Other emissions sources

N-fertilisation

The N_2O emissions from N fertilization were included in the reference level. The emission for years 2021-2025 is 0.0124 Mt CO_2 eq. per year which is the average of the emissions in the period of years 2000 to 2009. The methodology of GHG inventory was used (NIR 2019).

Controlled burning

CO_2, CH_4 and N_2O emissions from controlled burnings were included in the reference level. Cutting residues are classified in the litter pool and calculated as an instant oxidation after felling, therefore the CO_2 emissions are not reported to avoid double-counting. For controlled burnings the emissions for 2021 to 2025 were estimated as a constant value being the average of the emissions of the years

2000 to 2009 (NIR 2019). Thereby the total emission in the period of 2021 to 2025 is 0.0013 Mt CO_2 eq. per year.

Chapter 4: Forest reference level

4.1: Detailed description of forest reference level

According to MELA model estimates growing stock in forests increase from 2.35 bill. m^3 to 2.68 bill. m^3 between 2011 and 2030 (Table 14). According to the simulations with continuation of 2000-2009 sustainable forest management practices provided average annual loggings of 76.7 mill m^3/yr for 2021-2025, simultaneously tree increment increased from 106 to 110.7 mill. m^3/yr between 2011 and 2030. For long term predictions for areas, stem wood volumes and harvestings by development classes, see Appendix 6.

Table 14. Development of growing stock, increment, drain and natural mortality 2011 and 2030 (before ex-post calibration). Note that 2011-2015 period is based in the NFI11 data and on the fellings that took place during that period. The ratio of energy wood to solid wood for 2000-2009 [14.4%] has been provided in table 9. Note that unit of tree biomass sink is Mt CO_2 per year and ratio between solid- and energy use of forest biomass has been given in percentage (in grey at table).

	Start of projection (actual practises)	**Modelled with practises from 2000-2009**		
1000 mill. m^3	**2011**	**2016**	**2021**	**2026**
Growing stock	2347.1	2469.9	2571.8	2678.7
Growing stock, forest available for wood supply	2086.1	2183.7	2258.1	2337.4
mill m^3/ year				
	2011-2015	**2016-2020**	**2021-2025**	**2026-2030**
Increment (All area)	104.0	108.7	109.8	110.7
Drain	79.5	88.3	88.4	93.3
- Natural mortality	9.7	6.8	7.0	7.2
Total loggings	63.4	76.6	76.7	81.8
- Timber	55.1	70.9	70.9	76.1
- Stem wood for energy	8.3	5.7	5.7	5.7
- Timber for energy (from stem wood)	7.5	5.3	5.3	5.3
Wood chips + domestic fuelwood	12.8	10.1	10.1	10.8
Ratio between solid (HWP) and energy use of forest biomass [%] [(wood chips + domestic fuelwood) / timber]	23.2	14.3	14.3	14.2

The estimate of GHG impact for managed forests before the ex-post calibration was -18.88 Mt CO_2 eq. without HWP and -24.73 Mt CO_2 eq. with HWP for the period of 2021-2025 (Table 15). The calculation is shown here by different carbon pools and also for non-CO_2 emissions (Table 15).

Table 15. Development of carbon pools and GHG emissions between 2011 and 2030. Note that 2011-2015 period is based on NFI11 data and on fellings that took place during that period (Mt CO_2 eq. yr^{-1}). Values are before the ex-post calibration.

Carbon stock changes and other emissions	**2011-2015***	**2016-2020**	**2021-2025**	**2026-2030**
Living biomass (CO_2)	-21.52	-17.55	-17.71	-13.38
Mineral soils, including deadwood and litter (CO_2)	-6.43	-5.03	-4.89	-6.58
Organic soil, including dead wood and litter (CO_2)	4.50	3.12	0.90	0.13
Emissions from drainage (N_2O)	1.89	1.89	1.89	1.89
Emissions from drainage (CH_4)	0.91	0.91	0.91	0.91
Prescribed burning (CO_2, CH_4, N_2O)	0.00	0.00	0.00	0.00
N fertilization (N_2O)	0.01	0.01	0.01	0.01
Harvested wood products (CO_2)	-3.42	-6.46	-5.85	-6.32
Total without HWP	-20.63	-16.63	-18.88	-17.01
Total with HWP	-24.05	-23.09	-24.73	-23.33

* based on MELA modelling and best available data, i.e. actual loggings 2011-2015

The development of long term carbon sink and GHG emissions show that carbon net sink in forests strengthens slightly between 2031 and 2060 from a net sink of -19.83 Mt of CO_2 eq./yr to net sink of -20.34 Mt of CO_2 eq./yr with HWP, but being -17.27 Mt of CO_2 eq./yr for 2041-2050 (Table 16 and Table 17). Note that the presented values are before the ex-post calibration.

Table 16. Development of the long term carbon net sink and GHG emissions for Finnish forest according to FRL simulations (Mt CO_2 eq. yr^{-1}) up to 2015. Values are before the ex-post calibration.

	2031-2040	**2041-2050**
Living biomass (CO_2)	-7.93	-6.08
Mineral soils. including deadwood and litter (CO_2)	-8.37	-8.72
Organic soil. including dead wood and litter (CO_2)	0.35	1.02
Emissions from drainage (N_2O)	1.89	1.89
Emissions from drainage (CH_4)	0.91	0.91
Prescribed burning ($CO_{2.}$ $CH_{4.}$ N_2O)	0.00	0.00
N fertilization (N_2O)	0.01	0.01
Harvested wood products (CO_2)	-6.69	-6.31
Total without HWP	-13.14	-10.96
Total with HWP	-19.83	-17.27

Table 17. Development of the removals under projection between 2011-2050, where forest management continues as it was 2000-2009 (mill. m^3).

Drain (mill. m^3)	**2011-2015***	**2016-2020**	**2021-2025**	**2026-2030**	**2031-2040**	**2041-2050**
Total removal of stem wood	63.4	76.6	76.7	81.8	89.8	96.1
- Timber	55.1	70.9	70.9	76.1	84.1	90.4
- Stem wood for energy	8.3	5.7	5.7	5.7	5.7	5.6
- Timber for energy (from stem wood energy)	7.5	5.3	5.3	5.3	5.3	5.2
Wood chips + domestic fuelwood	12.8	10.1	10.1	10.8	11.9	12.7
Ratio between solid (HWP) and energy use of forest biomass [%] [(wood chips + domestic fuelwood) / timber]	23.3	14.3	14.3	14.2	14.2	14.1

* based on MELA modelling and best available data, i.e. actual loggings 2011-2015

It is important to note, that the long-term estimates (up to mid-century) for forest carbon net sink and GHG emissions have a high uncertainty as (i) up-dated information on future climate, forest disturbances and forest increment are expected to change, (ii) methodologies will be constantly developed, and (iii) MELA model is an empirical growth simulator and its growth functions have been developed based on long term historical data and may not represent future conditions. MELA growth and yield models have, however, been extensively tested in independent datasets (Haara and Leskinen 2009). Increment estimates of MELA model do not have constraints like increased disturbances reducing biomass stocks under changing climate. Currently, GHG inventory reports the uncertainty of 31% (95% confidence intervals) for forest carbon sink for Finland per year, including soil carbon stock change for mineral and organic soils (note that relative uncertainty varies year-to-year). These long-term projections have even higher uncertainty.

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

The model framework for changes in carbon stocks (Figure 3) is compatible and consistent with GHG inventory (NIR 2019 Section 6.4.2.1). The carbon pools and greenhouse gas sources included in the reference level were corresponding to the National Greenhouse Gas Inventory Report (NIR) submitted to the UNFCCC in April 2019. The NIR 2019 version was used due to fact that some methods employed by the Finnish GHG inventory were updated for the 2019 submission. These updates include namely, those for emission factors of N_2O emissions from drainage on organic soils (Ojanen et al. 2018) and those for the way how to use weather data with Yasso07 soil carbon model (Tuomi et al. 2011a).

