Ministry of Agriculture and Forestry (MMM)

Natural Resources Institute Finland (Luke)

National Forestry Accounting plan for Finland

Submission of National Forestry Accounting plan including forest reference level (2021 – 2025) for Finland (Draft 29 November 2018)

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Chapter 1: General introduction

1.1: General description of the forest reference level for Finland

The forest reference level for Finland for the period from 2021 to 2025 is -34.77 Mt CO_2 eq. with removals from harvested wood products (HWP) using the first order decay functions. The value is -27.88 Mt CO_2 eq. with assuming instant oxidation from HWP. The values are averages of the projected managed forest land and harvested wood products emissions and removals for the period 2021-2025 (Table 1.)

Table 1. Emissions and removals included into forest reference level of Finland.

Emissions and removals	**2021-2025 (Mt CO_2 eq. yr^{-1})**
Living biomass (CO_2)	-25.95
Mineral soils, including deadwood and litter (CO_2)	-6.49
Organic soil, including dead wood and litter (CO_2)	1.71
Emissions from drainage (N_2O)	1.92
Emissions from drainage (CH_4)	0.92
Prescribed burning (CO_2, CH_4, N_2O)	0.0013
N fertilization (N_2O)	0.0124
Harvested wood products (CO_2)	-6.90
FRL without HWP	-27.88
FRL with HWP	-34.77

The reference levels were prepared in accordance with the LULUCF Regulation and constructed from the projected emissions and removals as an average of the emissions and removals in 2021-2025 in managed forest land. The projections of carbon stock changes in living biomass, soils and those of harvested wood products were constructed as continuation of forest management practices in 2000 – 2009 and founded on a model based development of the forest resources in 2010-2061.

MELA forestry model (Hirvelä et al. 2017) was used to project future development of forest carbon sinks based on the national forest inventory data (see also Appendix 1). The outputs of the model were employed to calculate the projections of carbon stock changes.

Projections of emissions from GHG sources N-fertilization and controlled burning were estimated based on the emissions reported in the GHG inventory. For the projection of carbon stock changes in harvested wood products the output data from MELA modelling were used, e.g. division into sawnwood and pulpwood by species.

All elements mentioned in the Regulation (EU) No 525/2013 and Decision No 529/2013/EU that are applicable here in the reference level estimation for Finnish forests were taken into account.

1.2: Consideration to the criteria as set in Annex IV of 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 forest reference level for Finland is based on projections that enhance carbon stocks and removals by sinks in forests. Simultaneously forests that are managed according to principles of sustainable forest management provide raw materials for forest industry allowing substitution of fossil fuel intensive materials. Projection shows an increase of carbon sinks of forests from 2021 to 2050, and thus, to enable Finland to meet the goal of achieving balance between anthropogenic emissions and removals by the second half on 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 are allocated to litter and dead wood pools, roundwood removals to the HWP pool, and biomass used for energy is calculated as instantaneous oxidation. The same approach was applied to construct the FRL. The ratio of how much biomass was allocated to energy production is based on the actual volumes in 2000-2009. Thus, the change in the ratio during the period

from 2021 to 2025 will be properly accounted for. This 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 were calculated 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 2000–2009 as documented in Chapter 3 in this NFAP.

(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 forest reference level no forest harvesting was allowed in conservation areas to safeguard the biodiversity. In forest land available for wood supply, forest and nature conservation legislation and a number of other policies (see Adopted Policies) provide minimum 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. 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 agreed national policies. The Best Practices for Sustainable Forest Management is based on and consistent with principles of sustainable forestry/forest management as agreed in the Forest Europe process, EU forest strategy and national forest policies.

During the estimation of forest reference level, those best practises according to sustainable forest management guidelines (Tapio 2006) were used as constraints for MELA model.

(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;

Finnish reporting under Regulation (EU) No 525/2013 is consistent with the FRL estimation documented as both approaches report all forest 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. Same methodologies are used for projections reported under Regulation (EU) No 525/2013 as are used for the FRL. The development of forest resources are based on the results of MELA model, while for carbon stock changes and other emissions the GHG inventory methods are used.

(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 2018, Ojanen et al. 2018).

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
(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 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. N_2O emissions from nitrogen mineralization were taken into account but do not occur as mineral soils act as a sink of carbon. 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 that is burning 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 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, aboveground and belowground 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 waste wood from logging. The minimum diameter is 10 cm. On mineral soils, this carbon pool is reported as a combined estimate for dead wood, litter and soil organic matter pools. These are provided as aggregated pools due to the modelling framework. On drained organic forest soils, the pools are also reported as an aggregated estimate.

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 soils, this carbon pool is reported as a combined estimate for litter, dead wood and soil organic matter pools. These are provided as aggregated pools due to the modelling framework. On drained organic forest soils, this pool is assumed to be in a steady state (i.e. no change).

2.2.4 Soil carbon

Soil organic matter is built by the decomposed litter that has accumulated in soils. On mineral soils, dead wood and combined litter and soil organic matter pools are reported as aggregated values. They are calculated using the soil carbon model Yasso07 (Tuomi 2011a, b). It estimates soil carbon stocks and their changes to a depth of one metre. On drained organic forest soils, the carbon stock change of SOM is estimated based on the below-ground litter input and peat decomposition flux.

The possibility to report deadwood separately in the GHG inventory will be studied and that can be considered for the first technical correction of the Finnish FRL.

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 2018) 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 HWP – Harvested wood products

Carbon stock changes in harvested wood products include HWP in use originating from domestic forests, produced domestically and consumed domestically or exported. Imported timber and harvested wood products were excluded. All HWP was allocated to 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 Afforested land and deforested land

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 the forests and forest management

Forests cover 73 per cent of the land area of Finland. A total of 20.3 million hectares is available for wood production, 61 per cent privately owned. The growing stock is about 2,300 million cubic meters. 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 cubic meters per hectare. The mean volume is 143 cubic meters per hectare in Southern Finland and 87 cubic meters per hectare in Northern Finland.

The annual increment of growing stock on forest land and poorly productive forest land totals 107 million cubic meters according to 2018 National forest inventory results. Mean growth of the growing stock per hectare is 4.7 cubic meters. The annual mean increment is 6.7 cubic meters per hectare in Southern Finland and 2.7 cubic meters per hectare in Northern Finland. Three million hectares of the Finnish forests are protected or under restricted use, which represents ca. 13% of the forest area.

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 are made 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 sell the forest industry 80 per cent of the Finnish timber it needs. The state-owned forests managed by Metsähallitus cover a quarter of the forest land, while forest companies own just fewer than ten per cent of the forest land.

https://www.luke.fi/en/natural-resources/forest/forest-resources-and-forest-planning/forest-resources/

https://www.luke.fi/uutiset/tuoreimmat-metsavaratiedot-luken-tilastoportaalissa/

http://www.metla.fi/metinfo/sustainability/SF-1-main-lines.htm

Finnish forestry is based on sustainable forest management and the multiple use of forests, taking all dimension of sustainability into consideration. Economic sustainability means that the viability, productivity and profitability of forests are preserved in the long term. Action to secure ecological sustainability includes the protection of forest biodiversity and keeping the waters clean. Social sustainability means that that the people and various stakeholders continue to have access to the benefits derived from forests. Cultural sustainability comprises the understanding of natural environments and human action, including thoughts about the relationship between forest, economy and culture.

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 and recreational needs. Climate change mitigation and adaptation has become more significant objectives to be integrated both in both forest policy and management.

The minimum requirements (framework) for forest management is set in the forest and nature conservation legislation (see Adopted Policies). New kind of utilisation of forest-based biomass, growth in the popularity of nature-based tourism and recreational use, and the need to safeguard biodiversity are creating new forest-related needs and objectives in addition to wood production. Since the forest owners have heterogeneous values and preferences, the amendments to the Forest Act (amendments in 2013) increased the diversity and freedom of choice of forest owners to manage his/hers forest reflecting better his/hers objectives. Some forest owners value profitable and efficient wood production while others nature values or recreation especially. Most forest owners have multiple goals and combine different ways of forest use.

