Norwegian Ministry
of Climate and Environment

National Forestry Accounting Plan for Norway, including forest reference level for the first commitment period 2021-2025

Revised version

9 November 2020

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1 General introduction

According to Article 8(3) of the EU's Land Use, Land Use Change and Forestry Regulation (2018/841), Norway informally shared its draft National Forestry Accounting Plan to the EFTA Surveillance Authority (ESA) in March 2019, and formally communicated it on 12 March 2020. The EFTA Surveillance Authority issued a decision on 26 June 2020 (Decision No: 068/20/COL) with an assessment and technical recommendations to the National Forest Accounting Plans of Iceland and Norway. This revised National Forestry Accounting Plan is updated according to the technical recommendations from the EFTA Surveillance Authority. Please see the annexed Explanatory Note for detailed descriptions of how Norway has followed up on the recommendations.

1.1 General description of the forest reference level for Norway

The forest reference level (FRL) for Norway for the period 2021-2025 is on average -26.09 million tons CO_2-equivalents per year when including emissions and removals from harvested wood products (HWP) using the first order decay function and default half-lives. When instantaneous oxidation of HWP is assumed, the FRL is -24.86 million tons CO_2-equivalents per year. See Table 1 for information on average annual emissions and removals from the carbon pools included in the FRL for Norway.

Table 1. Average annual emissions and removals from the carbon pools included in the Norwegian forest reference level for the first commitment period 2021-2025

Emissions and removals	2021-2025 (Mt CO_2 eq. yr^{-1})
Living biomass (CO_2)	**-18.290**
Mineral soils, including dead wood and litter (CO_2)	**-7.604**
Below ground	*-0.145*
Dead wood	*-1.255*
Litter	*-6.205*
Drained organic soils (CO_2, N_2O, CH_4)	**1.036**
	0.000
CO_2	*0.695*
N_2O	*0.290*
CH_4	*0.051*
Biomass burning (wildfires) (N2O, CH4)	**0.0014**
N_2O	*0.0008*
CH_4	*0.0005*
N-fertilisation (N_2O)	**0.0001**
Harvested wood products (CO_2)	*-1.2276*
Sawn wood	*-0.8444*
Wood based panels	*-0.2918*
Paper and paperboard	*-0.0916*
Total without HWP	-24.8574
Total with HWP	-26.0850

The forest reference level includes the following carbon pools; living biomass (above and below ground), dead organic matter (dead wood and litter) and mineral soils, drained and undrained organic soils. In addition, the carbon pool of harvested wood products is included. The forest reference level also includes emissions of CH_4 and N_2O from forest fertilisation, drained organic soils, and biomass burning (wildfires).

The forest reference level for Norway is constructed in accordance with the LULUCF Regulation (Regulation (EU) 2018/841) and follows the "Guidance on developing and reporting Forest Reference Levels" in accordance with the LULUCF regulation. The forest reference level is constructed based on the continuation of the management practices in the Norwegian managed forests, as observed in the reference period 2000-2009. The simulation starts from the year 2010.

The definitions, methodologies and data used to calculate the forest reference level are consistent with the methods used to estimate emissions and removals related to the different carbon pools in the national greenhouse gas inventory report (NIR), where the main source of activity data is the National Forest Inventory (NFI).

We have used SiTree, an individual tree growth simulator, and imputation methods to project the future growth, mortality, ingrowth, and natural regeneration. The emissions and removals of total soil organic C (dead wood, litter, and soil pools) from forest land on mineral soil are estimated using the decomposition model Yasso07. For sources of non-CO_2 emissions, we have assumed that the emissions in the period 2021-2025 will be the average of the emissions from the sources in the reference period 2000-2009.

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

1.2.1 Annex IV section A

Annex IV section A of the LULUCF Regulation defines criteria for determining the Forest Reference Level (FRL). Below we give some considerations as to how these criteria are addressed in the construction of the Norwegian FRL, and where more information could be found, where relevant.

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**

This criterion encourages the Member States to reflect on the Paris Agreement and the long-term development of the carbon sink, including beyond 2030.

The carbon stocks in living biomass on forest land have historically increased in Norway due to planting of trees 60-70 years ago, and active forest management policy in the decades that followed. These trees are now in their most productive age and contribute to the increase in living biomass. At the same time, annual fellings are much lower than the annual increment. Hence, 43 per cent of the productive forest area in Norway consists of mature forest. The area harvested the last ten years has been about 0.45 % of the forest area. Therefore, Norway has a skewed age structure with a lot of old forests with declining annual increment. Figure 1 shows the forest area distributed on maturity classes.

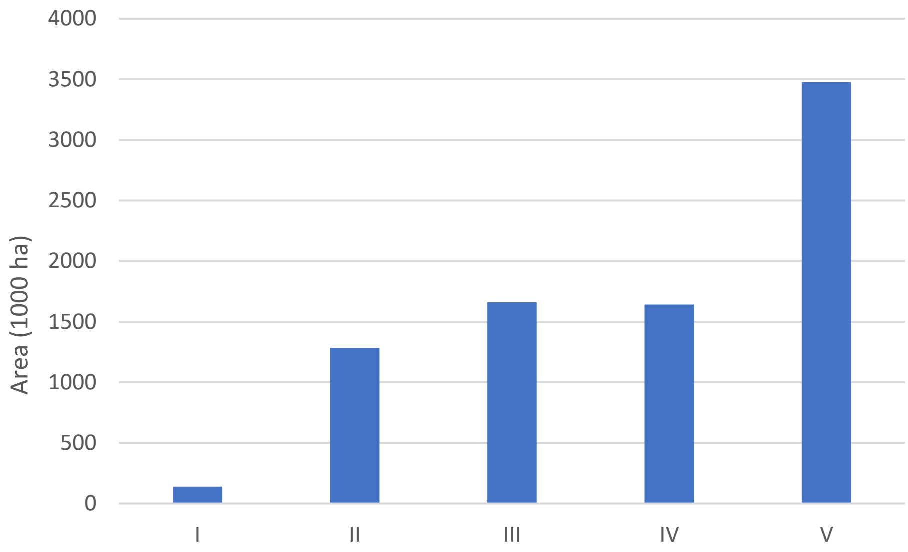

Figure 1. Forest area distributed on maturity classes in hectares. I – Under regeneration; II – Juvenile stands; III – Young production stands; IV – Older production stands; V – Old/mature stands. Source: The Norwegian Institute of Bioeconomy Research.

If we continue the same low harvest intensity as we have had historically, the area of old forest will increase in the next decades. The projections indicate that the annual increment in the forest has peaked, and we hence expect that the annual CO_2 removals will be declining in the future. The forest will, however, continue to be a sink.

To achieve the goal in the Paris agreement of balancing 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 would otherwise show progressively declining sinks, the harvest intensity could temporarily be increased to, or to a certain level above, the sustained yield in productive forest, while maintaining eco-system services and biodiversity (i.e. sustainable harvest).

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

This criterion is in accordance with the Kyoto Protocol Decision 16/CMP.1 (KP 2005), where the same principle was affirmed. It reflects the objective of enhancing the carbon stocks and the net carbon sinks where possible, instead of only preserving existing carbon stocks, since only annual removals will reduce the atmospheric carbon. By using a forward-looking reference level as the basis for accounting, as constructed in accordance with the LULUCF Regulation, there will be incentives to implement new measures to enhance the carbon stocks in the forests, since only removals above the reference level will be accounted for as credits. Existing carbon stocks in the forests will not be accounted for.

c) The reference level should ensure a robust and credible accounting system that ensures that emissions and removals from biomass use are properly accounted for

A credible accounting system is important to ensure proper accounting of emissions and removals from biomass, especially since CO_2 emissions from combustion of wood is not accounted for in the energy sector. The Norwegian forest reference level is constructed in accordance with the LULUCF Regulation. Hence, all carbon pools in the forest are included, and all carbon stock changes in the forest carbon pools will be accounted for. The criterion is, therefore fulfilled.

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 this document, Norway provides two reference levels, one assuming instantaneous oxidation of the carbon pool of harvested wood products, and one applying the first-order decay function and default half-life values.

The forest reference level for Norway is -26.09 million tons CO_2-equivalents, in which the HWP pool constitute -1.23 million tons CO_2-equivalents. If instantaneous oxidation of HWP were assumed, the FRL would be -24.86 million tons CO_2-equivalents.

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

In the reference period from 2000 to 2009, the ratio between annual harvest and annual data on national consumption and export was calculated for each of the three HWP categories sawnwood, wood-based panels, and paper and paperboard. Import was not included, since the "Production approach" is used. The average ratio for each category was then used to calculate the national consumption and export in the commitment period 2021-2025. The average ratio of total HWP/harvest for the reference period is 0.765. The rest of the harvested volume (ratio 0.235) is assumed to be used for energy. The energy use/HWP ratio is 0.308, see chapter 3.3.10 for details.

Table 2 gives an overview of the annual harvest level in the reference period, and the ratio used for national consumption and export for the three HWP categories. The average of these ratios is held constant when constructing the forest reference level.

Table 2. Annual harvest level in the reference period, and the ratio used for national consumption and export for the three HWP categories. The HWP ratio is calculated from thinning and final felling.

Year	Harvest (includes other harvest)	Commercial thinning and final felling	Sawnwood		Wood based panels		Paper and paperboard	
			National	Export	National	Export	National	Export
	m^3	m^3	Ratio	Ratio	Ratio	Ratio	Ratio	Ratio
2000	8 484 771	7 513 214	0.216	0.087	0.03	0.053	0.072	0.444
2001	11 206 536	9 842 569	0.17	0.059	0.028	0.035	0.031	0.35
2002	8 727 747	7 780 445	0.206	0.08	0.034	0.038	0.054	0.404
2003	9 208 585	7 319 424	0.222	0.076	0.033	0.041	0.073	0.431
2004	9 627 600	8 545 266	0.205	0.056	0.044	0.037	0.057	0.395
2005	8 557 084	7 406 180	0.254	0.06	0.052	0.04	0.071	0.435
2006	12 181 806	10 608 116	0.181	0.045	0.047	0.021	0.046	0.289
2007	10 088 445	8 535 933	0.236	0.045	0.047	0.034	0.058	0.338
2008	9 841 772	7 647 243	0.237	0.054	0.043	0.033	0.057	0.362
2009	11 430 140	10 234 791	0.139	0.045	0.034	0.021	0.046	0.213
Average	9 935 449	8 543 318	0.207	0.061	0.039	0.035	0.056	0.366

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

Biodiversity and forest policy are not covered by the EEA agreement, and the EU Forest Strategy and biodiversity strategy are therefore not implemented by Norway. Norway is, however, following the same principles as set out in these strategies. European countries have, through the ministerial process FOREST EUROPE, developed a framework which defines sustainable forest management. "Sustainable forest management" means the stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other eco-systems. As a signatory to FOREST EUROPE, Norway is committed to promote and to apply this framework in national policies.

The central objective of Norway's Forestry Act (2006) is to promote local and national economic development and to secure biological diversity, considerations for the landscape, outdoor recreation and the cultural values associated with the forest. The Forestry Act also contributes to the conservation of biodiversity and the sustainable use of natural resources.

The Government has a goal to protect 10 % of the forest area. The status as of January 2020, is that 5.0 % of the total forest area, including 3.8 % of the productive forest area, has been protected.

No forest harvesting is allowed in areas protected for biodiversity purposes, and hence these areas are kept aside in the construction of the FRL.

For more information on sustainable forest management practices and the Government's increased focus on environmental concerns, see chapter 2.3.

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

Since Norway is not a Member State of the EU, we are not obligated to report national projections of anthropogenic greenhouse gas emissions by sources and removals by sinks under Regulation (EU) No 525/2013. We have, however, on a voluntary basis, reported projections, including on LULUCF, to the European Environment Agency (EEA), in accordance with Regulation (EU) No 525/2013.

The forest reference level is consistent with the reported national projections in the sense that both the forest reference level and the projections reported to the EEA are based on activity data from the National Forest Inventory (NFI) and methodologies used in the national greenhouse gas inventory. Both approaches also include the carbon pools living biomass, dead wood, litter and soil carbon.

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 reference level is based on the same definitions, carbon pools, methodologies and historical data as applied in the national greenhouse gas inventory. It is hence based on transparent, complete, consistent, comparable and accurate information that undergoes revision by an expert team according to the guidelines in 24/CP.19. For the same reasons, the model used to construct the reference level can reproduce historical data from the national greenhouse gas inventory.

In chapter 4.2 we demonstrate that the FRL is consistent with the national greenhouse gas inventory.

1.2.2 Annex IV section B

Annex IV section B of the LULUCF Regulation sets out the key elements that the national forestry accounting plan (NFAP) shall contain. Norway has developed the NFAP according to the proposed common table of content, to make sure we document each step of the suggested approach to implementing the FRL requirements in line with the LULUCF Regulation.

2 Preamble for the forest reference level

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

The forest reference level includes the following carbon pools; living biomass (above and below ground), dead organic matter (dead wood and litter) and mineral soils, drained and undrained organic soils. In addition, the carbon pool of harvested wood products is included. Hence, no carbon pools are omitted.

The forest reference level also includes emissions of CH_4 and N_2O from forest fertilisation, drained organic soils, and biomass burning (wildfires).

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

The definitions, methodologies and data used to estimate carbon stock changes in the national greenhouse gas inventory are the same as applied in the calculations of the forest reference level.

The main source for activity data is the National Forest Inventory (NFI). The NFI utilises a 5-year cycle based on re-sampling of permanent plots. The same plots are distributed across the country in order to reduce the periodic variation between years, and each year 1/5 of the plots are inventoried. The current system with permanent plots was put in place between 1986 and 1993 and made fully operational for the cycle covering the years 1994 to 1998.