In order to compare the consistency of methods between the GHG inventory and the FRL, estimates produced by the presented FRL modelling framework applied for years 2006-2010 were compared against GHG inventory results from same time period. This comparison was accomplished by comparing estimates with and without harvested wood products for Forest land remaining forest land. The GHG inventory and the FRL modelling framework used consistent methods. Biomass sinks for 2006-2010 were calculated by using increment minus drain method and separate biomass conversion and expansion factors for increment, loggings and for natural mortality. For stock changes of soil carbon (dead wood, litter and SOM) Yasso07 model was driven from 1975 to 2000 (up to 2002 for Northern Finland) with litter input and initial values from the calculations of the latest greenhouse gas inventory submission (NIR 2019). The organic soil calculation used litter input from 1990 to 2000 (up to 2002 for Northern Finland). The FRL modelling framework for changes in carbon stocks, in both mineral and organic soils was able to reproduce the results of the greenhouse gas inventory. The simulation of HWP was conducted from 2002 onwards as that of forest biomass sink. For estimating initial stocks for HWP pools for 2002, time series of HWP pools from GHG inventory were used to ensure the consistency between FRL estimation and that of GHG inventory.

In order to do comparison between GHG inventory results and FRL modelling framework, following criteria were applied:

- MELA model was run with 2 years' time steps from 2000 for Southern Finland and from 2002 for Northern Finland with NFI9 data.
- The interest rate of 3.5% were used in the objective function and relative thinning areas and relative final felling areas were given as constraints for simulation as in the FRL projection.
- The MELA simulation of forest management options followed 2006 management guidelines of Tapio (2006), complemented with forest act from 1997 (see 3.2.2), as in the FRL projection
- Yasso07 and GHG inventory methods were applied for time series with annual times step
- As natural mortality and wastewood statistics have a stepwise change from 2007 to 2008 due to a change in methods, GHG inventory results before 2008 were corrected in order to compare GHG inventory against the FRL modelling framework (Ihalainen 2013, Appendix 5). The estimation of natural mortality and wastewood after and including 2008 corresponds better to the FRL modelling framework.
- HWP estimation was initialized from 2002 from the stock reported in the GHG inventory.
- Years from 2002 to 2005 were excluded from the comparison due to the characteristic of the optimisation models like MELA that initial conditions affect results in the beginning of simulation periods and have higher uncertainty than in later simulation periods (which is not included in the uncertainty of GHG inventory) (Peltoniemi et al. 2006).
- The uncertainties of the GHG inventory time series were estimated (Appendix 3).
- Instead of using year 2009 in the comparison between GHG inventory and FRL simulation the mean of 2008 and 2010 was applied. This was done due to unexceptional wood market conditions prevailing during 2009 (Appendix 4).

As it has been earlier noticed that results based on the net present value optimisation are sensitive for the interest rate given for the objective function (Lehtonen et al. 2019), MELA was run for the period of 2006 – 2010 with interest rates of 2.5%, 3%, 3.5% and 4%. According to simulation total average loggings varied for 2006-2010 from 24, 41, 56 to 62 mill m^3 per year, respectively. This indicates that 3.5% is appropriate for interest rate for that period as it produces loggings that agree with the level of actual harvestings (2006: 56.9, 2007: 63.9, 2008: 58.3, 2009: 48.3, 2010: 59.7 Mm^3 (stat.luke.fi)).

4.3 Ex-post calibration for developing forest reference level

Results for forest carbon net sinks for 2006-2010 were thereafter compared with actual GHG-inventory results and an ex-post calibration coefficient was estimated based on cumulative sums of GHG-inventory results and MELA predictions from 2006-2010 (Table 18).

Table 18. Ex-post calibration, a ratio between estimated value for Finnish forests carbon sink and with corrected GHG inventory results for 2006–2010 (Appendix 4). For relative uncertainty of GHG inventory, see Appendix 3.

	2006 [Mt CO_2 eq.]	2007 [Mt CO_2 eq.]	2008 [Mt CO_2 eq.]	average 2008 & 2010 [Mt CO_2 eq.]	Total sum	ex-post calibration [GHG / MELA]
TOTAL (based on FRL modelling framework)	-24.44	-23.02	-29.72	-30.08	**-107.26**	
TOTAL with HWP (based on FRL modelling framework)	-30.00	-26.38	-31.42	-32.37	**-120.18**	
TOTAL (based on corrected GHG inventory), Appendix 5 and NIR 2019	-33.86	-23.30	-31.36	-31.66	**120.19**	**1.121**
TOTAL with HWP (based on corrected GHG inventory), Appendix 5 and NIR 2019	-38.63	-28.91	-33.14	-33.66	**-134.34**	**1.118**

4.4 Forest reference level for Finland

After ex-post calibration, those rates were applied with MELA and GHG inventory method based estimates, allowing estimation of calibrated forest reference levels for Finland (Table 19).

Table 19. FRL for Finnish forests before and after ex-post calibration (Mt CO_2 eq.). Ex-post calibration rate 1.121 was used for the GHG estimate for Finnish forest without HWP, while 1.118 was used for calibration for value with harvested wood products.

Carbon stock changes and other emissions	2021-2025	2026-2030
FRL before ex-post calibration without HWP	-18.88	-17.01
FRL before ex-post calibration with HWP	-24.73	-23.33
FRL after ex-post calibration without HWP	**-21.16**	**-19.06**
FRL after ex-post calibration with HWP	**-27.64**	**-26.07**

4.5 Technical corrections planned for forest reference level

During the submission of forest reference level following issues have been noticed that may trigger technical corrections for reference level.

- Deadwood will be reported as a separate pool (now included in SOM) when employed in GHG inventory.
- Definition of forest and thus area of managed forest land will be corrected to be comparable to GHG inventory when the forest definition according to Regulation 2018/841 is employed in the GHG inventory.
- Area of managed forest land will be corrected to remove any erroneous estimates of carbon development caused by differences between the assumed area development and the area development (afforested and deforested areas) that actually took place during 2021-2025.
- The biomass conversion and expansion factors (BCEFs) will be updated after they are recalculated (for the past) or updated in the GHG inventory to ensure consistency.
- If the conversion time of 30 years to afforestation is employed in the GHG inventory, it will trigger a technical correction to FRL.
- If the natural disturbances provision is applied, the FRL will be corrected and a background level based on the natural disturbances emissions 2001-2020 will be calculated.
- Any methodological changes employed to improve GHG inventory that would cause an inconsistency with the FRL will trigger a technical correction.

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Appendix 1. MELA model

1. MELA, a Finnish forestry model

MELA (acronym from the Finnish word MEtsäLAskelma, meaning in English forest calculation) is a forestry model and an operational decision support system developed for Finnish conditions for solving such problems as (i) what are the production potentials of forests, and (ii) how to manage forest stands in order to achieve the overall goals for forestry (Siitonen et al 1996). MELA consists of 1) a forest stand simulator based on individual tree growth and development models, and 2) an optimization package (Lappi 1992) based on linear programming. The current version is MELA2016 (Hirvelä et al 2017). In MELA, the management of forests is endogenic, i.e. for example the decision when and how to cut an individual management unit is a result of model run based on the user-defined goals and restrictions concerning the whole forestry unit over the planning period unless the user has not defined otherwise by giving special instructions for stands. The growth, felling regimes and the development of growing stock are thus the results of the analysis. MELA does not contain exogenous equations for timber supply and demand as a function of price and quantity, and in this respect MELA is a pure supply model and not an equilibrium model.

MELA has been used commonly in Finland for evaluating both future cutting potentials and the consequences of the use of timber on forest resources: e.g. National Forest Programme 2010 (1999), 2015 (2007), Regional Forest Programmes (1998, 2000-2001, 2004-2005, 2008, 2015), Evaluation of Finnish Biodiversity Program (2004), National Energy and Climate Strategy (2008, 2016), Report from Council of State for forest policy 2050 (2014), Energy and climate roadmap 2050, Report of the Parliamentary Committee on energy and climate issues (2014), National Forest Strategy 2025 (2015) and for evaluating FMRL of Kioto2 for Finland (2011). Since 1996, MELA has been also used in practical forest planning in the Forest Service, in forest companies and in the organizations of the non-industrial private forest owners.

2. Simulation of schedules for management units

MELA simulates automatically a finite number of feasible and alternative management schedules for the management (calculation) units, e.g. stands, sample plots, over the chosen calculation period according to the given simulation instructions. Management schedules differ from each other, for example, in timing and intensity of management activities. The automated branching of the simulation is controlled by general decision rules and simulation instructions. There are a large number of parameters available to define the application dependent options for example, concerning the events, length of the calculation period and the sub-periods, and the unit prices and costs.