In Finland forestry generally involves the management of forest stands where trees are of a similar age. 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 specific 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 the objectives that forest owners. 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 out periodically 2 to 3 times during the rotation period, with some 25−30% of the trees removed during thinning. The increasing demand for wood for bioenergy has created new markets for the trees cut during thinnings, and for logging residues such as branches which earlier were left in the forest.

Continuous-cover (uneven-aged forestry) silvilculture methods were made available in the revision (2013) of the Forest Act. 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.

Both in even and even-aged methods the biodiversity of forests is being promoted by maintaining the characteristics of the valuable habitats. The most commonly used methods of nature management in commercial forests include leaving retention trees in regeneration 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 such a way that the special features of these habitats are maintained. A special feature of natural boreal forest is occurrence of fire and the organisms living in burned wood. Use of prescribed burning should be increased to revive these species in commercial forests.

The Best Practices for Sustainable Forest Management has been a key instrument to operationalize legislation and to promote sustainable forest management in practice. The Best Practices aim to support the forest owners in his/hers 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 a wide cooperation of private forest owners, forestry experts and forest, energy and environmental researchers. The Best Practices are completed with several detailed guide books on specific topics such as protection of waters, peatland forestry and biodiversity. 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.

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.

The Forest Act (1093/1996, amendment 1085/2013) sets requirements for the regeneration and conservation of certain key habitats. For instance, a new seedling stand has to be established within three years of the end of final felling. The Forest Act was amended in 2013 to increase the freedom of choice of forest owners in managing their own forest property, improve the profitability of forestry and operating conditions of wood-producing industry, and enhance the biodiversity of forests. One important objective in the reform was to have less detailed regulation on the treatment of forests and to clarify the legislation. The most important changes include allowing uneven-aged forest stands, abolition of age and diameter limits in regeneration cuttings, more diverse range of tree species, and increase in habitats of special importance (section 10). The Forest Act is complemented with guidelines for good forest management and silviculture, which have been compiled and promoted by public forestry extension organisations. **The guidelines for the sustainable management of forests** were also renewed, parallel to the Forest Act process. The state subsidizes the forest management undertaken by private forest owners. The aim is to safeguard the continuous growth and health of Finnish forests. An important reason for the subsidies is the fact that the benefits from a silvicultural investment are not necessarily reaped by the person who makes it. 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 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 forest as 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 NFS 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. In southern Finland, 72 per cent of the forests are owned by private persons. METSO therefore 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. The programme is being implemented through ecologically efficient, voluntary and cost-effective means. 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.

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 business, 2) Forest-based business 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 health 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 National Forest Strategy will be revised in early 2019.

The Parliament endorsed in 2014 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 preparation of the National Forest Strategy 2025 is based on the Government Report on Forest Policy.

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 while securing the operating conditions for the nature's ecosystems. The aim of the bioeconomy is to reduce our dependence on fossil natural resources and create new economic growth and jobs in line with the principles of sustainable development. Finland is committed to **reaching SDGs** both at home and in its international cooperation. Forests are important in reaching the all aspects of sustainability i.e. social, ecological and economical.

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 Act also sets a greenhouse gas emissions reduction target of at least 80% by 2050, compared to 1990. 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 National Energy and Climate Strategy (2016) outlines the actions that will enable Finland to attain the energy and climate targets specified in the Government Programme of Prime Minister Sipilä (27 May 2015) and adopted in the EU for 2030, and to systematically set the course for a low-carbon society. The main targets include that the share of renewable energy increases to 50 per cent of final consumption in the 2020's and, self-sufficiency in energy to 55 percent. Use of coal will be phased out in energy production and the domestic use of imported oil will be halved. The share of transport biofuels will be increased up to 30 per cent.

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.

In October 2009, the Government adopted the Foresight Report on **Long-term Climate and Energy Policy** and set a target to reduce Finland's greenhouse gas emissions by at least 80 per cent from the 1990 level by 2050 as part of a global effort. The roadmap discusses energy production and energy systems, use of energy, agriculture and forestry and carbon sinks, the waste sector and multidisciplinary measures that cut across several sectors. The Roadmap states that the measures Finland must take in any case in order to reduce greenhouse gases emissions by 80 to 95 per cent are related to renewable energy, energy efficiency and cleantech solutions.

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 National Adaptation Strategy to Climate Change (2005) as well as the latest scientific research and best practices.

Finland will submit the draft National Energy and Climate Plan latest by the 31st December 2018 and Long Term Strategy latest by the 1st of January 2020 as prescribed in the Governance Regulation of Energy Union.

2.3.2: Description of future harvesting rates under different policy scenarios

For the preparation of the National Climate and Energy Strategy (2016), the Finnish Natural Resources Institute prepared three scenarios describing different harvesting levels (Lehtonen et al. 2016).

The business as usual (perus) scenario was based on the continuation of the existing level of use of wood with a small increase due to the adopted investment decisions. Roundwood removals of industrial wood (timber logs and pulpwood) were estimated to remain on the level of 56 mill. m^3/yr (the level of removals in 2013-2014) with an annual increase of 5 mill. m^3 pulpwood from 2018.

The **policy scenario (politiikka)** was based on estimates of ”the Finnish forest industry in 2015-2035” by Pöyry Consulting (Pöyry Management Consulting 2016). In this scenario, the use of domestic roundwood of industrial wood was expected to increase up to 68 mill. m^3 / yr by the year 2035.

The third scenario was based on the determination of **the maximum sustainable removal (suurin kestävä)**, a concept used in National Forest Inventory (http://www.luke.fi/MELA-cutting-possibilities). This estimate is based on the presumption that in the successive 10-year periods, the roundwood removals of industrial wood, energy wood removals and net income have to be constant or increasing and the amount of harvested timber at least at the level of the 1st period. Taking previous preconditions into account the present value is maximised using 4 percent interest rate.

In all scenarios, the use of the energy wood is assumed to be 13.5 mill. m^3/yr, as in the latest National Energy and Climate Strategy (2013). In addition, the household use of fuelwood was expected to remain at the existing level of 6 mill. m^3/yr. In all the scenarios, the energy use of the stumps annually was restricted at to the level of 1 mill. m^3. The annual import of wood is assumed to be 9.1 mill. m^3 (the level of wood imported in 2015).

All the scenarios included the ecological preconditions as set in the forest and nature conservation legislation as well as the forest and nature management activities according to the sustainable forest management guidelines (Figure 1 and 2).