Below we give a short introduction to the definitions of the included carbon pools and associated methodologies used to estimate carbon stock changes. The methodologies are used both in the national greenhouse gas inventory (for more information, see NIR 2020) (Norwegian Environment Agency 2020) and applied in the calculation of the reference level.

2.2.1 Living biomass

Living biomass is defined as the biomass of living trees with a breast height diameter > 50 mm. For the biomass of all living trees observed on an NFI sample plot with a stem diameter larger than 50 mm at breast height (DBH), the carbon stock change is calculated. Thus, shrubs and non-woody vegetation are not included. Since tree coordinates are measured on NFI plots, each tree can be attributed to a land use category. Single tree allometric regression models developed by Smith et al. (2016; 2014), Marklund (1988), and Petersson and Ståhl (2006) are applied to DBH and height measurements from the NFI for estimating the tree biomass. The aboveground biomass of a tree is the sum of the estimates of the fractions of stem, stump, bark, living branches, and dead branches. The belowground biomass is the estimate of the fraction of stump and roots minus the estimate of the fraction of stump. The stock change method is used to calculate carbon stock changes (CSC) in living biomass. The method used corresponds to Tier 3, which uses a combination of NFI data and models to estimate changes in biomass. See the Norwegian NIR 2020 for more information on the models used to estimate the biomass of the different tree fractions.

The biomass models are defined for Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*), and birch (*Betula pendula and Betula pubescens*). These species constitute approximately 92 % of the standing forest volume (Larsson & Hylen 2007). Other broad-leaved species constitute most of the remaining eight per cent. The birch biomass models are applied to all broad-leaved species.

Living biomass is estimated consistently based on the same biomass models from 1990 and onwards.

2.2.2 Dead organic matter (dead wood and litter) and mineral soils

For forest land remaining forest land, the changes in the dead organic matter pool are the changes resulting from the input and decomposition of all dead organic material (woody and non-woody, aboveground and belowground; C input) regardless of size and stage of decomposition. Only the most recalcitrant material (humus) originating from root decomposition is allocated to the soil pool.

The model used to estimate C stock changes in soils provides an estimate for the soil organic carbon (SOC) in total, which includes the dead wood, litter, and soil pools. This methodology is used for the forest area on mineral soil only. The estimate of total SOC entails all stages of decomposition and all C input elements regardless of size and origin (input aboveground or belowground). The total SOC change estimate was allocated to the dead wood, litter, and soil pools, respectively.

The emissions and removals of total soil organic C (dead wood, litter, and soil pools) from forest land on mineral soil are estimated using the decomposition model Yasso07 (Tuomi et al., 2008; Tuomi et al., 2009; Tuomi et al., 2011a; Tuomi et al., 2011b). This corresponds to a Tier 3 method.

The same model is used from 1990 onwards.

See Dalsgaard et al. (2016) and the national greenhouse gas inventory (NIR 2020) for more information on the Yasso07-model and the Norwegian application of the model.

2.2.3 Drained organic soils

On forest land, organic soils are defined as having an organic layer deeper than 0.4 meters. Emissions (CO_2, N_2O and CH_4) from drained organic forest soil were included using the methodology of the national greenhouse gas inventory of Norway (NIR 2020).

Norway uses a Tier 1 methodology with default emission factors. We have assumed that the emissions in 2021-2025 will be the average of the emissions from this source in the reference period 2000-2009.

2.2.4 Undrained organic soils

Organic soils on forest land, defined as soils with an organic layer deeper than 0.4 meters, not subject to drainage, are assumed to be in equilibrium. No methods are available in the IPCC guidelines for the estimation of the carbon emissions or removals on these areas. The forestry activity in areas with undrained organic soils is relatively low.

The same methodology is used in the national greenhouse gas inventory, see NIR 2020 for further justification. The methodology is used consistently throughout the reporting- and estimating period.

2.2.5 Sources of non-CO_2 emissions

Projections of emissions from N-fertilisation and biomass burning (wildfires), were estimated based on the emissions reported in the national greenhouse gas inventory for the activity Forest management under article 3.4 of the Kyoto Protocol.

N_2O emissions from nitrogen mineralization were considered, but do not occur as mineral soils act as a sink of carbon. Emissions (CH_4 and N_2O) from biomass burning cover emissions from wildfires. Controlled burnings occur to a very little extent in Norway and is reported as NE in the national greenhouse gas inventory report (NIR).

N-fertilisation

Direct and indirect N_2O emissions from N-fertilisation were included in the reference level. The methodology of the national greenhouse gas inventory was used (NIR 2020). The N_2O-emissions for the years 2021-2025 are assumed to be the average of the emissions from the source in the reference period 2000-2009.

Biomass burning - wildfires

CO_2, CH_4 and N_2O emissions from wildfires were included in the reference level. CO_2 is part of the total estimates (reported in the common reporting format (CRF) as included elsewhere (IE). For wildfires, the emissions for 2021 to 2025 were estimated as a constant value being the average of the emissions in the reference period 2000-2009 (NIR 2020).

2.2.6 Harvested wood products

We present one forest reference level where we assume instantaneous oxidation (Tier 1) and one where we use the first-order decay function and the default half-life values for the three default HWP categories sawnwood, wood-based panels and paper and paperboard, as specified in Annex V of the LULUCF Regulation (Tier 2). We do not include imported harvested products; hence, we use the so-called "Production approach". Harvested wood products in solid waste disposal sites and harvested wood products that were harvested for energy purposes are accounted for on the basis of instantaneous oxidation.

This is the same approach and methodology as we use when reporting emissions and removals from harvested wood products in the national greenhouse gas inventory. For more information, see NIR 2020.

2.3 Description of the long-term forest strategy

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

Norway has an active forest policy, which, among other things, aims to increase forest carbon stocks. The forest also represents an important source of renewable energy and contributes to the production of wooden materials that can replace materials with a larger carbon footprint. The forest as a renewable resource is strengthened through research, value creation, and long-term sustainable management of the forest in which biological diversity is secured.

As mentioned, the projections indicate that the Norwegian forest capacity as a carbon sink has reached a peak and that annual increment is likely to decline over the next decades unless new measures are implemented. However, the carbon stocks are still increasing in Norwegian forests. The Government has implemented support schemes for regeneration, afforestation, increased seedling density on regeneration sites, enhanced breeding of forest seedlings, and fertilisation of forest stands to increase the forest sink capacity in the future. Norway has in the latest years increased support for these measures significantly.

Overall description of the forests

Forest land is, in the National Forest Inventory (NFI), defined as land with tree crown cover > 10%. The trees must be able to reach a minimum height of 5 meters at maturity in situ. Minimum area and width for forest land considered in the Norwegian inventory are 0.1 hectares (ha) and 4 meters, respectively. The values used in the NFI are within the range of parameters in the definition from the Global Forest Resources Assessment (FRA) 2005.

Forest land cover 12 million hectares and constitute 37.5 per cent of the land area in Norway. The most important species are Norway spruce (47 per cent), Scots pine (33 per cent) and birch (18 per cent). Forest ownership in Norway is dominated by private ownership with many small properties. Due to the ownership structure and specific terrain conditions, Norwegian forestry is diversified and characterized by small-scale activity.

All forests in Norway are considered managed, either for wood harvesting, protection and protective purposes, recreation, and to a greater or lesser extent, hunting and berry picking. On more marginal and less productive land, the various management practices may be less intense, but still present.

In 2018 forest land contributed to net removals of 27.8 million CO_2-equivalents. Figure 2 shows emissions and removals of CO_2 on forest land from the carbon pools living biomass, dead wood, litter, mineral soil and organic soil from 1990 to 2018.

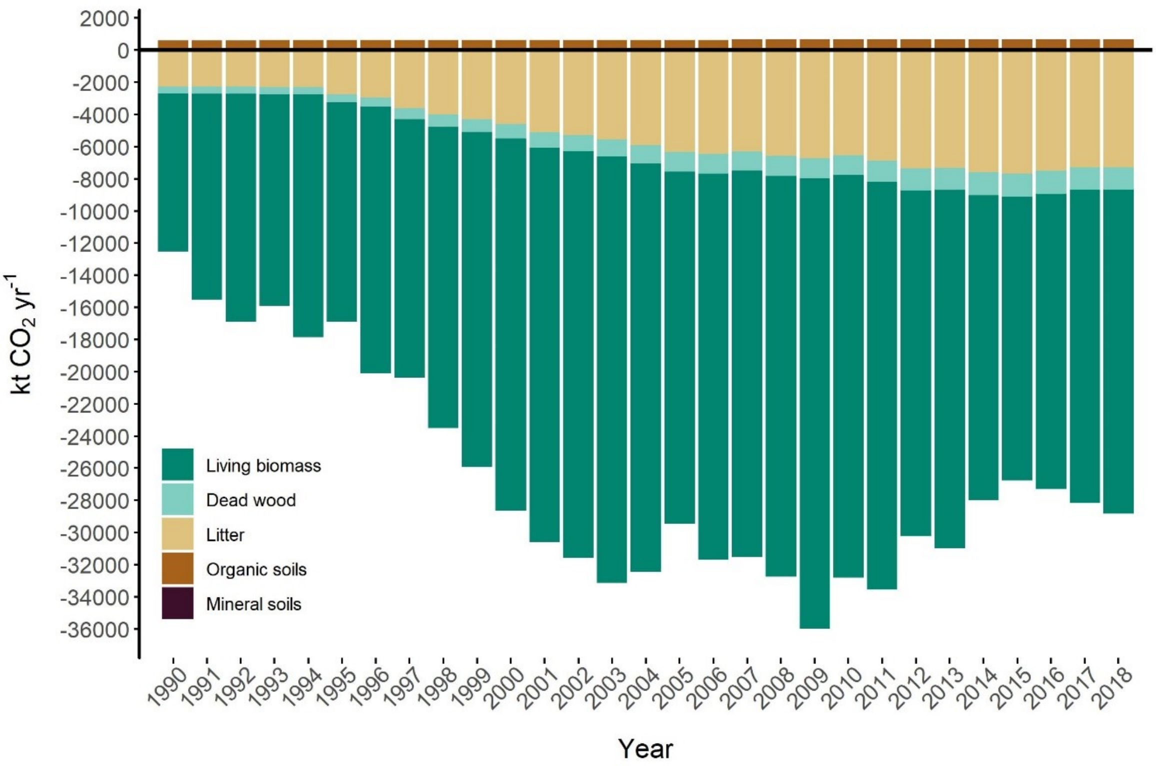

Figure 2. Emissions and removals of CO2 on forest land from living biomass, dead wood, litter, mineral soil and organic soil from 1990 to 2018. Source: Norwegian NIR 2020, Norwegian Institute of Bioeconomy Research.

Since 1990, the growing stock in Norway has increased by around 30 per cent (figure 3). The steady increase in the growing stock is the result of an active forest management policy over the last 60-70 years. The combination of the policy to rebuild the country after World War II and the demand for timber led to a great effort to invest in forest tree planting in new areas, mainly on the west coast of Norway, and replanting after harvest on existing forest land. In the period 1955-1992, more than 60 million trees were planted annually with a peak of more than 100 million planted annually in the

1960s. These trees are now in their most productive age and contribute to the increase in the living biomass, and hence the carbon stock. Furthermore, the annual fellings are much lower than the annual increment, causing an accumulation of available timber resources. The number of planted trees has been decreasing since 1992, with a bottom in 2003 when only 16 million trees were planted. Since then, the number of planted trees has more than doubled, to 44 million trees annually in 2019.

Due to a relatively low harvest rate (approximately 40 per cent of the annual increment) and decreasing number of planted trees since 1992, the Norwegian forest has a very skewed age class structure that will lead to a long-term reduction of the Norwegian forest sink. The projections also confirm that the Norwegian forest capacity as a carbon sink has reached a peak and that annual increment is likely to decline over the next decades due to aging forests and reduced investments in regeneration during the last decades.

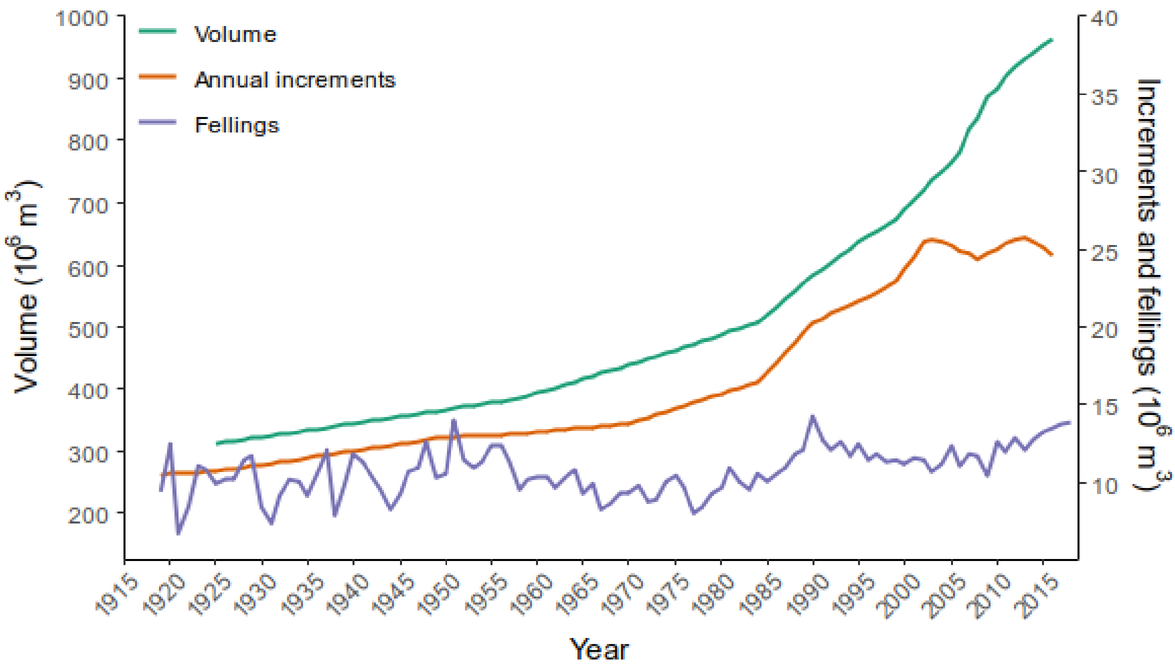

Figure 3. Forest fellings, annual increment and volume, 1919–2018. The 2014 value is the middle year in the National Forest Inventory cycle (2012-2016) for volume (without bark) and annual increment. The values for the two last years are extrapolated. Source: Norwegian NIR 2020, Norwegian Institute of Bioeconomy Research and Statistics Norway.