The simulation of the management schedules for each management unit consists of states and events (Figure A1.1). The event parameter of the MELA makes it possible to define a set of optional events for each state causing the branching of alternative schedules (a simulation tree) for each management unit (Figure A1.2).The events are i) natural processes (ingrowth, growth and mortality of trees) and ii) management actions, e.g. cuttings, silvicultural treatments, simulated applying the built-in basic event routines of the MELA. After simulation MELA can be used to select from these management alternatives simultaneously both a production programme for the whole forest unit and treatments for the individual management units according to the optimization problem (goals and restrictions) defined by the user.

The development of the growing stock is predicted by a set of non-spatial tree-level empirical models embedded in MELA (Hynynen ym. 2002, Ojansuu ym. 1991, Ojansuu 1996, Hynynen 1996, Hökkä 1996, 1997, Hökkä ym. 1997, Hökkä ym. 2000, Nuutinen ym. 2000, Jutras ym. 2003, Nuutinen ym. 2004). Only the expected values of the models are used, and the stochastic variation in natural processes, for example in the growth of the trees, has not been taken into account. Main explanatory tree variables in these models are tree species, diameter at the breast height (d1.3), height, age and such stand variables as basal area, mean diameter, dominant height, site type, temperature sum, height above sea level and latitude. The effect of nutrient loss due to the collection of cutting residues is calculated as an inverse fertilization reaction based on Helmisaari et al. (2011) and Jacobsen & Kukkola (1999).

MELA contains also a module (transformation functions) that can be used to predict the change in the growth rate as a function of the increases in mean temperature and CO_2 concentration (Matala et al.2005). The functions are based on the results obtained from FinnFor process based model (Kellomäki & Väisänen 1997).

Note that for FRL calculations the tree basal-area growth models for forest land were calibrated using growth measurement data from NFI11. For calibration, growth measurements were adjusted with growth indices to the average level of diameter increment for years 1994–2013. (Korhonen et al. 2007) and the calibration was done with sample trees from NFI measured in years 2009–2013. The estimate of volume growth obtained using calibrated basal area growth was still adjusted up to the NFI11 measured growth level applying the above mentioned transformation functions of Matala et al. (2005) as described at the page 25 of this report.

Volume and timber assortments are obtained from stem curve models as a function of tree species, diameter and height (Laasasenaho 1982). The saw timber volume based stem curve models are corrected with saw timber reduction model (Mehtätalo 2002) to take into account also the observed flaws.

The calculation of biomasses as dry masses of stems, branches, foliage, stumps, and roots is based on the models of Repola (2008, 2009). These models use tree species, d1.3, and tree height as input variables. The calculation of carbon is based on these dry masses and the general 50 % carbon content (IPCC 2003). Note that in FRL estimation described in this report, biomass expansion factors from GHG inventory and sc. gains and losses method were applied.

The time consumptions and the costs of human events (logging and silviculture) are calculated in MELA using tree-wise empirical productivity models of Kuitto et al. (1994), Rummukainen et al. (1995), Väkevä et al. (2001), Labour agreement (2010), Laitila et al. (2004, 2007, 2010), Kärhä et al. (2004, 2006), Heikkilä et al. (2005) and unit costs given with parameters.

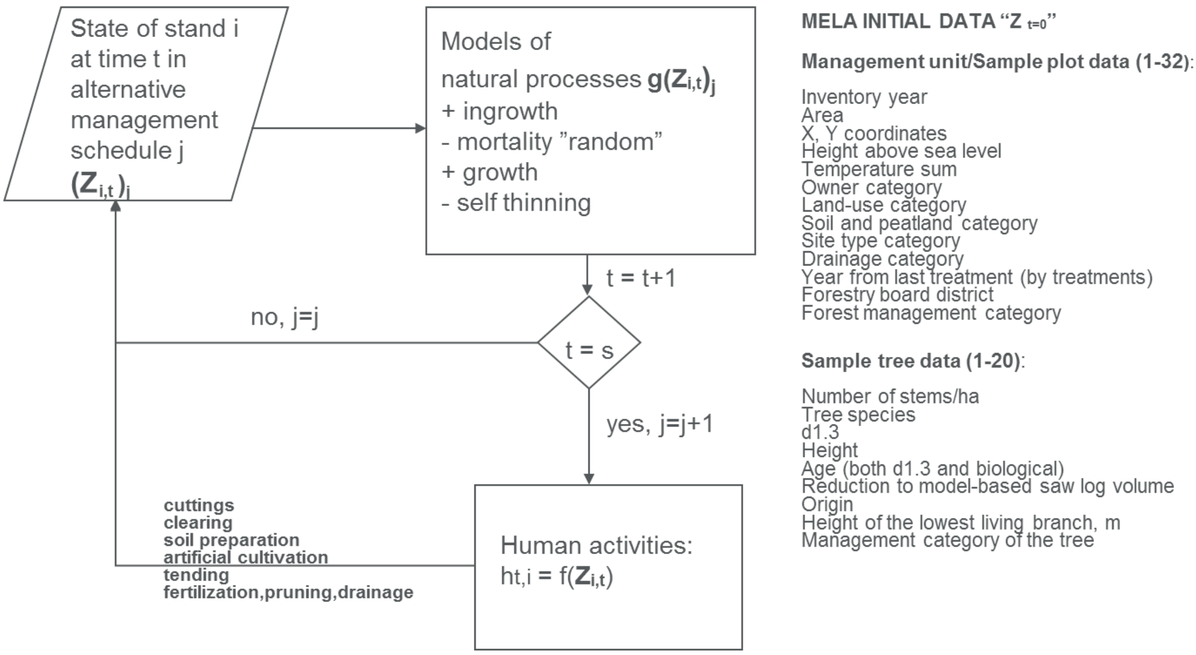

Figure A1.1. The simulation of management alternatives in MELA.

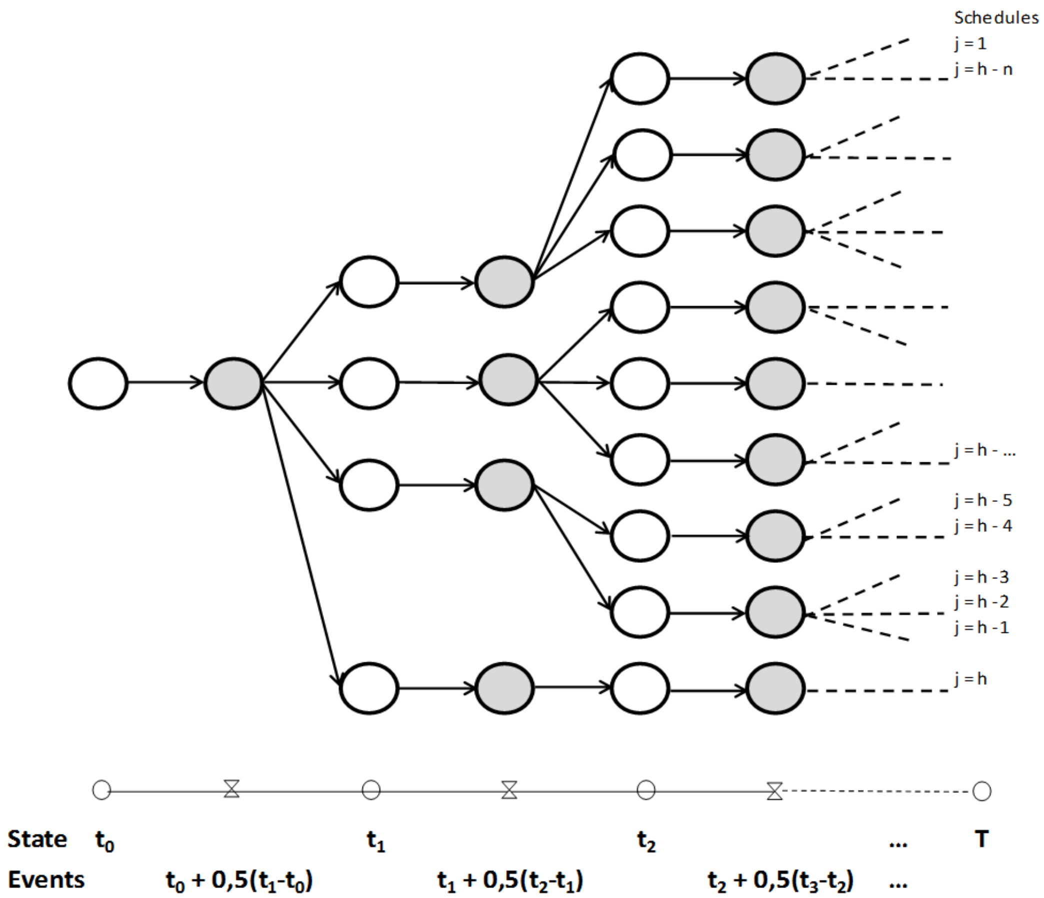

Figure A1.2. A scheme of simulation tree of schedules for each management unit as the product of MELA simulation.