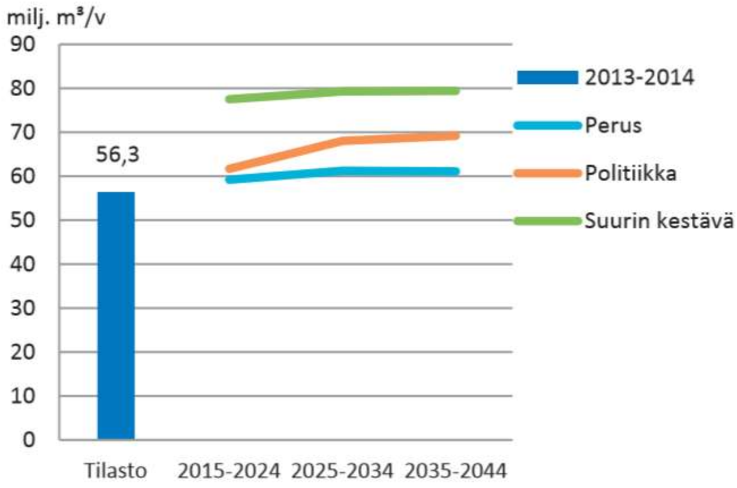
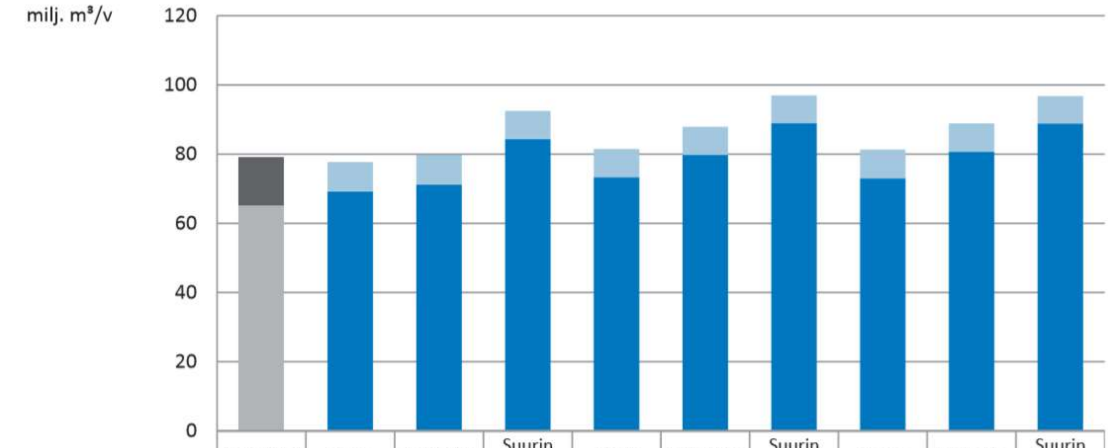


Figure 1. Roundwood removals for 2015-2044 in Base “Perus”, Policy “Politiikka”, Maximum sustainable “Suurin kestävä” scenarios (Lehtonen et al. 2016).



	Tot. 2013	Perus	Politiikka	Suurin kestävä	Perus	Politiikka	Suurin kestävä	Perus	Politiikka	Suurin kestävä
		2015-2024			2025-2034			2035-2044		
Lupo ja runkohukkapuu	13,9	8,5	8,5	8,1	8,2	8,2	7,9	8,2	8,1	7,9
Runkopuun kertymä	65,3	69,2	71,2	84,4	73,4	79,8	89,0	73,1	80,8	88,8

Figure 2. Total drain of Roundwood (Runkopuun hakkuumäärä) in different scenarios. Lupo =natural mortality, Runkohukkapuu =waste wood (roundwood) from fellings and silviculture .

Chapter 3: Description of the modelling approach

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

3.1.1 Models used for FRL estimation

The MELA forestry model (Hirvelä et al. 2016) 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. 2011) for mineral soils and emission factors for organic soils were used (NIR 2018). 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 was applied (NIR 2018).

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, and 2) an optimization package (Lappi 1992) based on linear programming (LP). MELA simulates number of feasible and alternative management schedules (options) for the management units 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 of the management schedules for each management unit consists of states and events. The events are i) natural processes (e.g. ingrowth, growth and mortality of trees) and ii) management activities (e.g. fellings, silvicultural treatments).

MELA model estimates for growth were adjusted first with growth indices to the average level of diameter increment for years 1984–2013 (Korhonen et al. 2007) of which the middle year is 1999 and the calibration was done with sample trees from the 11th NFI measured in years 2009–2013. The estimate of volume growth obtained using calibrated basal area growth was still adjusted to match with measured NFI11 growth level using the realized weather and CO_2 concentration data and transformation functions (Matala et al 2005). Those transfer functions by Matala et al. (2005) were used in order to predict the change in the growth rate as a function of the increased in mean temperature and CO_2 concentration linearly between 1999, 2010 and 2017. After 2017 modified growth rate was used for following years. This procedure ensured that MELA model was able agree with latest NFI increment data and with GHG inventory (see ch 4.2 and Appendix 1).

Assumptions in short used in the MELA calculations:

- The initial state of forest area, volume of growing stock and increment of growing stock were based on the 11th national forest inventory (NFI11) data measured 2009–2013 (mean year 2011).

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

- For the forests available for wood supply, forest management activities were simulated according to the Forest Management Guidelines (FMP) (Tapio, 2006) which were prevailing and applied in reference period 2000-2009. For the protected forest land and for all poorly productive forest land there were no silvicultural operations and only natural processes were simulated. According to the forest management guidelines (Tapio 2006), Finland was stratified further into three regions (chapter 3.2.1).

- 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, mainly the fellings define the development of forest resources in MELA model, and therefore during years 2011–2015 the data from reported fellings from these years were applied as an input to MELA model and from 2016 onwards the fellings were following 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). However prescribed burning, fertilization or pruning were not included in the management alternatives. For all treatments, except for the obligatory cultivation after clear felling, a no alternative treatments were simulated.

- 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 for calculating the FRL during the period from 2021 to 2025 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 net present value of 3.5% discount rate was used constraining felling areas as relative to corresponding forest land area and non-declining industrial roundwood removals between the successive periods during 2016–2061 (see chapter 3.2.2, table 7).

- For the energy wood removals during 2016–2061 the ratio between solid and energy wood use in 2000–2009 was used as a LP constraint (see chapter 3.22. table 8).

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, DOM and SOM were evaluated using biomass models embedded in MELA, soil carbon model Yasso07 (NIR 2018 Appendix_6e, Tuomi et al., 2011a,b) for mineral soils and a method based on emission factors for organic soils (NIR 2018 Appendix_6f, Sievänen et al. 2013), (Figure 3). All components of this model framework are compatible with those in the greenhouse gas inventory system (NIR 2018). 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 instead of NFI, otherwise the calculations are practically the same as in the greenhouse gas inventory.