From figure 4, we see that net land-use changes in Norway from 1990 to 2018 have been minimal. Only the area of settlements has increased slightly, while the other land-use categories have decreased or remained relatively constant. There have been land-use changes from all categories to forest land (afforestation). At the same time, there has also been forest land converted to other land uses (deforestation), resulting in a small net decrease in the area of forest land. Forest land made up 37.67 % of all land use in 1990 and 37.49 % in 2018.

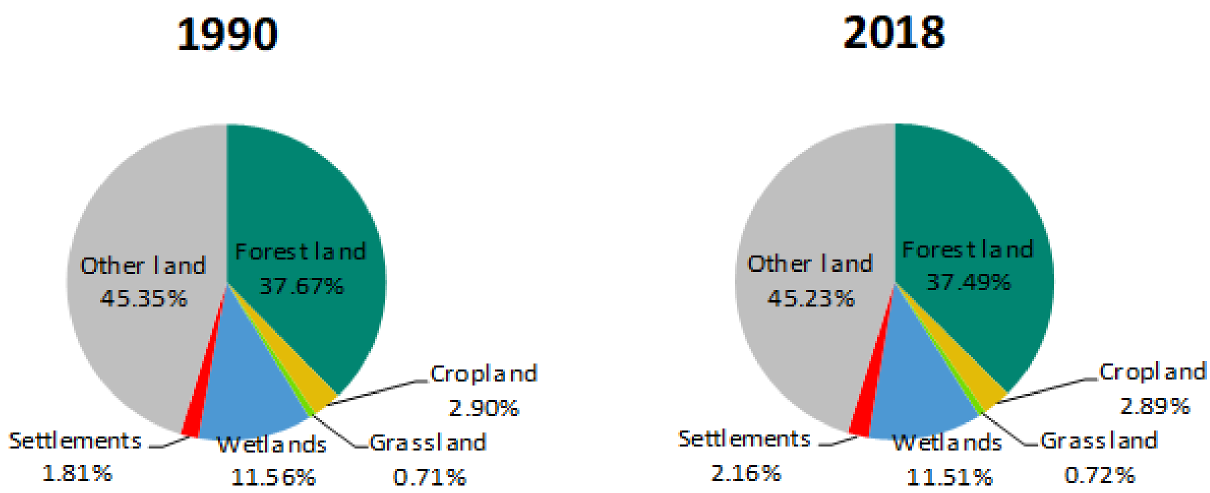

Figure 4. Area distribution of the IPCC land-use categories for 1990 and 2018. Source: Norwegian NIR 2020, Norwegian Institute of Bioeconomy Research

Forest management in Norway and the adopted national policies

A wide range of measures, including legislation, taxation, economic support schemes, research, extension services and administrative procedures, support the implementation of forest policy and mitigation actions. The main objective of the current Forestry Act from 2006 is to promote sustainable management of forest resources with a view to promote local and national economic development and to secure biological diversity. The Forestry Act also contributes to the conservation of biodiversity and the sustainable use of forest biomass. However, the measures implemented will also influence CO_2 sequestration.

As a part of the climate policy, the Government has introduced measures designed to maintain or increase the carbon stocks in forest and facilitate extended use of biomass as a substitute for fossil energy sources and building materials with a larger greenhouse gas footprint and convert to use of renewable biomass for several industrial processes. Several measures have been initiated aiming to increase greenhouse gas removals. These measures also encourage commercial activity and help to maintain a good resource base for the forest and wood industry. The Government will further develop and consider whether to strengthen these measures and will also review and further develop other measures for reducing emissions and increasing removals in the LULUCF sector.

For more information about adopted forest policies in Norway and their estimated effect, see Norway's Seventh National Communication and Norway’s Fourth Biennial Report.

2.3.2 Description of future harvesting rates under different policy scenarios

In the reference period from 2000 to 2009, the average total annual harvest level (including top and waste) from managed forests as recorded by the NFI was 9.9 million m^3 (see Table 2). In the period between 2000 to 2009 there were large changes in the Norwegian forest industry (closure of many pulp mills) and meagre prices on timber and pulpwood. In more recent years, we have seen a change in the Norwegian market, including an increasing demand for wood-based products, and the former decreasing trend of timber prices has reversed. At the same time, there is a steadily increasing amount of mature forest (especially commercially attractive planted Norway spruce). The combination of increased supply (mature spruce stands) and more normalised prices has led to an increased harvest rate in recent last years. After the reference period, the harvest level has increased to 12.7 million m^3 in 2019 (merchantable timber including, deforestation and firewood).

The Norwegian Parliament is aiming to increase harvest and has strengthened the forest industry since the beginning of this century. In the current Policy platform (the Granavolden Platform), the Government also states that it intends to take steps to increase the timber harvest. Increased focus on forestry should be followed by increased environmental considerations, latest expressed by the ***Parliament's treatment of the White Paper to the Stortinget, Meld St. 6 (2015-2016), on the forest policy***. According to the ***Governments Political platform,*** the Government will facilitate increased harvest. The Government set a goal in 2008 to ensure targeted and coordinated policy instruments for increased ***expansion of bioenergy*** *up to 14 TWh by 2020*. ***The Norwegian quota obligation for biofuels in road transport*** has increased the use of liquid biofuels strongly in recent years. The Government has pledged to increase the biofuel quota obligation (the required proportion of biofuels in annual sales of road traffic fuels) to 40 per cent in 2030 depending upon the development of technology and alternative energy carriers. In the latest National Transport Plan (2018 to 2029), the Government announced ambition of 30 per cent sustainable biofuel in aviation by 2030, and from 2020 0.5 per cent of the aviation fuel should be advance biofuels. The Government is also considering biofuel requirements in shipping and for non-road vehicles and machines. All the targets mentioned above correspond to a volume of approximately 10-12 million m^3 timber or harvesting residue. The Government is concerned about the Indirect Land Use Change (ILUC-effect) of conventional biofuels, and therefore highlights the importance of increasing the production of advanced biofuels. At the same time, biomass demand from processing industries is expected to multiply over the next decades, according to the industry's own roadmap for low carbon development. In sum, the political and industrial targets could raise a significant future demand for liquid biofuels and biomass.

The Government's bioeconomy policy (2016) includes sustainable, efficient and profitable production, extraction and use of renewable biological resources for food, feed, ingredients, health products, energy, materials, chemicals, paper, textiles and other products. The bioenergy policy has pledged to utilise the potential for increased, profitable and more efficient production, extraction and use of renewable biomass from agriculture, forestry, fisheries and aquaculture within sustainable boundaries. The Government presented a ***National Strategy for Green Competitiveness*** in October 2017. The aim of the strategy is to provide more predictable framework conditions for a green transition in Norway, while maintaining economic growth and creating new jobs. The strategy recognises the mitigation potential associated with increased use of the Norwegian forest resources and points out some prioritized measures like; increased use of wood in the building sector, increased use of chemicals from bio-refineries, use of timber based products as feed for the fish industry, increased use of biochar, biofuel and bioplastic.

Renewable timber resources can simultaneously contribute to the displacement of fossil emissions and prolonged carbon storage in the pool of harvested wood product. Access to sustainable forest biomass is also an important premise for carbon dioxide removal (CDR) technologies like biochar and bioenergy with carbon capture and storage (BECCS).

The Government’s strategies and policies indicate a higher harvest volume and more use of forest residues. They do, however, not say anything about the exact amount of additional biomass coming from the Norwegian forest. To meet the increased demand biomass can be imported.

The ***Office of the Auditor General of Norway*** (2016) has reprimanded that the trend of timber harvesting in Norway is not in line with the goals set by the Parliament. However, the Norwegian

Government intends to take steps to increase the sustainable timber harvest level to support national goals for bioeconomy and emission reductions in other sectors.

The Norwegian forest industry aims to increase the timber harvest to around 15 mill m^3 (merchantable timber including deforestation and firewood) (***SKOG 22 – National strategy for the Forest and Wood Industry, January 2015***). The goal set by the industry is based on an analysis from the Norwegian Institute of Bioeconomy Research on available forest resources, confirming that 15 mill m3 is both environmentally and economically sustainable. Increased sustainable use of residues (slash) is not included and may increase the utilised volumes of biomass in the future.

Studies have estimated that the long-term sustainable and realistic harvest level in Norway vary between 14-18 million m^3 dependent on the expectation of both demand (prices) and how additional environmental protection is implemented. The estimate is based on available mature forest, a continuation of the existing management practices and protection of 10 % of the forest area (doubling of the current protected area). For comparison, the estimated harvest volume in the FRL is approximately 14.6 million m^3 in the period 2021-2025, with a steady increase until the end of the century (Figure 7).

A recent study, Klimakur 2030, is analysing how Norway can reduce non-ETS emissions by 2030, including possible measures to increase removals and reduce emissions in the land sector. Results from the study show that few of the measures in managed forest land have an impact in the short term (before 2050). The measures having an effect in the short term are fertilisation and reduced harvest in the immature forest. These measures will also affect the harvest level, albeit in opposite directions. The effects in the long term are however significant.

These reports, strategies and policies are the basis for the Government's decision to take steps to increase the timber harvest in a sustainable manner and in line with the long-term goals of the Paris agreement.

The Government is currently writing a White Paper on how Norway can fulfil the climate target for 2030 under the Paris agreement. If new measures and policies are implemented in the forestry sector to improve the annual increment, the future harvesting volumes will also increase. An increased harvest rate will reduce removals in the short term (2021-2030) but increase long term removals (second half of the century) due to forest regrowth if relevant measures are implemented. Today, there is no industrial use of forest residues (e.g. branches and tops) and residues are left for natural decomposition in the harvested sites.

In the case that harvest residues will become utilised for energy purposes during the commitment period, this will result is an increase in emission for the LULUCF sector (reduced net uptake in DOM and soil compared to the FRL) and reduced emission in the energy sector.

The increased focus on forestry is followed by ***increased environmental consideration***s. It is currently under consideration what increased environmental considerations implies. The Government has set a goal to protect 10 % of the forest area. By January 2020, 5.0 % of all forest area is protected, including 3.8 % of the productive forest area. It is not decided which additional areas will be protected to achieve the goal. If 10 % of the forest area is protected, there will still be a large and increasing volume available for harvest. The Government will give greater weight to environmental concerns in forestry. The Government will, together with the forest owners' organizations, outline appropriate measures for increased safeguarding of key biotopes.

3 Description of the *modelling* approach

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

The overall approach used to construct the forest reference level is in accordance with the LULUCF Regulation and follows the Guidance on developing and reporting Forest Reference Levels in accordance with Regulation (EU) 2018/841. The forest reference level is constructed based on the management practices and intensities in managed forests in Norway in the reference period 2000 – 2009. The definitions, methodologies and data used to calculate the forest reference level are consistent with the methods used to estimate emissions and removals related to the different carbon pools in the national greenhouse gas inventory, see chapter 2.2.

The main data source of the national greenhouse gas inventory for managed forest is the National Forest Inventory (NFI). The general approach for constructing the forest reference level is to forecast the development and management of the NFI plots and then apply the same methods for estimating emissions of the different pools as in the national greenhouse gas inventory.

The main steps in the modelling approach are:

(1) **Stratification of the managed forest area (see section 3.2.1)**: Norway has a large forested area with a large variation in topography, accessibility, productivity and cost of forest operations. Consequently, the management practices and intensity vary greatly within the forested area. In general, there is a high management intensity in areas of high productivity dominated by spruce and pine. These areas often have low cost of operations (flat terrain and good road access). Generally, there is a very low management intensity in low-productive forests, hardwood forests and areas with poor infrastructure (road network). To account for this general variation in management practices seven strata are defined (see section 3.2.1) and applied to both the reference period and the forecast. Every plot remained in the same stratum for the full simulation.

(2) **Calculation of management intensity in the reference period (see section 3.2.2)**: In Norway, the forest management practices applied varies with the same factors as used in the stratification of the forest area. Highly productive spruce forests are most often clear cut and planted with high density. Lower productivity spruce forest is also clear cut but are regenerated with a lower density. Pine forests are naturally regenerated with seed trees, while hardwood forests are naturally regenerated. Hence, five different management practices were defined, and their area-based intensity is estimated with data from the reference period (see section 3.2.2).

(3) **Simulating the growth, mortality and ingrowth in the NFI plots (see section 3.3)**: The NFI consists of permanent plots where individual trees are re-measured at five-year time intervals. The key processes that affect the different carbon pools are growth, mortality and ingrowth. In order to forecast the NFI plots, an individual tree model (SiTree) is applied to the NFI plots which results in a data structure that is consistent with the data structure in the historic NFI (a table with individual trees and a table with plots variables) which makes it possible to directly use the methods from the national greenhouse gas inventory report to the forecasted data (see section 3.3).