The value of the wood is calculated by timber assortments (saw timber, pulpwood) and energy wood fractions (round wood, logging residues and stumps) with corresponding unit prices and volumes. The calculations are made using stumpage prices as well as road-side prices for industrial wood and for energy wood prices at the mill.

3. Comparison of management alternatives

In MELA, linear programming (Lappi 1992) is applied to select simultaneously forest (production program) and management unit level (management proposal) solutions. Thus instead of concerning only an individual stand (stand level analysis), the forest level strategic aspects are important (forest level analysis), and therefore the optimal solution is received simultaneously for the whole forestry unit and individual stands (integrated stand and forest level analysis).

The optimisation problem is open in MELA, and the users are able to define by themselves the desired objective function and the constraints. There are available approximately 1 000 conventional decision data variables for each sub-period, for example, volume, increment, drain and cutting removal by tree species and timber assortments, value, areas of different treatments and land categories, gross income, costs, net income, net present value discounted with different interest rates, etc. In addition, data collection requests can be used to generate additional decision data variables for the optimization or for the compilation of reports.

Table A1.1 Diameters based on the act 224/1997 and silvicultural guidelines by Tapio (2006) used to categorize stands as thinning stands or mature stands

	$D_{1.3}$ of thinning stand, cm				$D_{1.3}$ of mature stand, cm			
Site type	SF	CF	NF	NF (Lapland)	SF	CF	NF	NF (Lapland)
Very rich -rich	8 < 27	8 < 27	8 < 25	8 < 23	≥ 27	≥ 27	≥ 25	≥ 23
Mesic	8 < 27	8 < 26	8 < 25	8 < 23	≥ 27	≥ 26	≥ 25	≥ 23
Sub dry	8 < 25	8 < 25	8 < 24	8 < 23	≥ 25	≥ 25	≥ 24	≥ 23
Dry - Barren	8 < 23	8 < 23	8 < 22	8 < 22	≥ 23	≥ 23	≥ 22	≥ 22

MELA LP tasks definitions according to the FMP's 2000-2009 for FRL determination of Finalnd

			Southern Finland	Central Finland	Northern Finland	*Notes*
A) Objective function	Maximize Net Present value 3.5%					
subjet to						
B) Constraints						
*** Realized fellings (± 0.5 %) in 2011-2015, 1000 m³/y**						
	0.995*Total_roundwood_removal_1	≤	27461.6	22657.8	13665.4	(1
	1.005*Total_roundwood_removal_1	≥	27461.6	22657.8	13665.4	
	*					
	0.995*Total_energywood_removal_1	≤	6026.4	4635.8	2103.0	(2
	1.005*Total_energywood_removal_1	≥	6026.4	4635.8	2103.0	
	*					
	0.995*Industrial_roundwood_Pine_1	≤	8574.4	8697.0	8003.6	
	1.005*Industrial_roundwood_Pine_1	≥	8574.4	8697.0	8003.6	
	0.995*Pine_sawlog_1	≤	4169.2	3393.8	2665.8	
	1.005*Pine_sawlog_1	≥	4169.2	3393.8	2665.8	
	0.995*Industrial_roundwood_Spruce_1	≤	11459.4	7307.6	2048.4	
	1.005*Industrial_roundwood_Spruce_1	≥	11459.4	7307.6	2048.4	
	0.995*Spruce_sawlog_1	≤	7150.4	4235.6	802.2	
	1.005*Spruce_sawlog_1	≥	7150.4	4235.6	802.2	
	0.995*Industrial_roundwood_Dec.trees_1	≤	3425.8	3547.2	1860.8	
	1.005*Industrial_roundwood_Dec.trees_1	≥	3425.8	3547.2	1860.8	
*** Realized felling areas (± 2.5 %) in 2011-2015, 1000 ha/y**						
	0.975*total_felling_area	≤	219.8	216.5	219.2	
	1.025*total_felling_area	≥	219.8	216.5	219.2	
	0.975*Final_felling_area	≤	52.7	46.1	52.4	
	1.025*Final_felling_area	≥	52.7	46.1	52.4	
*** Felling area as a percentage of consequent development class acreage in 2000-2009; constraints for the periods 2-7 in 2016-2061**						
Thinnings by periods 2-7						
2016-2020	0.01*tha%*Thinning_stand_acreage_1 - Thinning_area_2	≥	0.	0.	0.	3) tha%
2021-2025	0.01*tha%*Thinning_stand_acreage_2 - Thinning_area_3	≥	0.	0.	0.	
2026-2030	0.01*tha%*Thinning_stand_acreage_3 - Thinning_area_4	≥	0.	0.	0.	
2031-2040	0.01*tha%*Thinning_stand_acreage_4 - Thinning_area_5	≥	0.	0.	0.	
2041-2050	0.01*tha%*Thinning_stand_acreage_5 - Thinning_area_6	≥	0.	0.	0.	
2051-2060	0.01*tha%*Thinning_stand_acreage_6 - Thinning_area_7	≥	0.	0.	0.	
Final fellings by periods 2-7						
2016-2020	0.01*ffa%*Area_of_Mature_stands_1 - Area_of_final_fellings_2	≥	0.	0.	0.	4) ffa%
2021-2025	0.01*ffa%*Area_of_Mature_stands_2 - Area_of_final_fellings_3	≥	0.	0.	0.	
2026-2030	0.01*ffa%*Area_of_Mature_stands_3 - Area_of_final_fellings_4	≥	0.	0.	0.	
2031-2040	0.01*ffa%*Area_of_Mature_stands_4 - Area_of_final_fellings_5	≥	0.	0.	0.	
2041-2050	0.01*ffa%*Area_of_Mature_stands_5 - Area_of_final_fellings_6	≥	0.	0.	0.	
2051-2060	0.01*ffa%*Area_of_Mature_stands_6 - Area_of_final_fellings_7	≥	0.	0.	0.	
*** Non-declining industrial roundwood removal between the subsequent periods 2-7 in 2016-2061**						
	Industrial_roundwood_3 - Industrial_roundwood_2	≥	0.	0.	0.	
	Industrial_roundwood_4 - Industrial_roundwood_3	≥	0.	0.	0.	
	Industrial_roundwood_5 - Industrial_roundwood_4	≥	0.	0.	0.	
	Industrial_roundwood_6 - Industrial_roundwood_5	≥	0.	0.	0.	
	Industrial_roundwood_7 - Industrial_roundwood_6	≥	0.	0.	0.	
*** Constant ratio of industrial wood removals and energy wood removals in 2000-2009; constraints for the periods 2-7 in 2016-2061**						
2016-2020	0.01*ew%*Industrial_roundwood_2 - Total_energywood_remova	≥	0.	0.	0.	5) ew%
2021-2025	0.01*ew%*Industrial_roundwood_3 - Total_energywood_remova	≥	0.	0.	0.	
2026-2030	0.01*ew%*Industrial_roundwood_4 - Total_energywood_remova	≥	0.	0.	0.	
2031-2040	0.01*ew%*Industrial_roundwood_5 - Total_energywood_remova	≥	0.	0.	0.	
2041-2050	0.01*ew%*Industrial_roundwood_6 - Total_energywood_remova	≥	0.	0.	0.	
2051-2060	0.01*ew%*Industrial_roundwood_7 - Total_energywood_remova	≥	0.	0.	0.	
*** From the total energy wood removal at least households' fuelwood is composed of stem wood**						
	1.005*Stem_energywood_2	≥	2483.	1819.	990.	
	1.005*Stem_energywood_3	≥	2483.	1819.	990.	
	1.005*Stem_energywood_4	≥	2483.	1819.	990.	
	1.005*Stem_energywood_5	≥	2483.	1819.	990.	
	1.005*Stem_energywood_6	≥	2483.	1819.	990.	
	1.005*Stem_energywood_7	≥	2483.	1819.	990.	
	*					