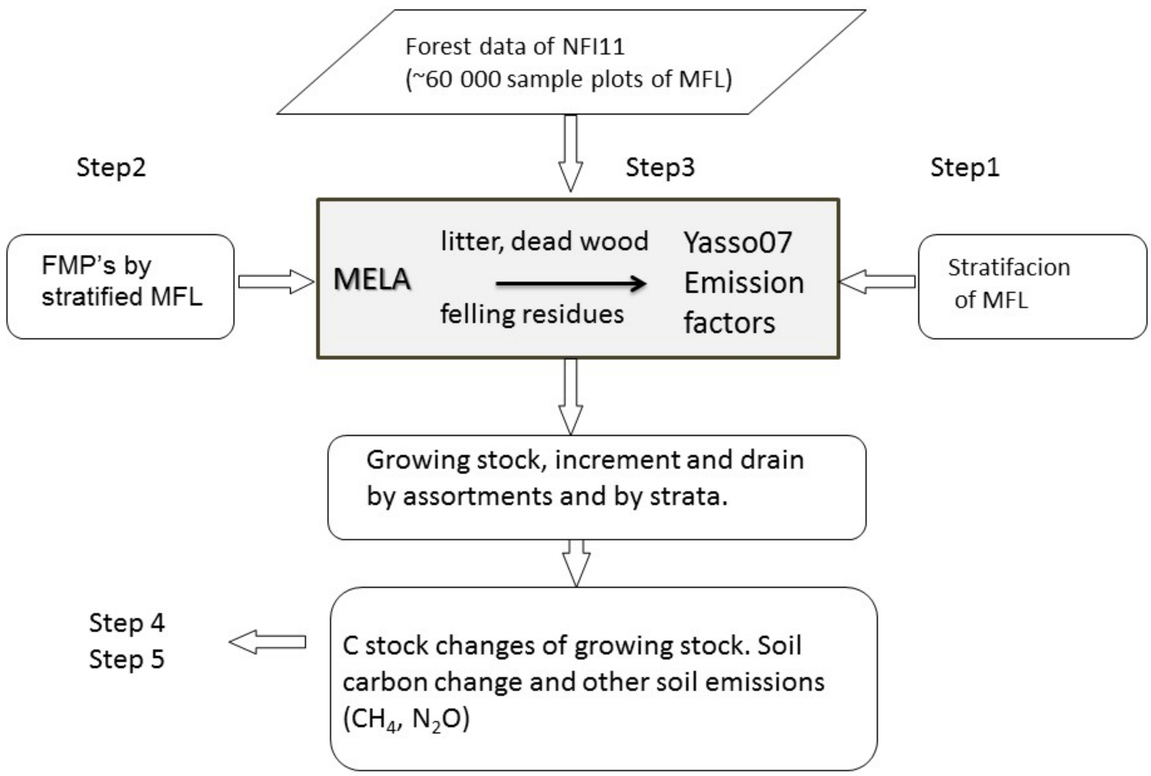


Figure 3. The model framework for changes in forest carbon stocks and for other soil emissions. MELA projects the development of forest resources and is also used to calculate amount of carbon in growing stock, litter from living trees, harvesting residues and unrecovered natural mortality. The litter input is used in Yasso07 (NIR 2018 Appendix_6e, Tuomi et al. 2011a, b) to calculate carbon changes of the aggregated pool of deadwood, DOM and SOM on mineral soils. A method based on emission factors was used for DOM and SOM on organic soils (NIR 2018 Appendix_6f, Sievänen et al. 2013). Change in biomass of understory vegetation is not considered but its litter input is included (NIR 2018, 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 11th national forest inventory (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 NFI9 (Tomppo et al. 2011), 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 et al. (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 (MFL) consists of the NFI11 sample plots defined either as forest land or as poorly productive forest land (scrub land) – totally about 60 000 sample plots. The management units were classified further into two categories according to restrictions concerning wood production (Table 3.1 a and b):

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

2. no wood production 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 MFL for RFL calculation was stratified further into these three regions (Figure 4, Table 3 and Table 4):

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 2018) 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 (2018) 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 3. Area by management categories in NFI11, million hectares

Management category	Area, mill. ha			%
	Forest land	Scrub land(*	Total	
Land available for wood production	18.42	1.12	19.54	85.8
- Southern Finland	5.07	0.16	5.22	96.6
- Central Finland	5.75	0.14	5.88	96.4
- Northern Finland	7.61	0.83	8.44	74.9
No wood production allowed	1.84	1.38	3.23	14.2
- Southern Finland	0.16	0.03	0.18	3.4
- Central Finland	0.17	0.05	0.22	3.6
- Northern Finland	1.51	1.31	2.82	25.1
Total	20.26	2.50	22.77	
- Southern Finland	5.22	0.18	5.40	
- Central Finland	5.92	0.18	6.10	
- Northern Finland	9.12	2.14	11.26	

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

Table 4. Volume by management categories in NFI11, million cubic meters.

Management category	Volume, mill. m³			%
	Forest land	Scrub land(*	Total	
Land available for wood production	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 production 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 production allowed or in no wood production 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)

The forest management in Finland was based in 2000-2009 on the system of periodic cover silviculture. 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) that had been defined separately for the Southern, Central and Northern Finland. 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 basing 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, etc.

In Finland, the stand-wise guidelines have been defined and applied using the concept of stand development classes (Box 1) (Tapio 2006), in which the forest stands have been categorized by the stage of development into eight classes (Table 5). From classes A0 to T2 as well as SHS and STS the measures are made for to guarantee the regeneration of the new tree generation and for classes (stands) of YTS, ATS and MS mainly the timber fellings are considered.

Box 1. Stand development classes used in Finland

A0:	Temporarily unstocked regeneration area
T1:	Young seedling stand
T2:	Advanced seedling stand
YTS:	Young thinning stand
ATS:	Advanced thinning stand
MS:	Mature stand
SHS:	Shelter tree stand
STS:	Seed tree stand

Table 5. Forest land available for wood production by development classes according to the 10th national forest inventory NFI10 (Korhonen et al 2013).

	Area of NFI10 Stand development classes, 1000 ha								
Finland	A0	T1	T2	YTS	ATS	MS	SHS	STS	Total
Southern*	847	3776	6214	13259	17055	8562	210	341	50268
Central*	950	4624	7097	20630	16844	7390	55	177	57771
Northern*	1027	6431	10249	36047	13511	9335	171	1053	77826
Total	2824	14831	23560	69936	47410	25287	436	1571	185865

*For estimating GHG emission and sinks these areas were aggregated into Southern – and Northern Finland, by summing regions of Southern and Central to be Southern Finland, as in (NIR 2018).

The development class distribution and existing forest management guidelines define the measures that forest managers are able to use as options. Regeneration measures are mainly obligatory as the consequences of final fellings. Therefore for defining the forest management practice applied 2000–2009, the documented (https://stat.luke.fi/en/metsa) cutting areas from 2000 – 2009 by stand development classes of were used (Box 1 and Table 6). These areas were used for determining relative areas for thinnings and for final fellings in order to define quantitative aspects of sustainable forest management for the compliance period as documented in chapter 3.2.3.

Table 6. 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 an important factor affecting the projections (see Assumptions in short used in the MELA calculations in 3.1.1 Models and 3.2.3 Documentation of the use of forest management practices 2000–2009 as applied in the estimation of the forest reference level). In order to estimate the appropriate value of the discount rate during the Reference Period (2000–2009), the real investment return in wood production in private forests in 2000 - 2009 was analysed. It amounted on the average 3.58 per cent for the period of 2000 – 2009 (Figure 5) and therefore interest rate of 3.5% was used with MELA simulations for net present value. This statistics provide an annual index for investment taking into account the yearly sale earnings, inputs (costs) to the silviculture and net value change of growing stock due to the growth and drain.

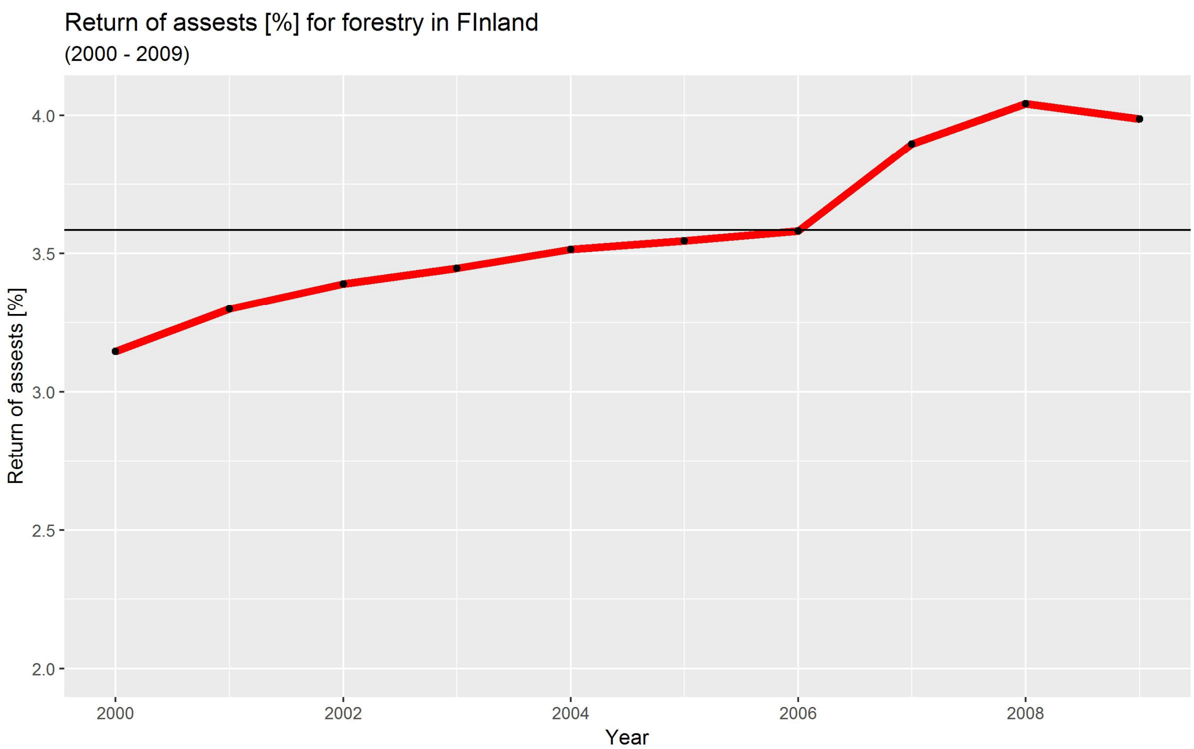


Figure 5. The real return on assets in wood production calculated with constant stumpage prices in RF period 2000-2009 for Finland (based on forest statistics: stat.luke.fi). The black line indicates the mean for period of 2000-2009, being 3.58%.