(4) **Implementing management in the simulations:** In the simulations of the NFI plots, the management intensities (section 3.2.2) for the different strata (section 3.2.1) must be

implemented consistently with the management in the reference period. In practice, this implies selecting which plots should be harvested and thinned in each stratum. To do this task, we apply a regression model (see Antón-Fernández and Astrup, 2012) that ranks the probability of harvest or thinning for all plots. The plots with the highest-ranking get scheduled for harvest until the target area of the stratum/maturity combination (Table 8) is reached (see section 3.2). The remaining plots, not scheduled for harvest, are then ranked according to their thinning probability (see Antón-Fernández and Astrup, 2012). The plots with the highest probability of thinning are scheduled for thinning until the target area for each stratum/maturity combination is met. Details of the implementation can be found in section 3.3.

(5) **Estimating emissions and removals based on the forecasted NFI plots**: Once the simulation is completed, the methods for estimating emissions and removals from the national greenhouse gas inventory (see section 2.2) is applied to the simulated data, and the forest reference level is complete.

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

Below we give an overview of the main sources of data used to construct the forest reference level:

- The main source for activity data in the national greenhouse gas inventory is the National Forest Inventory (NFI) which is documented and described in detail in the national greenhouse gas inventory (NIR2020). The NFI utilises a 5-year cycle based on re-sampling of permanent plots. The same plots are distributed across the country in order to reduce the periodic variation between years, and each year 1/5 of the plots are inventoried. The current system with permanent plots was put in place between 1986 and 1993 and made fully operational for the cycle covering the years 1994 to 1998.
- Climate data: Climate data is used in forecasting both the individual tree development, as well as in modelling of dead organic matter (DOM) and soil organic matter (SOM) with Yasso07. Climate data used in forecasting the individual tree development for the simulations follow the IPCC scenario RCP 4.5 downscaled to a 1 by 1 km grid for Norway. The climate data used in DOM and SOM simulations follow the GHGI methodology, and therefore assumes no climate change. The utilised downscaled climate data is freely available at http://www.senorge.no/aboutSeNorge.html?show=on
- Harvested Wood Products: For HWP the ratios between the different product categories are calculated based on data from FAOSTAT.

3.2.1 Documentation of stratification of the managed forest land

The managed forest land (MFL) was stratified into seven different strata (Table 3). The stratification of the managed forest land is based on stand species composition, productivity expressed as a site index, and harvest cost which can be seen as an integrated measure of terrain and road accessibility. The site index system in Norway is using a reference age of 40 years, where a site index of 17 means that the dominant height of the stand is 17 meters at 40 years. Harvest costs in Norwegian kroner per m^3 are estimated according to standard approaches in Norway which is described in detail by Granhus et al. (2011). See Table 5 for information on the different forest management practices (FMP) applied in the reference period.

Table 3. Stratification of the managed forest into seven strata with associated management practices.								
Stratification of MFL				**% distribution of forest management practices**				
Availability for wood supply	**Main species**	**Site index**	**Cost**	**FMP 1**	**FMP 2**	**FMP 3**	**FMP 4**	**FMP 5**
Not protected	Spruce	>= 17	< 300	100%				
		>= 14 and < 17	< 300		100%			
	Pine	>= 14	< 300			100%		
	Hardwoods	>= 14	< 300				100%	
	All	>= 6 and <14	No limit				100%	
		< 6	No limit				100%	
Protected	All	No limit	No limit					100%

Each plot was assigned a stratum according to Table 4 at the initial point of the simulation, that is, 2009, the last year of the reference period. Every plot remained in the same stratum for the full simulation. The area under forest management in 2009 was 12 089 kha in NIR 2020. The difference of 3 kha between the simulated area (12 092 kha), and the area under forest management in the NIR2020 corresponds to partial plots and unproductive and low-productive birch dominated plots. The difference between the area in the FRL and NIR2020 accounts for 0.02% and are in low-productive areas. The impact on the total FRL is therefore minimal.

Table 4. Area (kha) in each stratum in the last year of the reference period.				
Stratification of MFL				**Area (kha)**
Availability for wood supply	**Main species**	**Site index**	**Cost**	
Not protected	Spruce	>= 17	< 300	646
		>= 14 and < 17	< 300	500
	Pine	>= 14	< 300	291
	Hardwoods	>= 14	< 300	539
	Any	>= 6 and <14	Any	6340
		< 6	Any	3378
Protected	Any	Any	Any	398
Total				12092

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

In high latitude forests, growth rates and forest development are generally slow. This results in long rotation ages. Hence, only a small part of the forest area is treated each year. At the same time, the only management actions that have any significant effect on the stock changes in the period 2010-2030 is the amount of harvest and thinning carried out. Planting and tending intensities will have a large impact in the long run but will only have minor effects on the short-term stock changes. In the reference level, we apply five main forest management practices (FMP) (Table 5).

Table 5. Forest management practices.

Index	Name of practice	Short description of practice
FMP1	Spruce intensive	Clear cutting and artificial regeneration with 2500 trees/ha.
FMP2	Spruce	Clear cutting and artificial regeneration with 1500 trees/ha.
FMP3	Pine intensive	Seed tree with natural regeneration.
FMP4	Low intensity	Clear cutting (seed tree for pines) with natural regeneration. For spruce stands planting with 1500 trees/ha.
FMP5	Protected	No management

When thinning, 32 per cent of the aboveground biomass is removed, and in final felling 88 per cent of the aboveground biomass is removed (Table 6). The removal intensities are based on the observed removal intensities in the NFI in the reference period for forest land remaining forest land.

Table 6. Biomass removals in thinning and final felling.

Forest management practice		**Commercial thinning**		**Final felling**	
Index	**Name of practice**	**Age**	**% biomass removals**	**Age**	**% biomass removals**
FMP1	Spruce intensive	Any	32	Any	88
FMP2	Spruce	Any	32	Any	88
FMP3	Pine intensive	Any	32	Any	88
FMP4	Low intensity	Any	32	Any	88
FMP5	Protected	NA	NA	NA	NA

The forest management practices are applied to the different strata in accordance with Table 3. Thinning and final felling are not restricted to a given age-class, as the data in the reference period shows a large variability in the timing of both thinning and final felling.

For calculations of thinning and harvest intensities the forest is divided into mature and immature forests. Given the large variability in site productivity across the Norwegian forested landscape, the actual age at which a forest is mature vary with site productivity, where low-productive forest become mature at a much later age than more productive forests. In order to determine whether a forest is mature, we apply the age thresholds outlined in Table 7.

Table 7. Age threshold for classifying a forest as mature in the calculation of harvest intensities.

Species		Site index
Conifers	Hardwoods	
100	60	6
90	50	8
80	50	11
70	50	14
60	40	17
50	30	20
40	20	23
40	20	>23

The harvest and thinning intensities for each of the seven strata for both mature and immature forests were estimated based on the observed intensities in the NFI in the reference period (Table 8). It should be noted that the intensities vary greatly between the strata, which indicates that the strata definitions were successfully set, in order to divide the managed forest into strata with homogenous management activities. The pattern is clearly that harvest intensities are high in a highly productive conifer forest with low operation costs, while the intensity is low for low productive forest, especially for hardwoods.

Table 8. Thinning and harvest intensities in the reference period.

Stratification of Managed Forest Land (MFL)				% area managed every 5 years			
				Thinning		Final felling	
Availability for wood supply	Main species	Site index	Cost	Immature	Mature	Immature	Mature
Not protected	Spruce	>= 17	< 300	4.93	2.74	0.91	16.36
		>= 14 and < 17	< 300	2.14	1.53	0.53	11.82
	Pine	>= 14	< 300	8.63	6.17	0.98	9.97
	Hardwoods	>= 14	< 300	1.30	1.11	0.31	1.50
	Any	>= 6 and <14	Any	1.60	0.56	0.74	3.54
		< 6	Any	0.00		0.12	
Protected	Any	Any	Any	NA	NA	NA	NA

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

3.3.1 Starting year for the projection of the FRL

The initial point of the projection is 2009, and the first simulated results are for 2010. In practice we have used the 2007-2011 NFI plots on forest land as the initial point, corresponding to the year 2009 for forest land remaining forest land in the national greenhouse gas inventory report for 2020 (NIR 2020).

3.3.2 General description of the modelling framework

SiTree: Individual tree simulator

Growth, mortality and ingrowth occurring in all the NFI plots were simulated individually with SiTree which is a single tree growth simulator. The simulator is a publicly available R package (https://CRAN.R-project.org/package=sitree) and functions for growth, mortality, ingrowth and regeneration, and management are user-defined. All growth, mortality, and ingrowth functions used for the calculation of the FRL are fitted to the trees and plots in the NFI in the reference period. Specifically, the NFI cycle 2000-2004 (corresponding to the national greenhouse gas inventory report (NIR 2020) for 2002) until the NFI cycle 2007-2011 (corresponding to the national greenhouse gas inventory report (NIR2020) for 2009) were used to fit the functions that were applied in SiTree for the simulation of the forest reference level.

Functions for growth, mortality, ingrowth and natural regeneration

We used imputation methods to estimate growth, mortality, ingrowth, and natural regeneration. Nearest neighbour (NN) imputation algorithms are methods to estimate one or several variables for each tree or plot using values obtained from related cases in the reference database. The reference database is compiled using remeasurements from the NFI in the reference period. For example, to estimate growth, and mortality of a tree (target tree) during the simulation, we look for a similar tree in similar conditions (e.g. competition and social status) in the reference database, once we found the most similar tree in the reference database (reference tree), we assign its growth and if dead or alive to the target tree. In a similar way ingrowth can be imputed at plot level. To estimate ingrowth for a target plot one finds a similar plot in the reference database with similar characteristics (e.g. site index, basal area, and species composition), and assigns the ingrowth of the reference plot to the target plot, that is, the same number of trees, of the same size and species are assigned to the target plot.

Imputation methods have several advantages over traditional parametric regression techniques. Traditional parametric regression techniques need a predefined functional form, while nearest neighbour imputation methods neither require specifying the structure of the relationship between the target variable and the predictors nor do they require distributional assumptions. Since several variables can be imputed simultaneously for the same individual (tree or plot), the interrelations between them (e.g. DBH and height growth) are maintained for NN = 1 (McRoberts 2009). Another advantage of using imputation methods is that predictions are guaranteed to be within the realm of the biologically possible responses and in line with the reference period, in the sense that they have been observed, and that the range of imputed values is potentially as large as in the reference dataset. As a result, the original variability and range is maintained when NN = 1.

3.3.3 Growth and mortality (alive/dead/harvested)

To forecast tree growth and mortality we compiled a database (reference database) using data from the NFI in the reference period. This database consists of a set of variables describing the initial condition of the tree and stand and the outcome, growth and status (alive/dead/harvested), after 5 years. Plots that underwent final felling or thinning during those 5 years were discarded from the reference database. Plots that underwent other types of harvest than final felling and thinning were included. Therefore, the status of each tree in the reference database after the 5 years was "alive", "dead" or "harvested" (see section 3.3.7). Plot measurements from before 2000 were excluded due to concerns about data quality. For example, site index was not measured before 2000, but estimated by the field crews, therefore there were inconsistencies in the site index before 2000, compared to the newer measurements after 2000. Plots where we were unable to match all trees (5 full plots and 5 partial plots) were also removed from the reference database.

Growth and mortality were forecasted using the reference database with an imputation-based selection, based on the nearest neighbour (1-NN). To find the nearest neighbour for each tree (tree of interest) at each period we calculated the distance between the tree of interest (target tree) and the trees in the reference database of the same species group (spruce, pine, hardwoods). Distance was calculated based on the same variables as the latest published growth and mortality functions for Norway (Bollandsås et al., 2008), which are: site index (SI), initial DBH, latitude, basal area of larger trees, and stand basal area. Once the nearest neighbour tree was found, its growth (basal area increment and volume increment) and status (live/dead/harvested) was imputed to the tree of interest.

For trees in unproductive sites, where SI is missing, we used the probability of the plot being productive as explanatory variable instead of SI. Four imputation models were fitted using the NFI in the reference period, one for spruce trees in productive sites, one for pine trees in productive sites, one for hardwoods in productive sites, and one for trees in unproductive sites.

DBH increment is calculated as the DBH corresponding to the basal area (BA) which results from the initial BA + imputed BA increment for the tree. Height increment is then calculated by solving the volume equations used in the NFI, which calculates volume using DBH and height. The future volume is calculated as current volume + imputed volume increment.

To estimate the DBH, and height growth of dead and harvested trees, where we don't have estimates for DBH increment or volume increment, we have used DBH increment and volume increment from the next alive imputed tree.

3.3.4 Regeneration and ingrowth

Stand age is estimated in the NFI as the BA weighted stand age, and it is assessed in a circular plot of 1000 m^2.

When a plot is harvested it is assumed that the harvest occurs in the middle of the remeasurement period (2.5 years). Regeneration of a stand is assumed to happen shortly after harvest if the stand is replanted, or after a latency time if the stand is naturally regenerated. Latency time is the time that it takes for the harvested stand to produce enough seedlings to potentially form a stand. Table 9 gives an overview of the latency time for different site indices.

Table 9. Latency (years) for different site indices.

Site index	Conifers	Hardwoods
26	0	0
23	0	0
20	0	0
17	0	0
14	5	0
11	5	5
8	15	5

Ingrowth, the trees that during the 5-years period will grow over the 5 cm DBH limit, are imputed using a reference database based on data from the NFI in the reference period. To impute ingrowth at plot level SI for the main species, latitude, stand basal area, number of trees per ha, proportion of spruce, and proportion of hardwoods were used to find the NN plot in the reference period. For unproductive stands, we substituted SI for the probability of the plot to be productive. Natural regeneration is highly variable in terms of timing and density. Therefore, we simulate it through imputation after the latency period is over.