Notes:

[1] ***Total_roundwood_removal*** consists of industrial roundwood (saw log and pulpwood) and stems used to energy

[2] ***Total_energywood_removal*** consists of stems used to energy, cutting residues and stumps

[3] ***Thinning per cent (tha%)*** for Southern Finland 4.5, for Central Finland 3.4 and for Northern Finland 1.9

[4] ***Final felling per cent (ffa%)*** for Southern Finland 5.8, for Central Finland 8.6 and for Northern Finland 7.1

[5] ***Constant ratio of energywood (ew%)*** for Southern Finland 16.1, for Central Finland 14.4 and for Northern Finland 11.1

Appendix 2. Restrictions for wood production in MELA model

Restrictions for wood supply	**Restricted wood supply[1)]**	**No wood supply**
Areas based on the Nature Conservation Act		
National parks and Strict Nature Reserves		x
Areas belonging Mire Conservation Programme, Herb-rich Forest Conservation Programme, and Programme for the Protection Old-Growth Forests		x
Areas having protected habitat types	x	x
Areas based on landscape conservation	x	x
Areas based on other legislation		
Wilderness areas	x	x
Hiking routes and state owned hiking areas	x	
Areas having species of special concern	x	x
Other protected areas based on legislation	x	x
Areas based on owner's own decisions		
Classified (protected) forests of Metsähallitus (State Forest and Park Service)		x
Regional landscape ecology areas of Metsähallitus	x	x
Timber line protective forest areas owing Metsähallitus	x	
Areas reserved for forest tree breeding, research or demonstration	x	x
Military rehearsal areas	x	x
Other habitat/species management areas e.g. recreation areas	x	x
Fixed term private-owned protected areas e.g. areas based on the Forest Biodiversity Programme for Southern Finland (METSO)	x	x
Areas reserved for conservation		
Areas belonging into National park and Strict Nature Reserve development programmes		x
Areas belonging into the development plans of the Mire Consevation Programme, Herb-rich Forest Conservation Programme, and Programme for the Protection Old-Growth Forests		x
Areas belonging into the Waterfowl Habitats Conservation Programme, Esker Conservation Programme, Shore Conservation Programme	x	x
Other areas reserved for conservation based on decisions in principle of the Finnish Council of State		x
Land use planning areas		
Areas having regional plan, local master plan, local detailed (municipality) plan or shoreline master plan	x	x
Other areas		
Other restrictions based on decisions of Metsähallitus not listed above	x	x
Other areas (small) having impacts on the forestry e.g. habitats of special importance to forest biodiversity, shorelines, immediate vicinity of settlement etc.	x	
Low productive forest land (scrub land)		x
1) Only thinnings are allowed, thus no final fellings		
2) In MELA calculations no logging events on scrub land		

Appendix 3 Uncertainty of GHG inventory for period 2000 – 2013

Within period 2000 – 2013, uncertainty of annual estimates of the Finnish GHG inventory (NIR 2019) concerning net emissions/removals over the pools and sources included in the reference level varied between 32.8% and 45.7% so that the percent uncertainty decreased when the sink increased, but the absolute uncertainty remained nearly constant (Table A3.1, Figure A3.1).

Table A3.1. Mean emissions and removals, Mt CO2 eq., included into forest reference level of Finland over two years' periods in 2000 - 2013 based on NIR (2019); uncertainties (twice the relative standard errors of the estimates, %) in *italic font*.

Emissions and removals	**2000 -2001**	**2002 -2003**	**2004 -2005**	**2006 -2007**	**2008 -2009**	**2010 -2011**	**2012 -2013**
Living biomass (CO_2)	-28.86 *18.10*	-32.64 *16.27*	-36.95 *14.50*	-38.91 *14.04*	-44.51 *13.03*	-36.40 *16.90*	-33.53 *18.81*
Mineral soils (CO_2)	-8.51 *31.50*	-7.25	-6.35	-5.47	-5.20	-5.13	-6.85
Organic soils (CO_2)	8.37 *150.0*	8.03	8.00	7.97	7.51	6.73	6.09
Emissions from drainage (CH_4)	1.26 *82.00*	1.20	1.14	1.08	0.98	0.87	0.84
Emissions from drainage (N_2O)	1.98 *80.00*	1.97	1.96	1.95	1.94	1.92	1.92
Prescr. burning (CO_2, CH_4, N_2O)	0.0017 *0*	0.0021	0.0007	0.0009	0.0007	0.0004	0.0005
N fertilization (N_2O)	0.0079 *0*	0.0088	0.0088	0.0134	0.0231	0.0168	0.0124
Harvested wood products (CO_2)	-5.41 *50.00*	-4.82	-3.69	-5.19	-0.07	-2.18	-2.02
FRL without HWP	-25.76 *54.30*	-28.68 *47.05*	-32.18 *41.71*	-33.35 *40.13*	-39.25 *32.86*	-31.99 *37.67*	-31.53 *36.28*
FRL with HWP	-31.16 *45.71*	-33.50 *40.92*	-35.87 *37.77*	-38.54 *35.37*	-39.32 *32.80*	-34.17 *35.41*	-33.55 *34.23*

For CO_2 emissions/removals due to changes in dead wood, litter and organic soil matter, uncertainty values 31.5% for mineral soils and 150% for organic soils were obtained from NIR (2019, 6.4.3.2). For non-CO_2 emissions, uncertainties 82% (CH_4) and 80% (N_2O) were reported in NIR (2019, 6.10.2.3). The effect of contributions of emissions from prescribed burning and N fertilization to the reference level was considered negligible, and 0 uncertainty was applied. Uncertainty of 50% for the CO_2 due to harvested wood products was obtained from NIR (2019, 6.11.3).

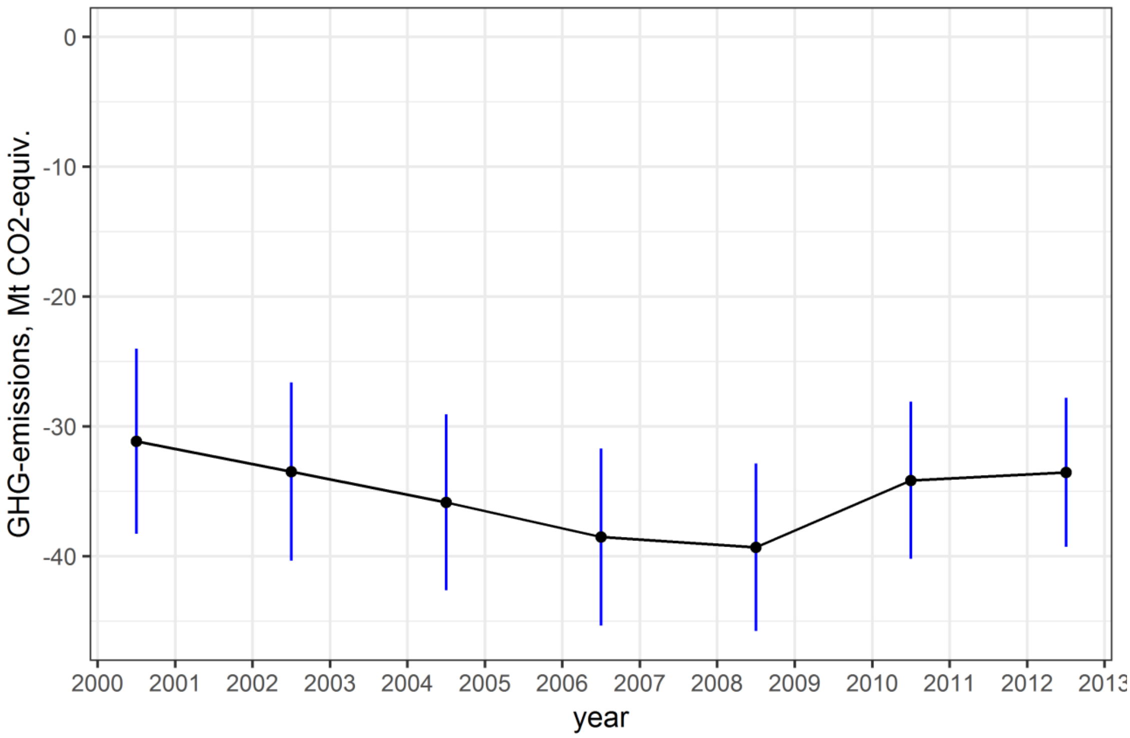

Figure A3.1. Net emissions over pools and sources included into forest reference level (Table A3.1) together with error bars (blue) extending one standard error above and below the estimated value.