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 7) were applied in MELA calculations for the reference level period (2021-2025). This approach was adopted on the basis of the guidance document by Forsell et al. (2018). MELA applied in simulation of management of individual forest stands the Forest Management Guidelines (Tapio, 2006) that were operational during the years 2000-2009. This together with realized relative thinning and final felling areas reflects accurately the forest management of the RP period (Forsell et al. 2018).

Table 7. Felling areas in 2000–2009 as a per cent of corresponding development class, %

	1000 ha				Felling area as per cent	
Region	Thinning	Final felling	Thinning	Mature	Thinning	Final felling
	area	area	stands	stands	tha%	ffa%
Southern Finland	1287	580	30314	8563	**4.2**	**6.8**
Central Finland	1270	542	37473	7390	**3.4**	**7.3**
Northern Finland	970	562	49560	9336	**2.0**	**6.0**
Finland	3528	1683	117347	25289	3.0	6.7

Documented (Table 7) felling (ffa%) and thinning (tha%) area percentages were used in MELA calculations as constraints beyond the first calculation period 2011–2015 since 2016 onwards (Table 9). The percentages were applied in the MELA calculations according to equations [1] and [2]:

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

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

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

In order to calculate 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) and industrial wood were calculated based on statistics of 2000–2009 (https://stat.luke.fi/en/metsa) – (Table 8). These ratios were used as constraints in MELA calculation as defined in [3].

Table 8. Removals of energy wood (forest chips + households' fuelwood) and industrial roundwood in 2000-2009, 1000 m³/year. (Source: https://stat.luke.fi/en/metsa)

Region	Energy wood (EW)	Industrial roundwood (RW)	EW%
	1000 m³/y	1000 m³/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

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

*) comprise of forest chips and households' fuelwood

The formulation of the LP task from the simulated MELA data was operationalized such it would reflect the FMP's of the reference period (2000–2009): the net present value was maximized by using 3.5% discount rate basing on the real return on assets in wood production calculated with constant stumpage prices in RF period 2000-2009 (see ch 3.2.2) subject to the felling areas as relative to corresponding forest land area (see chapter 3.2.2, table 7) and non-declining industrial roundwood removals between the successive periods during 2016–2061.

Table 9. 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.

		2011	2016	2021	2026	2031	2041	2051	2061
Southern Finland	(a) Thinning stands	2939.3	2981.6	3006.9	2963.9	2984.8	3164.2	3444.8	3620.7
	(b) Thinning area	111.0	125.2	126.3	124.5	125.4	132.9	144.7	
	% (b/a)	3.8	4.2	4.2	4.2	4.2	4.2	4.2	
	(a) Mature stands	1259.8	1113.3	992.8	943.8	916.1	906.4	879.3	920.3
	(b) Final fellings	79.5	75.7	67.5	64.2	62.3	61.6	41.9	
	% (b/a)	6.3	6.8	6.8	6.8	6.8	6.8	4.8	
Central Finland	(a) Thinning stands	3547.2	3592.1	3672.8	3696.1	3632.3	3647.4	3593.3	3499.9
	(b) Thinning area	153.5	122.1	124.9	125.7	123.5	124.0	122.2	
	% (b/a)	4.3	3.4	3.4	3.4	3.4	3.4	3.4	
	(a) Mature stands	1062.9	967.3	842.6	806.2	813.0	895,1	899,0	950,7
	(b) Final fellings	67.1	70.6	61.5	58.9	59.3	65.3	64.1	
	% (b/a)	6.3	7.3	7.3	7.3	7.3	7.3	7.1	
Northern Finland	(a) Thinning stands	5229.8	5188.6	5150.9	5073.7	4909.3	4591.8	4372.0	4335.2
	(b) Thinning area	145.8	103.8	103.0	101.5	98.2	91.8	87.4	
	% (b/a)	2.8	2.0	2.0	2.0	2.0	2.0	2.0	
	(a) Mature stands	1270.8	1272.0	1203.5	1233.4	1309.5	1493.1	1725.7	1972.2
	(b) Final fellings	54.0	76.3	72.2	74.0	78.6	71.4	58.9	
	% (b/a)	4.2	6.0	6.0	6.0	6.0	4.8	3.4	

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

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 2018). All calculations were made by tree species groups, soil types, South and North Finland. Steps of the calculation were:

1. Volume increments were calculated as mean increments m^3/ha and converted to biomass, carbon and CO_2.

2. Natural drain (mortality) per hectare and harvest drain per hectare were calculated and converted to biomass, carbon and CO_2.

3. Mean values were multiplied by the land area under forest management.

4. The difference between gains and losses in living biomass is the net sink of tree biomass.

5. The separate CO_2 balance projections for South Finland and North Finland were calculated. The values between mid-years (see Table 3) were interpolated. The projection for whole Finland was a sum of the two regional projections (Table 5).

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 2018). 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 2018 for details.

Projections for dead organic matter and soils are given in Table 5.

3.3.3 Litter input

Litter input for period prior 2011 was the same as in latest submission of greenhouse gas inventory, and the same way of estimation of litter input was applied for future projections, see NIR 2018, section 6.4.2.1. MELA forestry model provided estimates for future tree stocks starting from 2011 with intervals of 5 and 10 years (Table 3). These stocks were then converted to biomass with biomass functions currently applied in the national greenhouse gas inventory (NIR 2018, Appendix_6d). The litter input to the soils from living trees was estimated with turnover rates that are applied in the GHG inventory (NIR 2018 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 with 10 years intervals (Table 3). The biomass of natural mortality and harvesting residues were estimated with the same BEFs (NIR 2018 Appendix_6c) and biomass functions (NIR 2018 Appendix_6d) of the GHG inventory. The estimated use of the energy wood in the scenario prepared for the National Energy and Climate Strategy for 2030 was used in the soil carbon simulations. The origin of bioenergy was 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. Litter input of ground vegetation was estimated in the same way as in the GHG inventory (NIR 2018 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 2018 Appendix_6e). Yasso07 calculations provide estimates of changes in carbon stocks of dead wood, DOM and SOM. The initial values of carbon stocks for Yasso07 in 2011 was taken from the results of the latest greenhouse gas inventory submission (NIR 2018). The input weather conditions (mean annual temperature, amount of precipitation and amplitude of monthly mean temperature) were taken as 30 years moving average as in the greenhouse gas inventory that will be submitted during 2019**.** For parameter values and model description, see section 6.4.2.1. and Appendix_6e in NIR (2018).

3.3.5 Organic soils

Changes in carbon stocks of DOM and SOM on Organic soils/peatlands on drained organic soils were calculated as the difference of emissions from the soil and below-ground litter input in the same way as in GHG inventory (NIR 2018 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 decomposition flux to obtain net gas exchange for these lands. In order to upscale emissions to the national level the area of drained organic forest lands were multiplied with net emission factors.

Carbon stock change of above-ground dead wood pool on organic soils was evaluated in the same way as on mineral soils, that is, with NFI data (NIR 2018).