3.3.5 Site index

Site indices for the three main groups of species (spruce, pine, and hardwoods) are required at each productive plot. The NFI currently estimates site index for the main species, and potential site index for the potential main species. Potential main species is estimated for some plots where other species than the one currently growing on the stand would give higher productivity. Initial site index is taken from the 2007-2011 NFI, when available, either from the current site index or from the potential site index. Boosted regression trees (BRT) models fitted to the NFI plots are used to estimate site index for the species groups when the site index for that species group is not available from the NFI. The probability of a plot being productive, which is used instead of site index in unproductive sites, was also estimated using BRT and NFI data.

3.3.6 Climate change

Climate change affects the forest dynamics in the simulation through changes to the site index. Climate data is used in forecasting both the individual tree development, as well as in modelling of DOM and SOM with Yasso07. Climate data for the simulations of individual tree development follow the IPCC scenario RCP 4.5 downscaled to a 1 by 1 km grid for Norway. Climate data for the simulation of DOM and SOM with Yasso07 follow no climate change scenario, consistently with the methodology used in NIR2020. The utilised downscaled climate data is freely available at http://www.senorge.no/aboutSeNorge.html?show=on Site index changes due to climate change is projected using a Norwegian climate-sensitive SI model (Antón-Fernández et al., 2016) fitted to the NFI data.

3.3.7 Forest management practice: Harvest and harvest intensity

Removals of biomass from the forest were classified into three types: final felling (clear-cuts, patch clear-cuts, clear-cut with edge, seed-tree cutting, shelterwood, and selective cutting), thinning (free thinning, and high thinning), and other harvest (e.g. non structured cutting such as firewood cutting, salvage logging of small disturbances, and pre-commercial thinning).

Other harvest does not follow any planned pattern and was therefore implemented through imputation in the same way as natural mortality.

As described in section 3.2.2, final felling and thinning intensities were estimated based on the observed intensities in the reference period. Table 8 Thinning and harvest intensities in the reference period defines the % of area that should be managed at each period. Within each strata and maturity group, plots are ranked according to the probability of harvest (Antón-Fernández and Astrup, 2012), and final felling/thinning is scheduled for all plots, starting at the ones with highest probability of harvest, until the target harvest intensity is obtained.

3.3.8 How the harvest is applied at tree level

At each plot scheduled to be harvested, the amount of biomass to be removed is calculated as the total standing biomass of the plot multiplied by the % of the biomass removals (Table 6). To achieve the target biomass to be removed at each plot the largest trees (smaller trees for thinning) will be scheduled for removal until the target amount of biomass to be harvested is as close as possible to the target.

Dead and harvested trees are assumed to die in the middle of the period (2.5 years from the last measurement).

3.3.9 Assumptions concerning natural disturbances

We assume that natural disturbances will be similar to the ones observed in the reference period. They are included in the simulation approach when using imputation to model growth and mortality.

3.3.10 Calculation of harvested wood products ratios

In the reference period 2000-2009 the ratio of use of solid forest biomass (HWP)/harvest was on average 0.765 (Table 2) while the energy use/harvest was 0.235, i.e. the energy use/HWP ratio = 0.308. The total volume for HWP cannot be summarised directly since sawnwood and wood-based panels are provided in m^3 and paper and paperboard as metric tonnes. Hence, to demonstrate that energy use/HWP ratio is constant throughout the projection, the volumes of harvest and HWP is recalculated to Mg C. Table 10 demonstrate that the ratio of energy use/HWP remains constant throughout the projection.

Table 10. Demonstrating, for selected years, a constant ratio for energy use/HWP throughout the projection.

Year	HWP (Mg C)	Energy use (Mg C)	Energy use/HWP ratio
2018	1 520 234	467 642	0.308
2019	2 206 264	678 673	0.308
2020	2 335 200	718 335	0.308
…			
2028	2 260 232	695 274	0.308
2029	2 338 779	719 436	0.308
2030	2 363 999	727 194	0.308
…			
2038	1 709 215	525 775	0.308
2039	2 535 474	779 942	0.308
2040	2 162 209	665 121	0.308
…			
2048	2 739 732	842 774	0.308
2049	2 009 514	618 151	0.308
2050	2 578 326	793 124	0.308
…			
2058	2 564 141	788 760	0.308
2059	2 363 502	727 042	0.308
2060	2 643 843	813 278	0.308
…			
2068	2 218 760	682 517	0.308
2069	2 358 324	725 448	0.308
2070	3 186 481	980 200	0.308
…			
2078	2 425 330	746 061	0.308
2079	2 483 281	763 887	0.308
2080	2 960 069	910 552	0.308
…			
2088	2 497 023	768 114	0.308
2089	2 590 450	796 853	0.308
2090	**2 451 991**	**754 262**	**0.308**

4 Forest reference level

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

Norway has an age-class structure where large portions of the forest in the intensively managed state (highly productive spruce forests) are becoming mature in the next decades (Figure 5). As a result, the annual carbon removals are expected to decrease over time (Figure 6). In addition, the harvest level is expected to increase given the harvest intensity from the reference period (Figure 7).

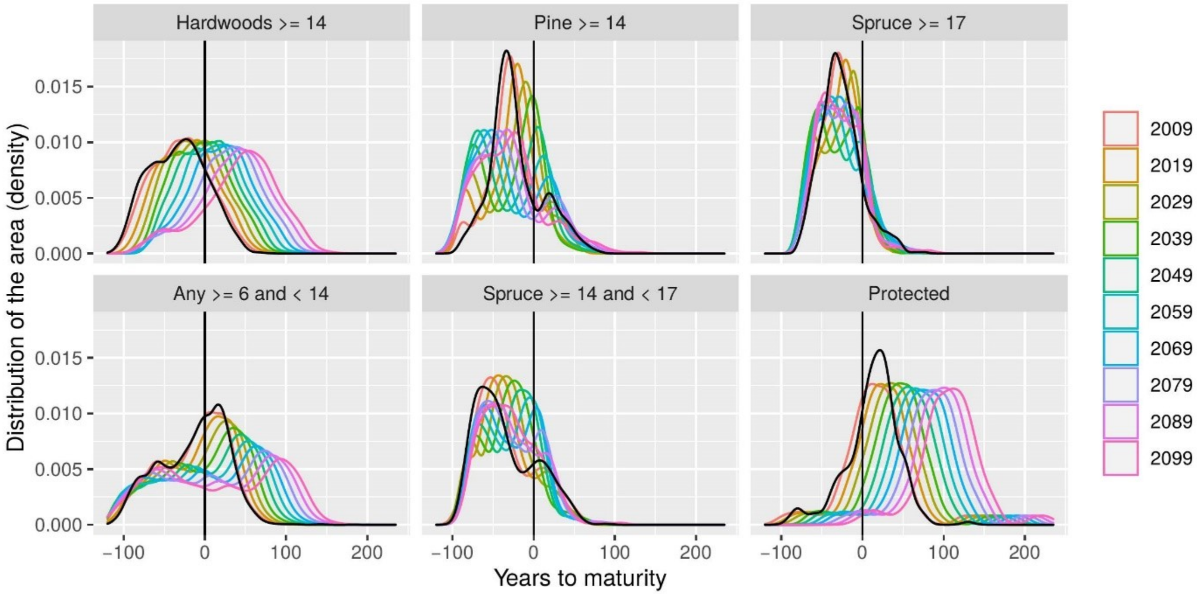

Figure 5 Development of the distribution of the area by stratum and years to reach maturity. The area to the left of the vertical line corresponds to "immature" stands and the area to the right of the vertical line corresponds to "mature" stands, following the definition in Table 7. The black line is the observed stand age distribution in the reference period and the coloured lines are changes in projections over time.

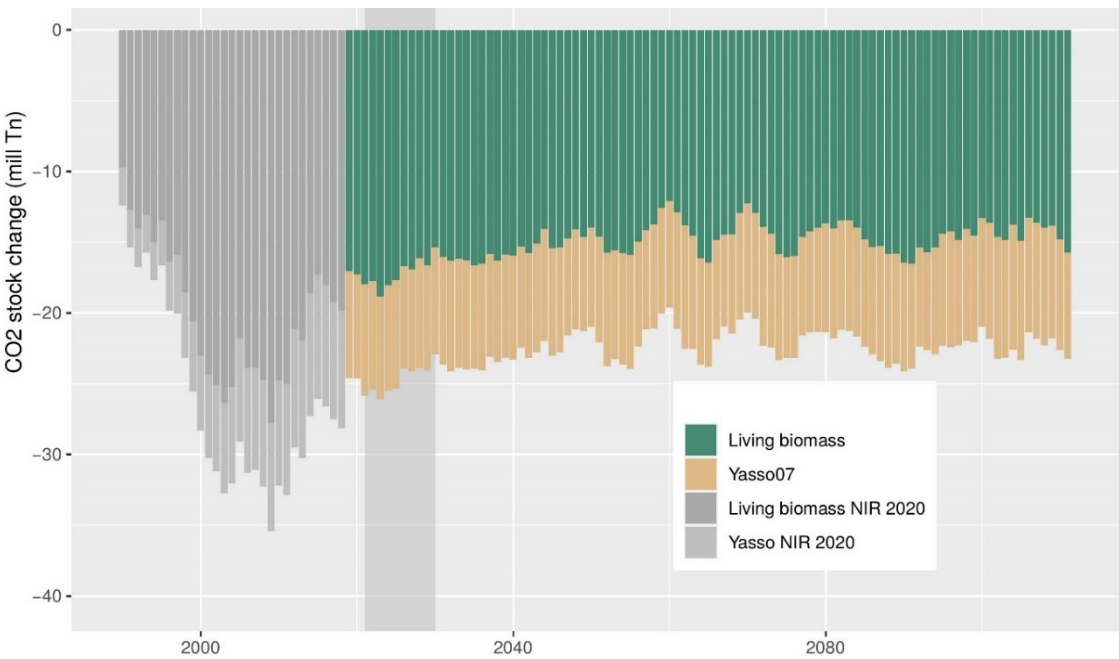

Figure 6 Development in carbon stock changes (in million tonnes CO2) in living biomass (green) and in mineral soils, dead wood and litter as modelled with Yasso07 (yellow).

However, the managed forests in Norway are still expected to have an increasing standing volume (Figure 7) and to be a significant carbon sink (Figure 6) in the next century, even with a higher harvest level than today and an ageing forest composition.

Given that the harvest level increases, harvested wood products will also act as a sink in the future (Figure 8). At an annual timestep, the HWP pools show large variability due to the variability in the annual predicted harvest level (Figure 7).

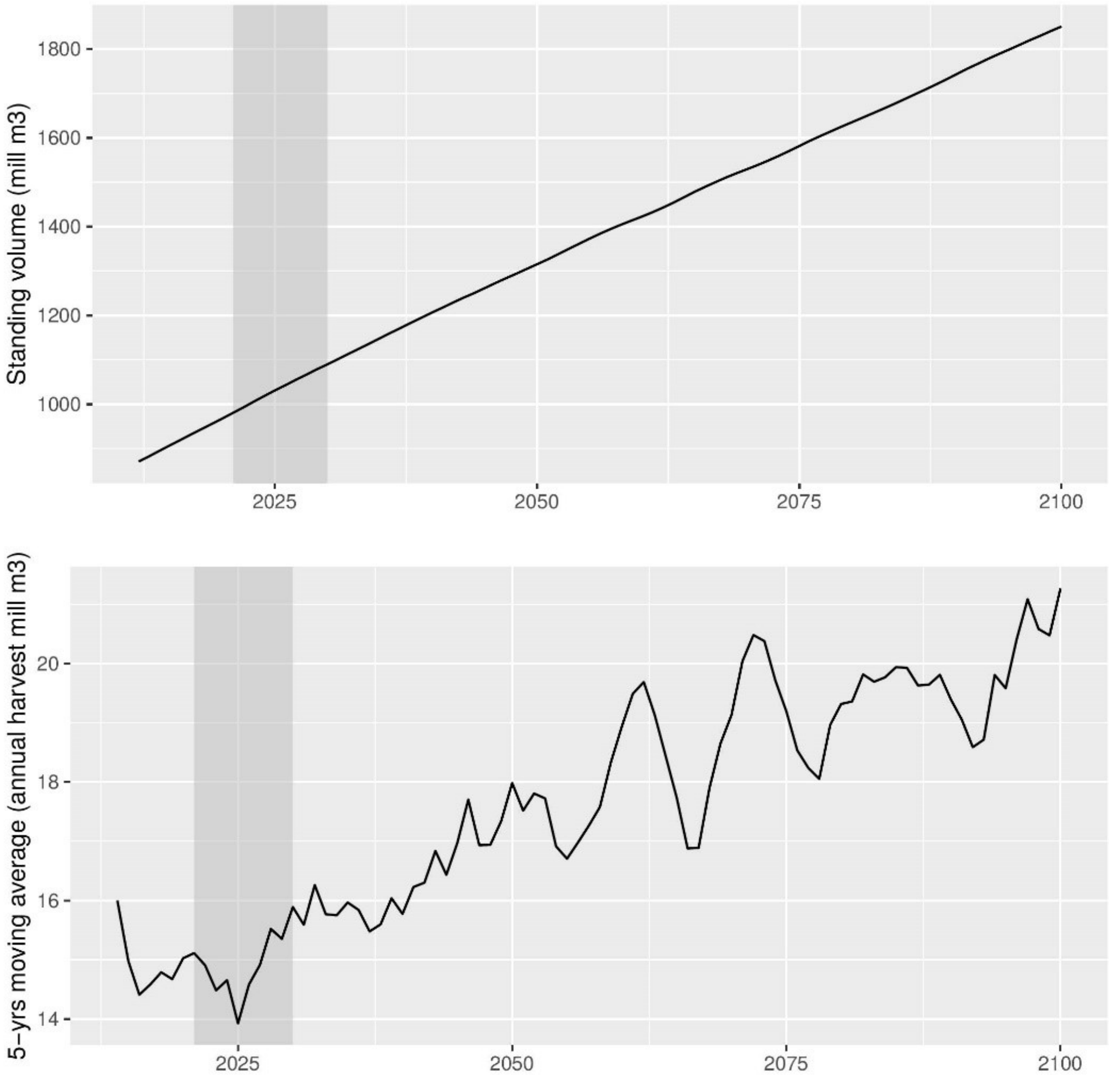

Figure 7. Projected development in standing volume and harvest rates. The dark grey area in the figures represent the commitment period 2021-2030.