Relative uncertainty of all components contributing to the net change in living biomass is fairly constant and it is rather small for the main components: increment and fellings. Uncertainty of their difference is substantially greater and the relative uncertainty of the difference increases, when the difference itself decreases (Table A3.2).

Table A3.2. Mean changes in living biomass, Mt/a, on total forest land over two years' periods in 2000 - 2013 based on NIR (2019); uncertainties, U (twice the relative standard errors of the estimates, %) in *italic font*.

	2000 -2001	**2002 -2003**	**2004 -2005**	**2006 -2007**	**2008 -2009**	**2010 -2011**	**2012 -2013**
Increment	64.53	66.70	68.58	70.06	71.52	72.58	73.39
sampling U	*1.34*	*1.34*	*1.34*	*1.34*	*1.35*	*1.35*	*1.36*
Fellings	-46.15	-46.18	-45.63	-46.06	-42.85	-48.15	-50.43
sampling U	*5.91*	*5.92*	*5.94*	*5.97*	*6.68*	*6.61*	*6.58*
Natural losses	-2.05	-2.14	-2.23	-2.23	-3.83	-3.83	-3.83
sampling U	*14.70*						
Net change	16.32	18.38	20.71	21.78	24.85	20.60	19.13
sampling U	*17.63*	*15.74*	*13.90*	*13.43*	*12.36*	*16.39*	*18.35*
model U	*4.12*						
total U	*18.10*	*16.27*	*14.50*	*14.04*	*13.03*	*16.90*	*18.81*

Uncertainty of annual estimates of the increment in living biomass was propagated from region-, soil-, and species-specific increment series and their uncertainty in the same way as in NIR (2016, Table 6.4-7). Although the same uncertainty values were applied throughout the series, there was slight variation in the total uncertainty due to changes in the structure of increment (Table A3.3).

Uncertainty due to NFI sampling for the biomass expansion and conversion factors of fellings was propagated similarly (cf. NIR 2016, Table 6.4-8) and uncertainty of 5% in annual volumes of commercial timber removals (NIR 2016, 6.4.3.1) was added to the total (Table A3.4).

Sampling uncertainty 14.7% of unrecovered natural losses (NIR 2016, 6.4.3.1) was applied throughout the time series. Parameter uncertainty associated with the biomass models, 4.12% (NIR 2016, Table 6.4-10), was added to the sampling uncertainty of the net change.

Table A3.3 Mean increment of living biomass, Mt/a, on total forest land over two years' periods in 2000 - 2013 based on NIR (2019); uncertainties, U (twice the relative standard errors of the estimates, %) in *italic font*.

Region	**Soil**	**Species**	**2000 -2001**	**2002 -2003**	**2004 -2005**	**2006 -2007**	**2008 -2009**	**2010 -2011**	**2012 -2013**
south	mineral	pine	11.98 *2.30*	12.54	12.78	12.79	12.82	12.97	13.16
		spruce	13.69 *2.90*	13.86	14.28	14.91	15.51	15.89	16.25
		deciduous	9.79 *3.10*	10.21	10.63	11.04	11.44	11.70	11.95
	organic	pine	3.71 *3.10*	3.86	3.88	3.82	3.78	3.80	3.82
		spruce	2.87 *5.70*	2.97	3.03	3.05	3.09	3.28	3.50
		deciduous	2.97 *4.90*	3.00	3.04	3.10	3.12	2.99	2.83
north	mineral	pine	7.42 *6.20*	7.91	8.25	8.20	8.15	8.28	8.57
		spruce	2.49 *7.60*	2.64	2.76	2.88	2.98	3.03	3.03
		deciduous	3.10 *8.50*	2.94	2.91	3.12	3.35	3.45	3.43
	organic	pine	3.13 *3.80*	3.33	3.48	3.47	3.47	3.38	3.21
		spruce	1.24 *8.70*	1.38	1.50	1.55	1.59	1.61	1.59
		deciduous	2.17 *6.30*	2.09	2.06	2.16	2.26	2.23	2.07
total			64.53	66.70	68.58	70.06	71.53	72.58	73.39
			1.34	1.34	1.34	1.34	1.35	1.35	1.36

Table A3.4 Mean biomass of fellings, Mt/a, on total forest land over two years' periods in 2000 - 2013 based on NIR (2019); uncertainties, U (twice the relative standard errors of the estimates, %) in *italic font*.

Region	**Soil**	**Species**	**2000 -2001**	**2002 -2003**	**2004 -2005**	**2006 -2007**	**2008 -2009**	**2010 -2011**	**2012 -2013**
south	mineral	pine	9.58	9.84	9.43	10.18	8.96	10.17	10.75
			1.20						
		spruce	16.19	15.70	15.22	14.67	11.21	12.92	13.61
			1.40						
		deciduous	6.28	6.31	6.31	6.55	8.78	9.59	9.91
			10.10						
	organic	pine	1.42	1.46	1.39	1.49	1.30	1.48	1.59
			1.90						
		spruce	2.17	2.10	2.03	1.96	1.50	1.74	1.84
			4.70						
		deciduous	1.55	1.56	1.57	1.60	2.14	2.33	2.42
			7.10						
north	mineral	pine	4.41	4.49	4.63	4.65	4.08	4.52	4.65
			2.70						
		spruce	1.46	1.54	1.72	1.55	1.08	1.26	1.24
			4.80						
		deciduous	1.13	1.18	1.21	1.25	1.56	1.68	1.85
			11.70						
	organic	pine	0.66	0.65	0.68	0.70	0.63	0.70	0.72
			3.40						
		spruce	0.38	0.39	0.45	0.41	0.29	0.34	0.33
			6.40						
		deciduous	0.92	0.95	0.98	1.04	1.31	1.41	1.52
			4.00						
total			46.15	46.18	45.63	46.06	42.85	48.15	50.43
U in BCEF due to NFI			*3.15*	*3.16*	*3.20*	*3.26*	*4.43*	*4.32*	*4.28*
U in logging statistics			*5.00*						
total U			*5.91*	*5.92*	*5.94*	*5.97*	*6.68*	*6.61*	*6.58*

Uncertainty propagation for the totals was based on Equation 3.2 in IPCC (2006). Different sources of uncertainty affecting the same estimate (e.g., sampling and model error) were combined assuming independence: If x is an estimate affected by independent uncertainties U_1 and U_2 (twice the standard error as percentage of x), then

$$x = X + \varepsilon_1 + \varepsilon_2,$$

where X is the true quantity and ε_1 and ε_2 are independent random variables with variances

$$\sigma^2{}_i = (U_i x/200)^2,$$

and the total uncertainty of x is

$$U = \frac{200\sqrt{\sigma^2}}{x} = \frac{200\sqrt{{\sigma^2}_1 + {\sigma^2}_2}}{x} = \sqrt{{U_1}^2 + {U_2}^2},$$

where $\sigma^2 = {\sigma^2}_1 + {\sigma^2}_2$ is the variance of x.

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Appendix 4. Year 2009 in Finnish forest sector.