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. 2018) for N_2O emissions by soil fertility for drained organic forest lands have been given in Table 10.

Table 10. N_2O emission factors for drained organic forest soils. These emission factors have been updated since 2018 submission of the GHG inventory of Finland, see Ojanen et al. (2018).

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 11. CH_4 emission factors for drained organic forest soils (NIR 2018).

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

The CH_4 emissions consist of emissions 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 11).

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 2018) and national projections, estimation was started from the carbon stocks of

GHG inventory in the end of year 2010. The result from the MELA modeling, 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. HWP in solid waste disposal sites and HWP harvested for energy purposes were accounted for on the basis of instantaneous oxidation and imported harvested wood products were excluded. All HWP was allocated to managed forest land.

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 2018).

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 2018). 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: Forest reference level and detailed description of the development of the carbon pools

According to MELA model estimates growing stock in forests increase from 2.36 bill. m^3 to 2.60 bill. m^3 between 2011 and 2025 (Table 12). According to the simulations with continuation of 2000-2009 sustainable forest management practices provided total annual loggings of 83.1 mill m^3 for 2021-2025, simultaneously tree increment increased from 106 to 113.2 mill. m^3 between 2011 and 2025.

Table 12. Development of growing stock, increment, natural mortality and living biomass carbon sink between 2011 and 2025.

1000 mill. m^3	**2011**	**2016**	**2021**
Growing stock	2360.71	2508.98	2604.68
Growing stock, forest available for wood supply	2090.47	2212.46	2279.19
mill m^3/ year			
	2011-2015	**2016-2020**	**2021-2025**
Increment (All area)	106.03	112.27	113.16
Drain	76.41	93.14	93.69
- Natural mortality	10.00	7.39	7.97
Total loggings	63.47	83.01	83.07
- Timber	55.20	77.25	77.25
- Stem wood for energy	8.27	5.76	5.82
- Timber for energy (from stem wood energy)	7.52	5.27	5.27
Wood chips + domestic fuelwood	12.83	11.00	11.00
t CO_2 ekq, Per year	**36.83**	**26.04**	**25.95**

The forest reference level for Finnish managed forests is -27.88 Mg CO_2 eqv. without harvested wood products and -34.77 Mg CO_2 eqv. with harvested wood products for the period of 2021-2025 (Table 13). Forest reference level is shown here by different carbon pools and also for non-CO_2 emissions (Table 13).

Table 13. Development of carbon pools and GHG emissions between 2011 and 2025.

Carbon stock changes and other emissions	2011-2015 (Mg CO_2 eq. yr^{-1})	2016-2020 (Mg CO_2 eq. yr^{-1})	2021-2025 (Mg CO_2 eq. yr^{-1})
Living biomass (CO_2)	-36.83	-26.04	-25.95
Mineral soils, including deadwood and litter (CO_2)	-8.41	-8.72	-6.49
Organic soil, including dead wood and litter (CO_2)	5.19	4.07	1.71
Emissions from drainage (N_2O)	1.92	1.92	1.92
Emissions from drainage (CH_4)	0.92	0.92	0.92
Prescribed burning (CO_2, CH_4, N_2O)	0.0013	0.0013	0.0013
N fertilization (N_2O)	0.0124	0.0124	0.0124
Harvested wood products (CO_2)	-3.76	-8.02	-6.90
FRL without HWP	**-37.20**	**-27.84**	**-27.88**
FRL with HWP	**-40.95**	**-35.86**	**-34.77**

The development of long term carbon sink and GHG emissions show that carbon sink in forests strengthens between 2031 and 2060 from a sink of -33.1 Mg of CO_2 ekq. to sink of -49.6 Mg of CO_2 ekq. (Table 14).

Table 14. Development of the long term carbon sink and GHG emissions for Finnish forest according to FRL simulations. Note that soils, dead wood and litter include also non-CO_2 emissions (CH_4 and N_2O)

	2031-2040	2041-2050	2051-2060
Living biomass	-29.31	-35.92	-42.70
Soils, dead wood and litter	-3.81	-5.25	-6.92
Others	0.0137	0.0137	0.0137
Total without HWP	**-33.11**	**-41.15**	**-49.61**

It is important to note, that these long term estimates (up to mid-century) for forest carbon 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 data. Currently, increment functions of MELA model do not have constraints like, lack of nitrogen limiting growth or that of increased disturbances reducing biomass stocks under changing climate. Currently, GHG inventory reports the uncertainty of 76% (95% confidence intervals) for forest carbon sink for Finland, including soil carbon stock change for mineral- and organic soils. 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 the system of greenhouse gas inventory (NIR 2018 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 EC in January 2019. The NIR 2019 version was used due to fact that some methods employed by the Finnish GHG inventory has been updated recently. 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).

Biomass carbon sink provided by MELA model was compared against greenhouse gas inventory for a period of 2011 – 2016 (NIR 2018). It has to be noted that MELA runs with 5 year time step and showing therefore constant sink for 2011-2016. On average a good agreement was found between MELA model and data (Figure 6).

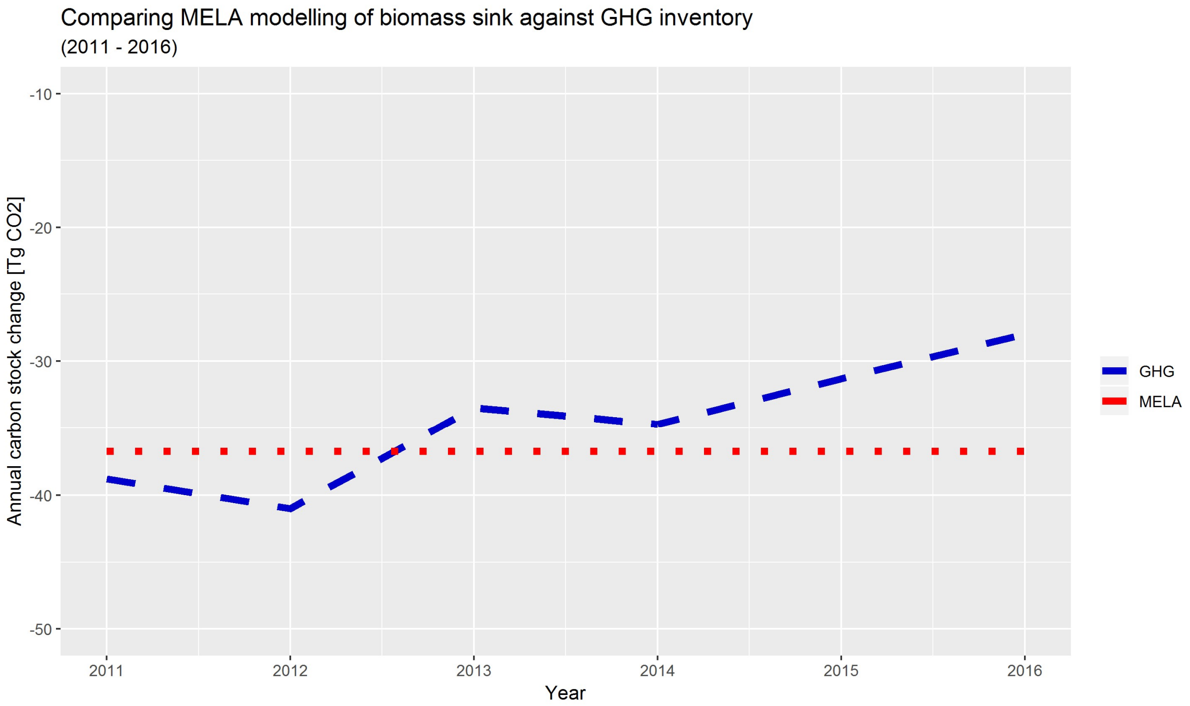


Figure 6. Comparison biomass carbon sink values by MELA model (red dotted line) and those from the latest submission of the greenhouse gas inventory of NIR 2018 (blue dashed line) on mineral and organic soils.