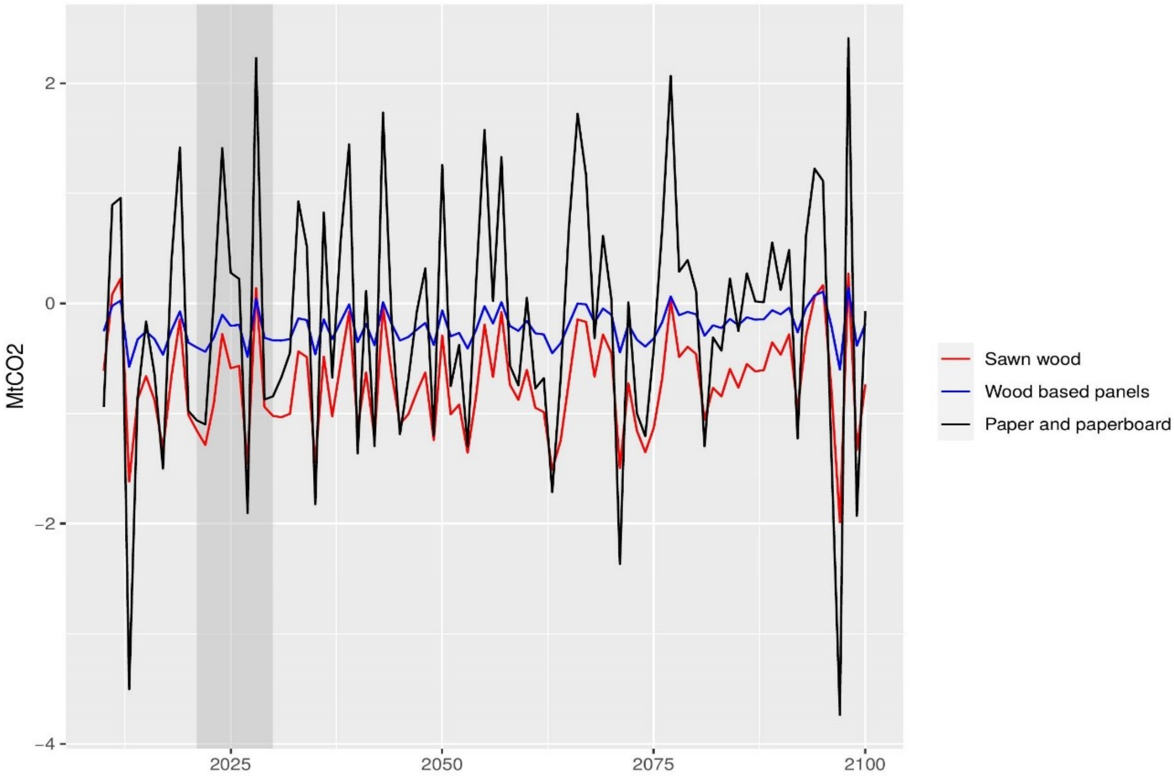

Figure 8. Annual change in HWP categories. The dark grey area in the figures represent the commitment period 2021-2030.

Figure 9 and Figure 10 shows harvesting and thinning as a percentage of the total forest area (sum of five years) in the reference period for the seven forest management strata, grouped by mature forest, young forest, and unproductive and protected forest. The intensity in the reference period is the same as in Table 8. The figures show that both thinning and harvest intensities remain approximately constant per stratum and management class in the reference period and the simulation.

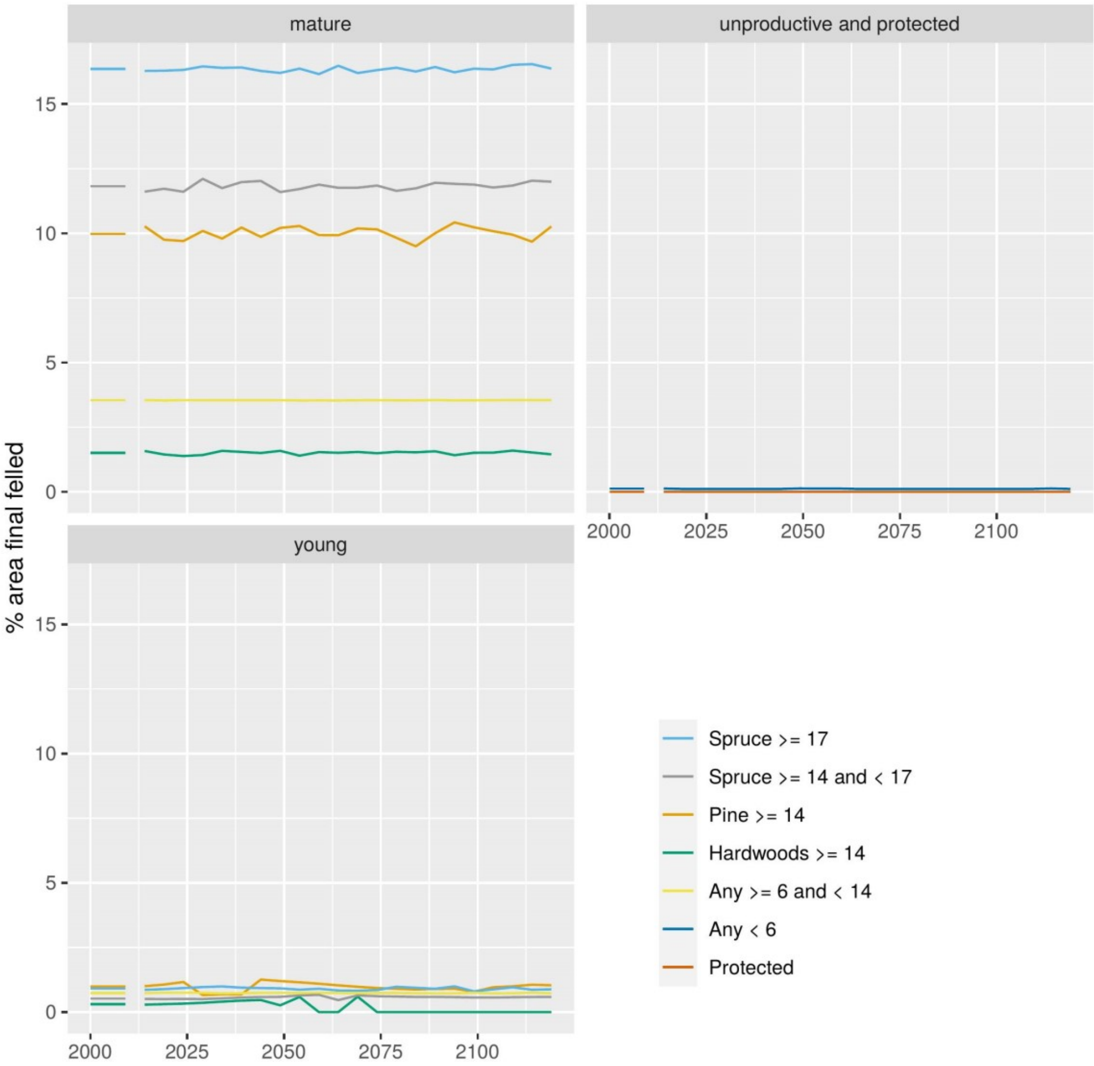

Figure 9 The percentage of area that is harvested grouped by the seven different strata for mature, young and unproductive and protected forest (sum of five years). Management intensities for the reference period are shown in the figures in the period 2000-2009, to the left of the gap. Projected management intensities are shown onwards from 2015 to the right of the gap.

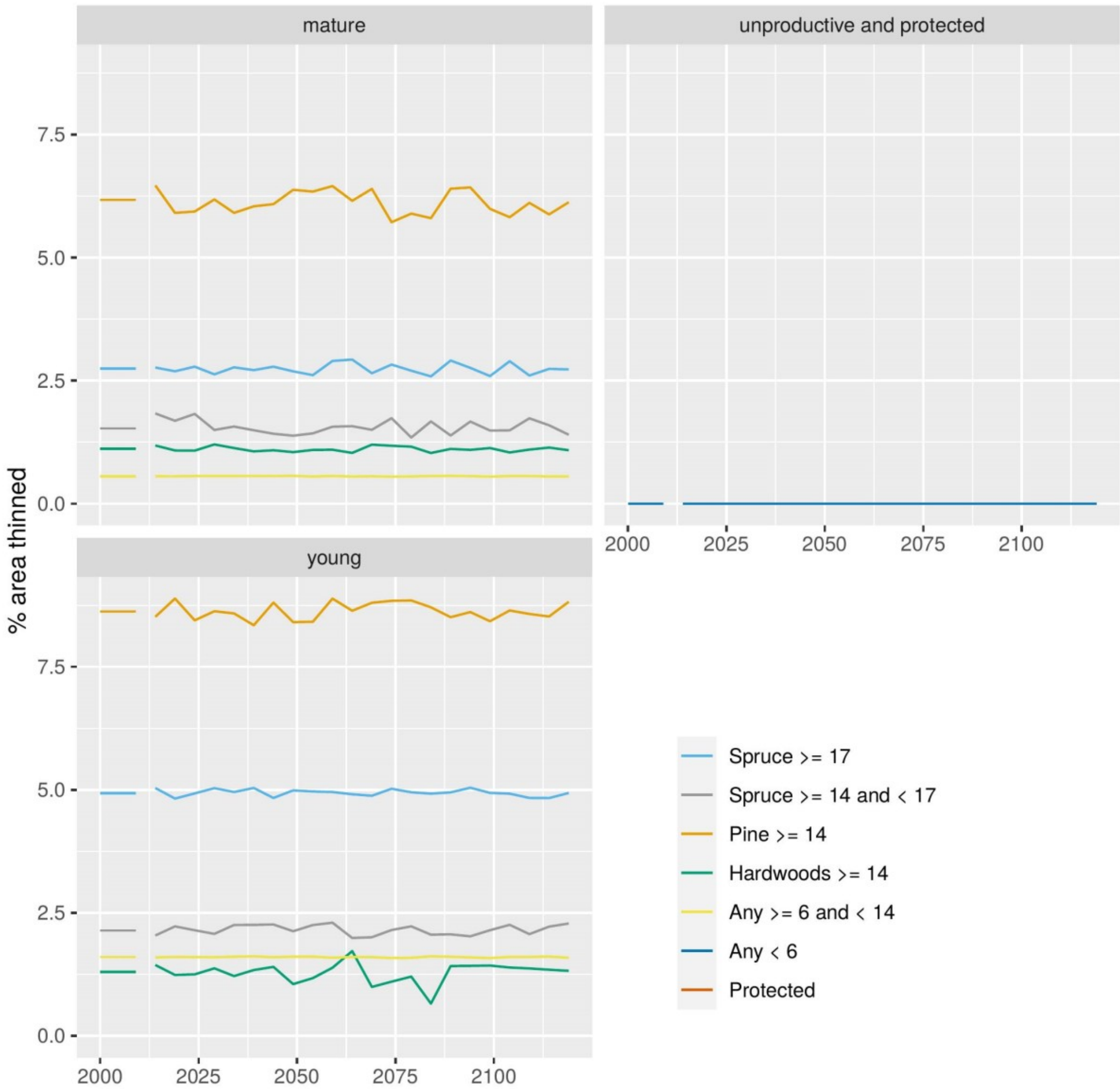

Figure 10 The percentage of area that is thinned for the seven different strata for, shown for mature, young and unproductive and protected forest (sum of five years). Management intensities for the reference period are shown in the figures in the period 2000-2009, to the left of the gap. Projected management intensities are shown onwards from 2015 to the right of the gap.

Figure 11 shows the development in biomass for the reference period (red) and the two commitment periods (blue). The calculation of gross annual biomass increment is the annual volume increment of all trees, including trees which have been felled or have died.