In many ways, 2009 was an exceptional year for the Finnish forest sector. Firstly, year 2009 was the bottom of the recession for the Finnish forest industry. The production volumes of forest industry products dropped sharply compared to 2008: sawnwood -23 per cent, plywood -62 per cent, wood pulp -31 per cent, paper -26 per cent, and paperboard -16 per cent (Fig. A4.1). In fact, the production volumes were - except for paper - the lowest in the 2000's and 2010's. The main underlying reason for the decrease in forest industry's production was the global financial crisis of 2008 and the following Great Recession, which were reflected in the export demand for forest industry products.

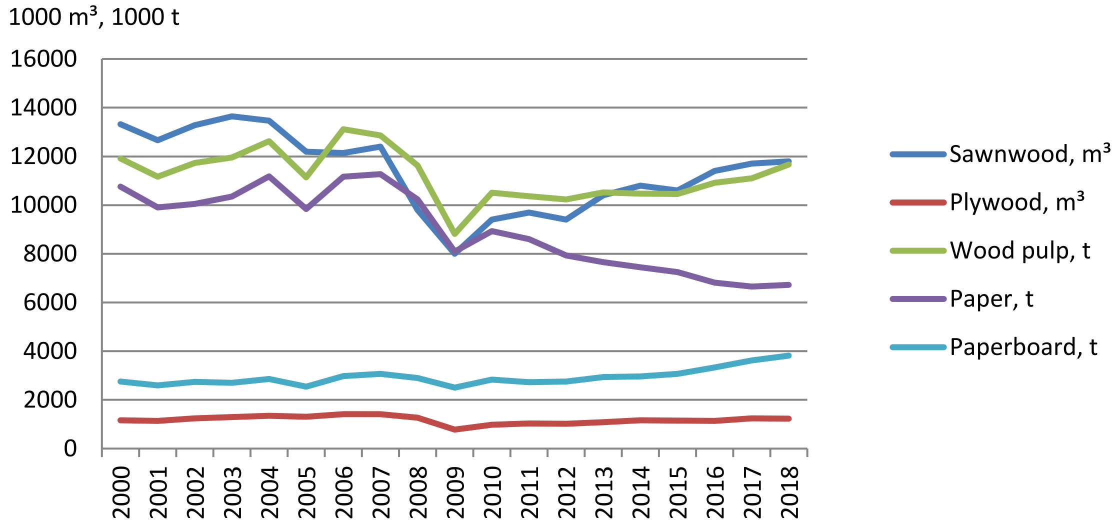

Figure A4.1. Production of forest industry products in Finland (Luke 2019a).

Secondly, in the pulp and paper industry, the drop in production volumes - induced by the weak export demand - was enhanced by the massive closures of production capacity. The closures were a reaction to the evident structural downward trend in paper consumption in Europe due to the rise of digitalisation. The start of restructuring of pulp and paper industry is typically identified with the closure of Voikkaa paper mill in 2006. The peak of closures were years 2008 and 2009, when roughly 1.30 mill. tonnes of paper production capacity (mainly newsprint and magazine paper) and 1.0 mill. tonnes of pulp production capacity (soft- and hardwood Kraft pulp, chemi-thermomechanical pulp) was shut down permanently in Finland (Finnish Statistical Yearbook... 2009, Finnish Statistical Yearbook... 2010). The closures of paper production capacity continued in the following years. Decreases of production capacity had a direct impact on the use of roundwood.

Thirdly, in addition to the decrease of demand for forest industry products and the permanent closures of production capacity, the fellings in 2009 were also affected by the plans of the Russian Federation to increase export duties on roundwood. The Finnish forest industry started importing increasing volumes of roundwood in the 1990's from Russia. At first, the main import article was birch pulpwood. In the late 1990's and early 2000's, the import volumes of softwood, and softwood logs especially, grew. In the peak year 2005, 21 mill. m^3 of roundwood was imported into Finland, and 80 per cent of the import volume originated from Russia (Finnish Statistical Yearbook... 2010). Imported roundwood had become an integral part of wood procurement, and the share of imported wood of the total wood consumption by the Finnish forest industry was the highest, about one fourth, in 2005.

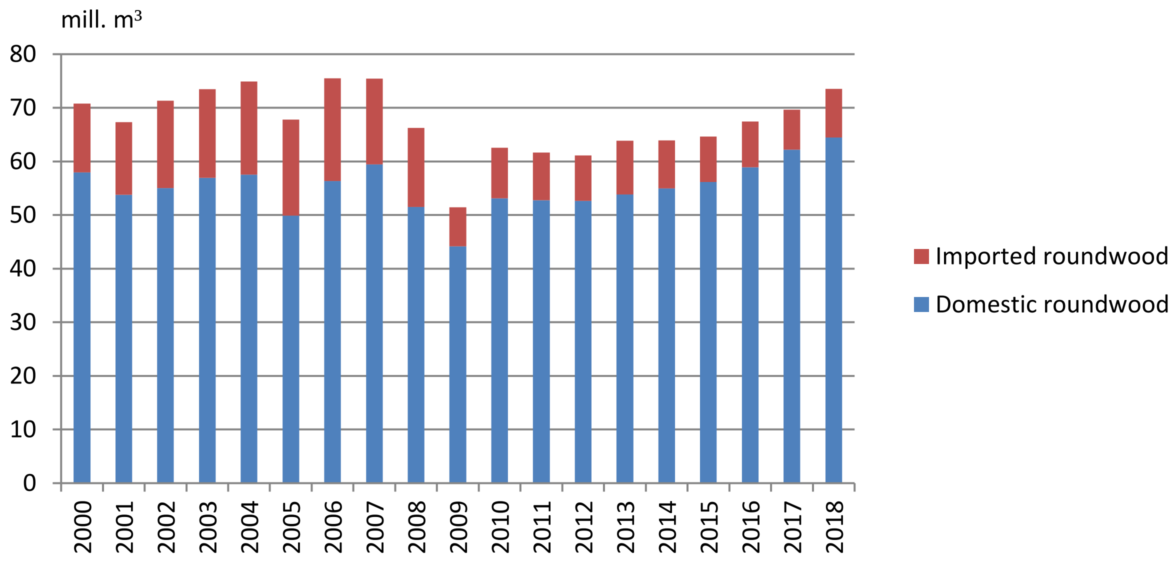

Figure A4.2. Consumption of domestic and imported roundwood by the Finnish forest industry (Luke 2019b).

However, political pressure on restricting the exports of roundwood grew in Russia, and according the governmental decree issued in February 2007, the export duties on roundwood would be gradually increased in such a way that in the beginning of 2009, the minimum export duty for softwood timber assortments and birch logs having a diameter over 15 cm would have been EUR 50 per cubic metre. Minimum duty level of EUR 50 per cubic metre would have been levied on birch of diameter under 15 cm as well as on aspen from January 1st 2011 onwards. The minimum export duties of EUR 50 per cubic metre would practically have stopped imports of roundwood from Russia into Finland. Two duty increases were implemented in July 2007 and in April 2008, and the threat of further increases in the beginning of 2009 was obvious. As a result, companies were trying to import wood as much as possible from Russia in 2008, as they could not be sure how much and at what price wood would be available in Finland in 2009. Consequently, the stocks of imported roundwood grew considerably in the late 2008, and this decreased the need for domestic wood in 2009. A governmental decree of postponing the highest raises of minimum export duties was issued in Russia on December 24th 2008 and the raises were repeatedly postponed until the WTO membership of the Russian Federation in August 2012. (Mutanen & Viitanen 2017)

Notwithstanding the somewhat stabilised situation regarding Russian roundwood trade policies, the post-2008 Finnish roundwood import volumes have remained on a much lower lever than earlier, as forest industry has been reluctant to rely on the availability of Russian roundwood. The share of imported roundwood of the total roundwood consumption by the Finnish forest industry has decreased from 26 per cent in 2005 to 11–16 per cent in 2009–2018.

In 2009, several overlapping and mutually reinforcing factors contributed to the removals of industrial wood, which were reduced by 20 per cent compared to 2008 (Luke 2019c). Indeed, the drop of one fourth in annual felling volumes of industrial wood was historically large: a decrease of comparable size was experienced only in 1991, when Finland was entering its worst recession since gaining independence, and when private forest owners organised a so called wood sales “strike” (Mutanen & Toppinen 2005). The considerable drop in felling volumes in 2009 was, however, temporary. Already in 2010, the removals of industrial wood rebounded and even exceeded the level of 2008 (Luke 2019c).