For the comparison of stock changes of soil carbon (dead wood, litter and SOM) with the results of greenhouse gas inventory Yasso07 was driven from 1975 to 2010 with litter input and initial values from the calculations of the latest greenhouse gas inventory submission (NIR 2018). The organic soil calculation used litter input from 1990 to 2010. The model framework for changes in carbon stocks can reproduce the results of the greenhouse gas inventory (Figure 7 and Figure 8).

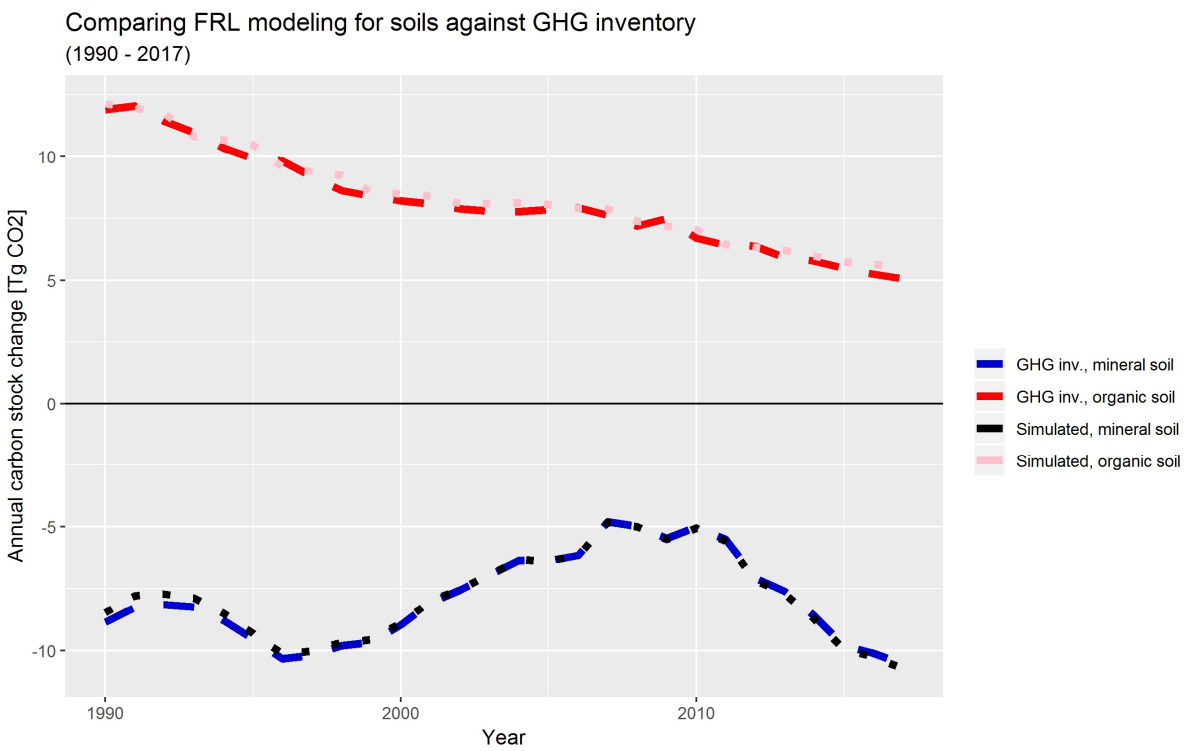


Figure 7. Comparison soil carbon stock (combined dead wood, litter and SOM) changes calculated with the model framework (solid line) with the latest submission of the greenhouse gas inventory of NIR 2018 (circles) on mineral and organic soils, note that for mineral soils updated weather data of 30 year mean was used.

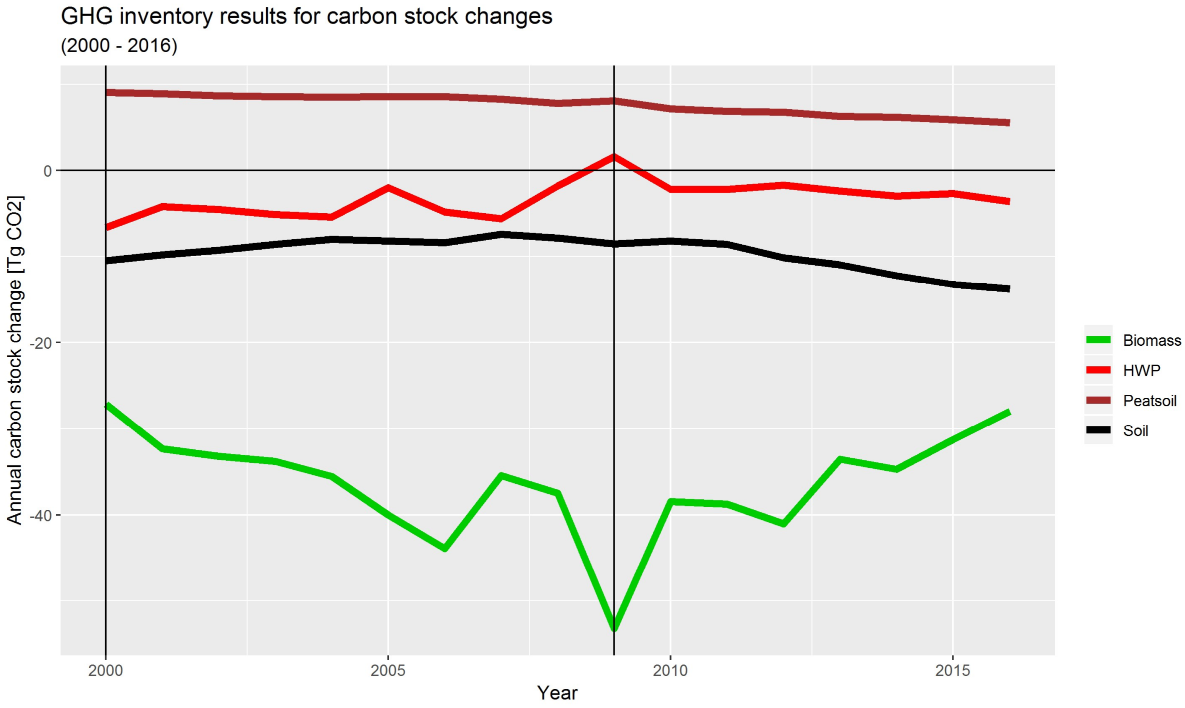


Figure 8. Time series of forest carbon sinks between 2000 and 2016 as presented in the NIR (2018) for Living biomass (green), harvested wood products (HWP, red), organic soils (brown) and mineral soils (black), here excluding non-CO_2 emissions from soils.

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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 mode 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). 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 A2).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).

Note 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.

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). The calculation of carbon emissions is made as a difference of total biomasses between consequent states (note that in Finnish GHG inventory the calculation is made as the difference of growth and total drain of biomasses).

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).

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.