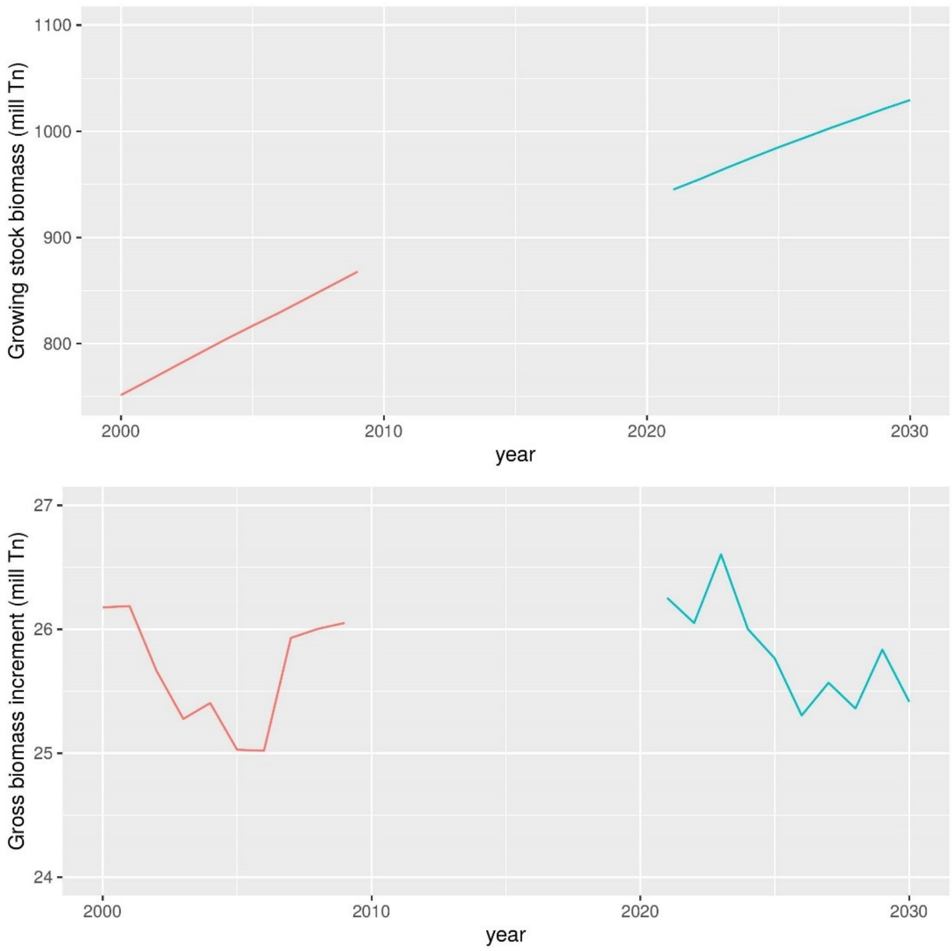

Figure 11 Growing stock biomass and gross annual biomass increment for the reference period (red) and the two commitment periods (blue). The gross annual biomass increment is calculated as the annual volume of increment of all trees. It includes the increment of trees which have been felled or have died.

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

The consistency between the FRL and the latest national inventory report (NIR 2020) has been verified by comparing the sum of the simulation's output against the sum of the time-series of historical data (Table 11). We verified the consistency of the living biomass stock change (Table 12), the biomass gains (Table 13), the biomass losses (Table 14) and the change in dead organic matter and soil organic matter (Table 15). We also verified their trends (Figure 12, Figure 13, and Figure 14).

Before the year 2000, the site index was visually estimated by the field crews, not measured. Site index is one of the main drivers of the projection and inconsistencies between the two methods for estimating site index would create spurious results in the simulation. Therefore, the comparisons below start from year 2002.

Not all the NFI plots that are part of the national greenhouse gas inventory (GHGI) were established at the start of the reference period. The NFI plots in Finnmark was added in 2012 and high mountain birch forest, were included from 2005 (Breidenbach et al. 2020). These plots are backcasted for GHGI purposes, but only on stand level and are therefore not part of the initial dataset of the individual tree simulations. Other plots, where biomass had to be estimated instead of measurement (e.g. unreachable plots) at any point during the period 2002-2018 for the GHGI, were excluded from the simulation.

The above-mentioned exclusions of plots results in the simulation of an average of 73.68% of the area of managed forest land, corresponding to 89,39% of the biomass change. For the rest of the plots historical data was used.

The difference between the sum of the simulation's output and the sum of the NIR 2020 (Table 11) for the living biomass stock change carbon pools are well within one standard deviation. We use the standard deviation of the different pools to indicate the magnitude of the interannual variability. For living biomass change the standard deviation is 2.41 for the simulation's output, and 3.16 for the NIR 2020, for gains in living biomass the standard deviation is 0.26 for the simulation's output, and 0.84 for the NIR 2020, for losses in living biomass the standard deviation is 2.35 for the simulation's output and 2.60 for the NIR 2020, and for the Yasso07 output the standard deviation is 0.86 for the simulation's output, and 0.80 for the NIR 2020.

Table 11. Comparison of the sum of the living biomass stock change, the biomass gains, the biomass losses, and the stock change in dead organic matter and soil organic matter (Yasso07) in NIR 2020 and the simulation of the forest reference level (Mt CO2) for the period 2002-2018

	NIR 2020	FRL	Difference	Standard deviation
Living biomass stock change	384.53	392.78	-8.25	13.04
Living biomass gains	816.12	806.8	9.32	3.45
Living biomass losses	-431.58	-414.06	-17.52	10.70
Dead organic matter and soil organic matter stock change	131.00	118.84	12.16	3.29

Table 12. Comparison of living biomass stock change (Mt CO2) in NIR 2020 and the simulation of the forest reference level

Year	NIR 2020	FRL	Difference	%difference
2002	25.12	24.34	-0.78	-3.11
2003	26.37	25.67	-0.70	-2.65
2004	25.22	24.70	-0.52	-2.06
2005	21.78	21.53	-0.25	-1.15
2006	23.86	24.04	0.18	0.75
2007	23.86	24.34	0.48	2.01
2008	24.74	25.06	0.32	1.29
2009	27.77	27.81	0.04	0.14
2010	24.75	24.97	0.22	0.89
2011	25.05	24.54	-0.50	-2.00
2012	21.13	21.39	0.26	1.23
2013	21.92	22.64	0.73	3.33
2014	18.60	20.18	1.57	8.44
2015	17.29	18.87	1.59	9.20
2016	18.04	19.90	1.86	10.31
2017	19.20	21.12	1.91	9.95
2018	19.83	21.68	1.85	9.33

Table 13. Comparison of living biomass gains (Mt CO2) in NIR 2020 and the simulation of the forest reference level				
Year	**NIR 2020**	**FRL**	**Difference**	**%Difference**
2002	47.59	46.91	-0.67	-1.41
2003	48.17	47.45	-0.72	-1.49
2004	48.46	47.70	-0.76	-1.57
2005	47.91	47.22	-0.68	-1.42
2006	47.59	47.18	-0.40	-0.84
2007	47.85	47.29	-0.56	-1.17
2008	48.46	47.53	-0.93	-1.92
2009	49.02	47.62	-1.40	-2.86
2010	49.44	47.89	-1.55	-3.14
2011	49.42	47.84	-1.57	-3.18
2012	48.74	47.78	-0.96	-1.97
2013	48.17	47.60	-0.57	-1.18
2014	47.03	47.42	0.40	0.85
2015	46.82	47.29	0.47	1.00
2016	46.83	47.31	0.48	1.02
2017	47.17	47.34	0.18	0.38
2018	47.45	47.43	-0.02	-0.04

Table 14. Comparison of living biomass losses (Mt CO2) in NIR 2020 and the simulation of the forest reference level				
Year	**NIR 2020**	**FRL**	**Difference**	**%Difference**
2002	-22.47	-22.57	-0.10	0.45
2003	-21.80	-21.79	0.02	-0.09
2004	-23.24	-23.00	0.24	-1.03
2005	-26.13	-25.69	0.44	-1.68
2006	-23.73	-23.15	0.58	-2.44
2007	-23.99	-22.95	1.04	-4.34
2008	-23.73	-22.47	1.25	-5.27
2009	-21.25	-19.81	1.43	-6.73
2010	-24.69	-22.92	1.77	-7.17
2011	-24.37	-23.30	1.07	-4.39
2012	-27.61	-26.39	1.22	-4.42
2013	-26.26	-24.96	1.30	-4.95
2014	-28.42	-27.25	1.18	-4.15
2015	-29.53	-28.42	1.11	-3.76
2016	-28.78	-27.41	1.37	-4.76
2017	-27.96	-26.23	1.74	-6.22
2018	-27.62	-25.75	1.87	-6.77

Table 15. Comparison of dead organic matter (DOM) and soil organic matter (SOM) with Yasso07 (Mt CO_2) in NIR 2020 and the simulation of the forest reference level

Year	NIR 2020	FRL	Difference	%Difference
2002	6.07	5.57	-0.51	-8.40
2003	6.39	5.77	-0.62	-9.70
2004	6.82	6.00	-0.82	-12.02
2005	7.31	6.37	-0.94	-12.86
2006	7.42	6.61	-0.81	-10.92
2007	7.22	6.42	-0.80	-11.08
2008	7.51	6.57	-0.95	-12.65
2009	7.65	6.75	-0.90	-11.76
2010	7.44	6.64	-0.80	-10.75
2011	7.83	6.94	-0.89	-11.37
2012	8.38	7.61	-0.76	-9.07
2013	8.34	7.77	-0.57	-6.83
2014	8.66	8.16	-0.51	-5.89
2015	8.77	8.22	-0.55	-6.27
2016	8.57	8.06	-0.51	-5.95
2017	8.30	7.73	-0.57	-6.87
2018	8.32	7.65	-0.67	-8.05

The trends of the different pools are closely following the trends, highs, and lows of the NIR 2020 (Figure 12, Figure 13, and Figure 14).

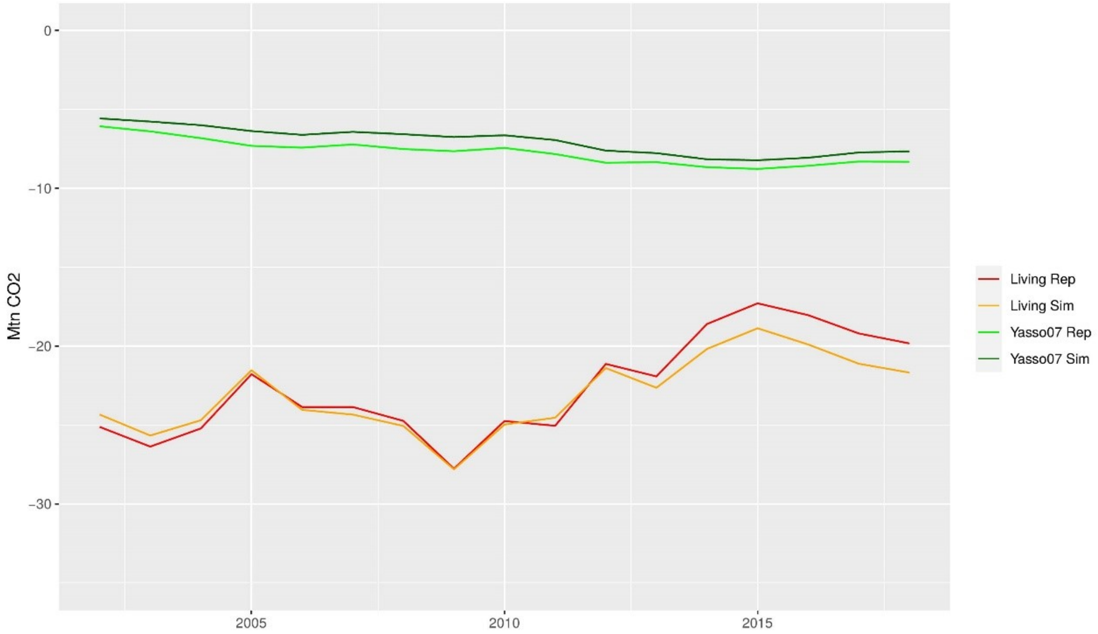

Figure 12. Development of the level and trend for living biomass in the NIR 2020 (Living Rep), and simulation output (Living Sim), and for Yasso07 outputs in the NIR 2020 (Yasso07 Rep) and simulation output (Yasso07 Sim).

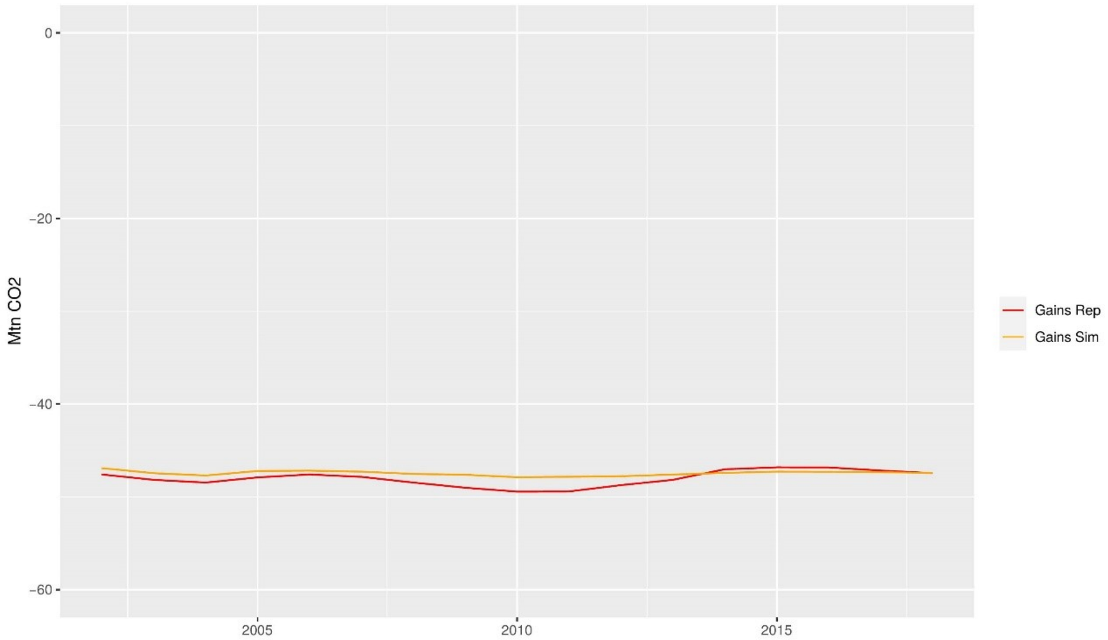

Figure 13. Development of the level and trend for gains in living biomass in the NIR 2020 (Gains Rep), and simulation output (Gains Sim).