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Appendix 5. Modification of natural mortality- and wastewood statistics and GHG inventory

The drain estimate used in the GHG inventory is obtained directly from the official statistics (stat.luke.fi) (Figure A5.1). The official statistics are updated when new information is available, but do not recalculate the previous years. This causes the drain to change stepwise which does not describe the actual harvesting practices or natural processes. This is especially seen regarding natural mortality and harvest losses. A major change in the statistics was made in 2008, meaning that the natural mortality and harvest losses are calculated differently from 2007 backwards[1]. The data since 2008 is more reliable and describes the period of 2000-2007 better than the one used in the statistics, because it is based on NFI9 permanent plots (established in 1996-2003, remeasured in NFI10 2004-2008) (Ihalainen 2013).

The modeling approach cannot reproduce the artificial changes due to updates in the statistics. This is why the effect of the update in the natural mortality and harvest losses was calculated, ie. what would the results of the GHG inventory be, if the harvesting losses and natural mortality were calculated in the same way for the period of 2000-2007 as after 2008 (Table A5.1). This was necessary to do before the ex-post calibration, because the change in statistics affects only years before 2008 compared to MELA modeling and is not a modeling discrepancy that would affect years 2021-2015.

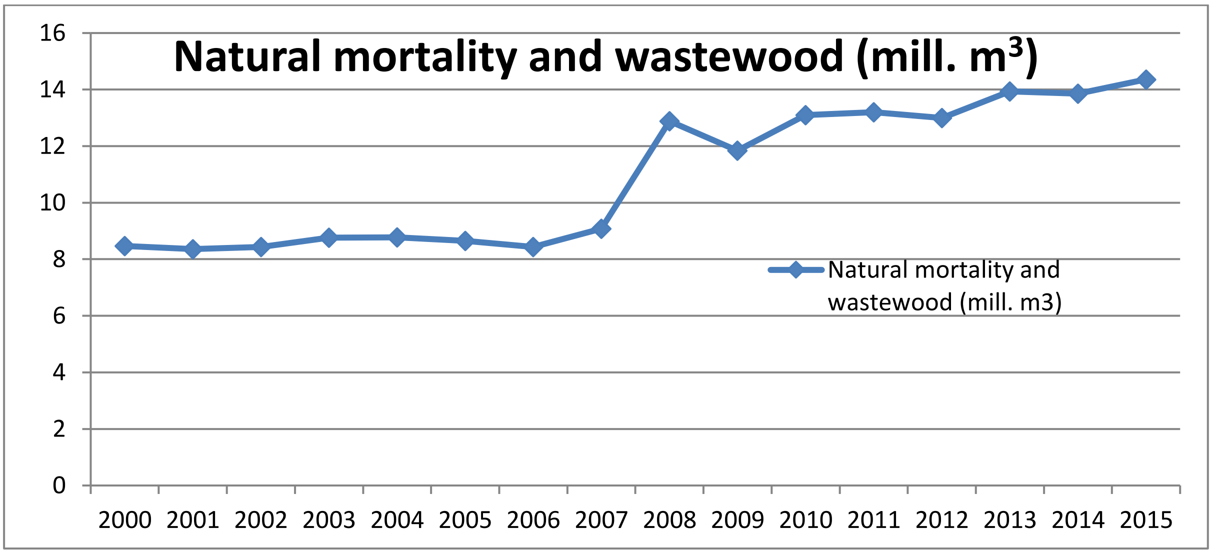

Figure A5.1 Time series of natural mortality and wastewood 2000-2015 according to statistics (stat.luke.fi).

	2006	2007
Biomass	-5.72	-6.13
Mineral soils, dead wood (CO_2)	1.35	0.61
Drained peat soils (CO_2)	0.17	0.19
Total impact	-4.20	-5.34

Table A5.1 Impact of corrected natural mortality and wastewood time series for GHG-inventory 2006-2007 in Mt CO_2.

References

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Appendix 6. Development of area and stem volume estimates based on NFI data and MELA prediction for 2000 – 2051

Table A6.1 Area of forest land available for wood supply by development classes and by regions for Finland, mill. ha. Note that gray columns are based on NFI9 – NFI11 data.

Region	Group	2000	2006	2011	2016	2021	2026	2031	2041	2051
South	Mature	1.06	0.99	1.05	1.24	1.23	1.26	1.26	1.31	1.31
South	Thinning stands	2.84	2.86	2.92	2.86	2.90	2.75	2.60	2.55	2.57
South	Other	1.19	1.17	1.10	0.97	0.93	1.05	1.21	1.21	1.18
Central	Mature	0.69	0.63	0.67	0.90	0.89	0.93	0.95	1.01	1.11
Central	Thinning stands	3.52	3.68	3.78	3.74	3.77	3.65	3.46	3.15	3.13
Central	Other	1.64	1.46	1.30	1.10	1.09	1.17	1.34	1.59	1.51
North	Mature	0.93	0.79	0.67	0.88	0.88	0.99	1.14	1.43	1.65
North	Thinning stands	5.14	5.12	5.43	5.43	5.26	5.13	4.93	4.48	4.26
North	Other	2.15	1.87	1.51	1.30	1.47	1.49	1.54	1.70	1.70
TOTAL		19.17	18.59	18.42	18.42	18.42	18.42	18.42	18.42	18.42

Table A6.2 Stem volume of forest land available for wood supply by development classes and by regions for Finland, mill. m^3. Note that gray columns are based on NFI9 – NFI11 data.

Region	Group	2000	2006	2011	2016	2021	2026	2031	2041	2051
South	Mature	246.5	243.4	263.0	268.2	254.4	259.4	256.3	258.8	275.3
South	Thinning stands	436.8	458.4	470.2	479.9	504.8	520.6	535.1	537.6	559.2
South	Other	45.3	39.0	30.5	29.6	31.6	26.6	24.9	28.0	24.0
Central	Mature	152.3	147.4	165.1	185.0	163.4	163.5	164.1	169.3	178.4
Central	Thinning stands	436.0	483.1	526.6	540.7	575.5	599.7	616.8	609.9	611.0
Central	Other	44.4	41.8	28.6	26.0	31.7	27.3	25.0	37.0	30.5
North	Mature	98.4	87.1	83.9	92.6	88.1	100.6	122.6	157.4	175.8
North	Thinning stands	404.8	436.2	495.3	543.7	574.2	610.3	627.9	640.7	644.0
North	Other	51.1	43.2	26.5	22.0	37.8	32.8	27.9	34.6	35.4
TOTAL		1915.5	1979.5	2089.7	2187.5	2261.6	2340.9	2400.6	2473.3	2533.6

Table A6.3 Cutting removal of stem wood by felling methods from the forest land available for wood supply by development classes for Finland, mill. m^3/year based on MELA simulations.

	2011-2015	2016-2020	2021-2025	2026-2030	2031-2040	2041-2050
Thinnings	25.7	24.8	25.4	26.3	30.1	29.6
Final fellings	36.6	50.7	48.6	51.8	58.2	64.7
Other (e.g. removal of seed trees)	1.1	1.3	2.8	3.8	1.6	1.8

Table A6.4 Cutting removal of stem wood by felling methods by sub-regions from the forest land available for wood supply by development classes and regions, mill. m^3/year based on MELA simulations.

		2011-2015	2016-2020	2021-2025	2026-2030	2031-2040	2041-2050
South	Thinnings	9.7	9.5	8.9	9.6	11.8	11.6
South	Final fellings	17.1	20.1	20.2	21.1	22.5	23.6
South	Other (e.g. removal of seed trees)	0.5	0.7	1.1	1.4	0.5	0.5
Central	Thinnings	10.0	8.2	9.0	9.2	10.8	10.7
Central	Final fellings	12.3	19.8	18.4	19.1	21.3	23.0
Central	Other (e.g. removal of seed trees)	0.3	0.4	1.0	1.5	0.5	0.8
North	Thinnings	6.0	7.1	7.4	7.5	7.6	7.3
North	Final fellings	7.2	10.9	10.0	11.6	14.3	18.2
North	Other (e.g. removal of seed trees)	0.3	0.2	0.8	0.9	0.6	0.6