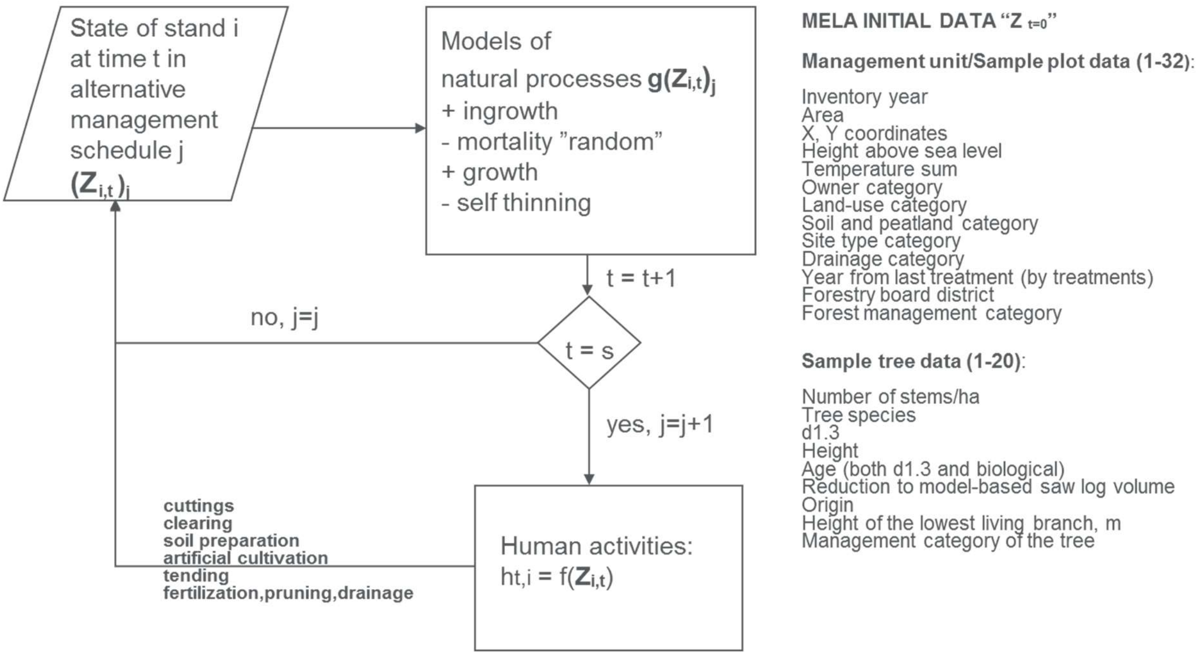

Figure A1. The simulation of management alternatives in MELA.

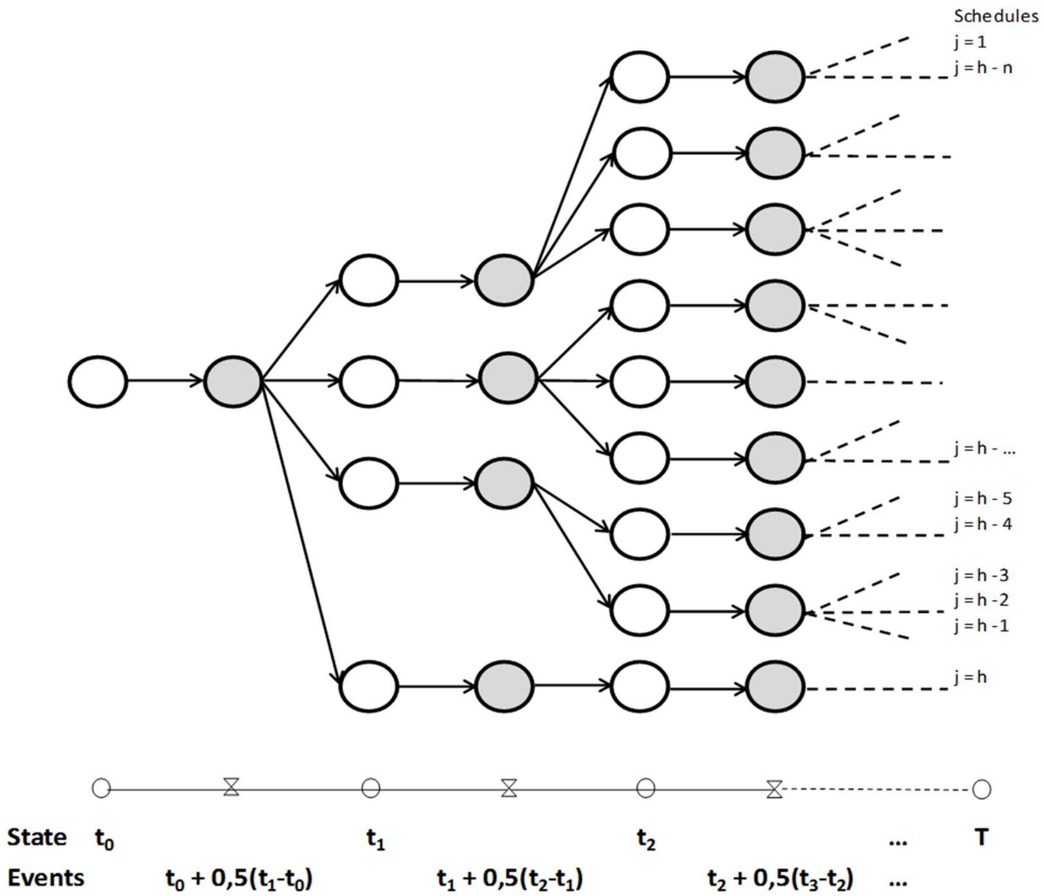

Figure A2. A scheme of simulation tree of schedules for each management unit as the product of MELA simulation.

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.

$\max Z = c'x$

s.t.

$Ax \leq / \geq b$

$x \geq 0$

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/v**						
	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	2665.8	
	1.005*Industrial_roundwood_Spruce_1	≥	11459.4	7307.6	2048.4	
	0.995*Spruce_sawlog_1	≤	7150.4	4235.6	2048.4	
	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	
*** 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_2b - Thinning_area_2	≥	0.	0.	0.	3) tha%
2021-2025	0.01*tha%*Thinning_stand_acreage_3b - Thinning_area_3	≥	0.	0.	0.	*2b-7b*
2026-2030	0.01*tha%*Thinning_stand_acreage_4b - Thinning_area_4	≥	0.	0.	0.	
2031-2040	0.01*tha%*Thinning_stand_acreage_5b - Thinning_area_5	≥	0.	0.	0.	
2041-2050	0.01*tha%*Thinning_stand_acreage_6b- Thinning_area_6	≥	0.	0.	0.	
2051-2060	0.01*tha%*Thinning_stand_acreage_7b - Thinning_area_7	≥	0.	0.	0.	
Final fellings by periods 2-7						
2016-2020	0.01*ffa%*Area_of_Mature_stands_2b - Area_of_final_fellings_2	≥	0.	0.	0.	4) ffa%
2021-2025	0.01*ffa%*Area_of_Mature_stands_3b - Area_of_final_fellings_3	≥	0.	0.	0.	*2b-7b*
2026-2030	0.01*ffa%*Area_of_Mature_stands_4b - Area_of_final_fellings_4	≥	0.	0.	0.	
2031-2040	0.01*ffa%*Area_of_Mature_stands_5b - Area_of_final_fellings_5	≥	0.	0.	0.	
2041-2050	0.01*ffa%*Area_of_Mature_stands_6b - Area_of_final_fellings_6	≥	0.	0.	0.	
2051-2060	0.01*ffa%*Area_of_Mature_stands_7b - 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_removal_2	≥	0.	0.	0.	5) ew%
2021-2025	0.01*ew%*Industrial_roundwood_3 - Total_energywood_removal_3	≥	0.	0.	0.	
2026-2030	0.01*ew%*Industrial_roundwood_4 - Total_energywood_removal_4	≥	0.	0.	0.	
2031-2040	0.01*ew%*Industrial_roundwood_5 - Total_energywood_removal_5	≥	0.	0.	0.	
2041-2050	0.01*ew%*Industrial_roundwood_6 - Total_energywood_removal_6	≥	0.	0.	0.	
2051-2060	0.01*ew%*Industrial_roundwood_7 - Total_energywood_removal_7	≥	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 4.2, for Central Finland 3.4 and for Northern Finland 2.0

2b-7b b = state in the beginning of correpondin period

[4] ***Final felling per cent (ffa%)*** for Southern Finland 6.8, for Central Finland 7.3 and for Northern Finland 6.0

2b-7b b = state in the beginning of correpondin period

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