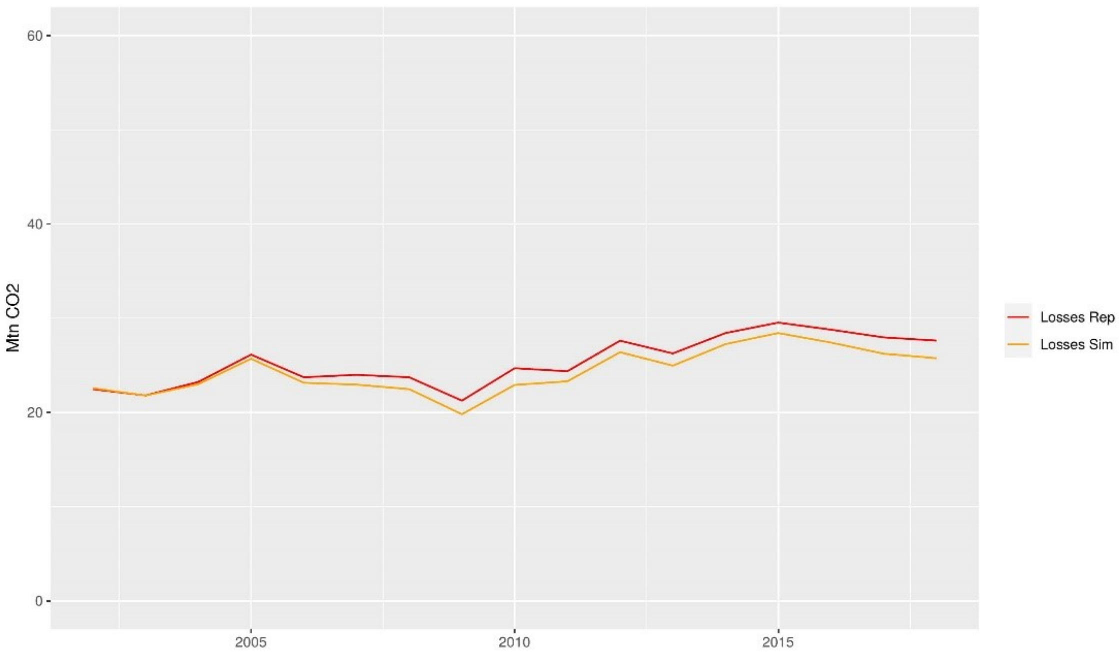

Figure 14. Development of the level and trend for losses in living biomass in the NIR 2020 (Losses Rep), and simulation output (Losses Sim).

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

Based on the simulations of the forest development and application of the carbon estimation approaches applied in the national inventory report, the forest reference level for the first commitment period can be summarized as illustrated in Table 15.

Table 16. Average annual emissions and removals from the carbon pools included in the Norwegian forest reference level for the first commitment period 2021-2025

Emissions and removals	**2021-2025 (Mt CO_2 eq. yr^{-1})**
Living biomass (CO_2)	**-18.290**
Mineral soils, including dead wood and litter (CO_2)	**-7.604**
Below ground	*-0.145*
Dead wood	*-1.255*
Litter	*-6.205*
Drained organic soils (CO_2, N_2O, CH_4)	**1.036**
CO_2	*0.695*
N_2O	*0.290*
CH_4	*0.051*
Biomass burning (wildfires) (N2O, CH4)	**0.0014**
N_2O	*0.0008*
CH_4	*0.0005*
N-fertilisation (N_2O)	**0.0001**
Harvested wood products (CO_2)	*-1.2276*
Sawn wood	*-0.8444*
Wood based panels	*-0.2918*
Paper and paperboard	*-0.0916*
Total without HWP	*-24.8574*
Total with HWP	*-26.0850*

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6 Annex

Table 1 Harvest and activity data for the three HWP categories. Average ratios (FRL Table 2, page 8) for the reference period was used to calculate allocations to HWP categories 2010-2100.

	Harvest	Sawnwood		Wood-based panels		Paper and paperboard	
		Domestic	Export	Domestic	Export	Domestic	Export
Year	m³	m³	m³	m³	m³	metric t	metric t
2010	7 150 000	1 477 326	434 203	282 140	252 316	403 262	2 618 736
2011	6 503 949	1 343 840	394 969	256 647	229 518	366 824	2 382 115
2012	14 780 071	3 053 845	897 559	583 224	521 574	833 600	5 413 301
2013	11 561 173	2 388 759	702 083	456 206	407 982	652 053	4 234 358
2014	10 693 789	2 209 541	649 408	421 979	377 373	603 132	3 916 672
2015	11 740 884	2 425 891	712 996	463 297	414 324	662 189	4 300 178
2016	13 808 109	2 853 019	838 534	544 870	487 274	778 781	5 057 313
2017	10 949 968	2 262 472	664 966	432 087	386 413	617 581	4 010 500
2018	8 680 681	1 793 594	527 157	342 541	306 333	489 593	3 179 358
2019	12 597 977	2 602 982	765 045	497 118	444 570	710 529	4 614 094
2020	13 334 215	2 755 103	809 755	526 170	470 551	752 053	4 883 746
2021	14 021 014	2 897 009	851 463	553 271	494 788	790 789	5 135 291
2022	12 455 057	2 573 452	756 366	491 478	439 527	702 468	4 561 749
2023	9 682 461	2 000 581	587 993	382 071	341 684	546 093	3 546 267
2024	11 106 739	2 294 864	674 486	438 274	391 946	626 423	4 067 918
2025	11 055 645	2 284 307	671 383	436 257	390 143	623 541	4 049 205
2026	15 135 043	3 127 189	919 115	597 231	534 101	853 620	5 543 311
2027	8 059 656	1 665 279	489 444	318 035	284 417	454 567	2 951 903
2028	12 906 139	2 666 655	783 759	509 278	455 445	727 910	4 726 960
2029	13 354 652	2 759 326	810 996	526 977	471 272	753 206	4 891 231
2030	13 498 662	2 789 081	819 742	532 659	476 354	761 328	4 943 976
2031	13 451 169	2 779 268	816 858	530 785	474 678	758 649	4 926 581
2032	10 987 472	2 270 221	667 243	433 567	387 737	619 696	4 024 236
2033	11 260 696	2 326 675	683 835	444 349	397 379	635 106	4 124 306
2034	15 594 684	3 222 159	947 028	615 369	550 321	879 544	5 711 658
2035	11 408 785	2 357 273	692 828	450 192	402 605	643 458	4 178 544
2036	13 897 110	2 871 408	843 939	548 382	490 415	783 801	5 089 910
2037	11 810 026	2 440 177	717 195	466 025	416 764	666 088	4 325 502
2038	9 759 780	2 016 557	592 688	385 122	344 413	550 454	3 574 585
2039	14 477 801	2 991 390	879 203	571 296	510 907	816 552	5 302 592
2040	12 346 423	2 551 007	749 769	487 192	435 693	696 341	4 521 961
2041	15 070 475	3 113 848	915 194	594 683	531 822	849 979	5 519 663
2042	9 824 814	2 029 994	596 638	387 689	346 708	554 122	3 598 405
2043	12 503 091	2 583 377	759 283	493 374	441 222	705 178	4 579 341
2044	14 677 200	3 032 590	891 312	579 165	517 944	827 798	5 375 624
2045	14 364 551	2 967 990	872 325	566 827	506 911	810 164	5 261 114
2046	13 555 543	2 800 834	823 196	534 904	478 362	764 536	4 964 809

2047	12 822 860	2 649 448	778 702	505 992	452 506	723 213	4 696 459
2048	15 644 131	3 232 376	950 031	617 320	552 066	882 333	5 729 768
2049	11 474 518	2 370 854	696 820	452 786	404 924	647 166	4 202 620
2050	14 722 487	3 041 947	894 062	580 952	519 542	830 352	5 392 210
2051	14 415 724	2 978 564	875 433	568 847	508 717	813 051	5 279 856
2052	16 459 474	3 400 841	999 545	649 493	580 839	928 319	6 028 393
2053	14 283 527	2 951 249	867 405	563 630	504 051	805 595	5 231 438
2054	11 415 616	2 358 684	693 243	450 462	402 846	643 844	4 181 046
2055	13 581 662	2 806 231	824 782	535 934	479 283	766 009	4 974 375
2056	10 980 325	2 268 745	666 809	433 285	387 485	619 293	4 021 618
2057	13 958 126	2 884 015	847 644	550 790	492 568	787 242	5 112 258
2058	14 641 493	3 025 212	889 143	577 756	516 684	825 784	5 362 546
2059	13 495 826	2 788 495	819 570	532 547	476 254	761 168	4 942 937
2060	15 096 599	3 119 246	916 781	595 714	532 744	851 452	5 529 231
2061	15 358 647	3 173 390	932 694	606 055	541 991	866 232	5 625 208
2062	17 801 776	3 678 187	1 081 060	702 461	628 207	1 004 025	6 520 020
2063	16 733 706	3 457 503	1 016 198	660 315	590 516	943 785	6 128 833
2064	14 359 430	2 966 932	872 014	566 625	506 730	809 876	5 259 238
2065	11 963 634	2 471 915	726 523	472 087	422 185	674 752	4 381 762
2066	12 074 355	2 494 792	733 247	476 456	426 092	680 997	4 422 314
2067	14 328 347	2 960 510	870 127	565 399	505 633	808 122	5 247 854
2068	12 669 331	2 617 726	769 379	499 934	447 088	714 554	4 640 228
2069	13 466 253	2 782 385	817 774	531 380	475 211	759 500	4 932 106
2070	18 195 111	3 759 457	1 104 946	717 982	642 087	1 026 209	6 664 082
2071	14 861 739	3 070 719	902 518	586 447	524 456	838 206	5 443 212
2072	16 850 115	3 481 555	1 023 268	664 908	594 624	950 351	6 171 468
2073	17 839 516	3 685 984	1 083 352	703 950	629 539	1 006 153	6 533 843
2074	16 960 731	3 504 411	1 029 985	669 273	598 527	956 590	6 211 982
2075	15 030 662	3 105 622	912 777	593 112	530 417	847 733	5 505 081
2076	11 900 188	2 458 806	722 670	469 583	419 946	671 174	4 358 524
2077	14 223 044	2 938 752	863 732	561 244	501 917	802 183	5 209 286
2078	13 848 868	2 861 440	841 009	546 478	488 713	781 080	5 072 241
2079	14 179 775	2 929 812	861 104	559 536	500 390	799 743	5 193 438
2080	16 902 276	3 492 333	1 026 435	666 966	596 465	953 293	6 190 573
2081	15 698 474	3 243 604	953 331	619 464	553 984	885 398	5 749 672
2082	16 114 808	3 329 627	978 614	635 893	568 676	908 879	5 902 157
2083	15 066 904	3 113 110	914 977	594 542	531 696	849 777	5 518 355
2084	15 882 057	3 281 536	964 480	626 708	560 462	895 752	5 816 911
2085	14 986 919	3 096 583	910 120	591 386	528 873	845 266	5 489 060
2086	15 334 633	3 168 428	931 236	605 107	541 144	864 877	5 616 413
2087	15 337 561	3 169 033	931 414	605 223	541 247	865 042	5 617 485
2088	14 258 241	2 946 025	865 869	562 632	503 159	804 168	5 222 177
2089	14 791 717	3 056 251	898 266	583 683	521 985	834 257	5 417 566
2090	14 001 101	2 892 895	850 254	552 486	494 085	789 666	5 127 998
2091	17 107 547	3 534 746	1 038 901	675 066	603 708	964 870	6 265 754

2092	14 159 780	2 925 681	859 890	558 747	499 685	798 615	5 186 115
2093	12 610 187	2 605 505	765 787	497 600	445 001	711 218	4 618 566
2094	12 118 372	2 503 887	735 920	478 193	427 645	683 479	4 438 436
2095	16 411 398	3 390 908	996 625	647 596	579 142	925 607	6 010 785
2096	21 873 678	4 519 519	1 328 337	863 139	771 900	1 233 681	8 011 382
2097	11 876 659	2 453 944	721 241	468 655	419 116	669 847	4 349 907
2098	19 066 875	3 939 580	1 157 886	752 382	672 851	1 075 377	6 983 372
2099	16 501 736	3 409 574	1 002 111	651 161	582 330	930 702	6 043 872
2100	12 447 508	2 571 893	755 908	491 181	439 260	702 043	4 558 984

Table 2 Net annual change in kt CO2 for total HWP and the three HWP categories, including domestically consumed, exported and total HWP 2010-2100.

	HWP			Sawnwood			Wood-based panels			Paper and paperboard		
	Dom.	Export	Total	Dom.	Export	Total	Dom.	Export	Total	Dom.	Export	Total
Year	kt CO2	kt CO2	kt CO2	kt CO2	kt CO2	kt CO2	kt CO2	kt CO2	kt CO2	kt CO2	kt CO2	kt CO2
2010	-551	-1256	-1807	-349	-264	-613	-77	-176	-253	-125	-816	-940
2011	351	605	957	188	-104	84	44	-66	-22	120	775	895
2012	491	720	1211	295	-69	226	67	-42	26	128	831	959
2013	-1852	-3848	-5700	-1132	-485	-1618	-252	-325	-577	-468	-3038	-3506
2014	-792	-1257	-2049	-557	-313	-871	-122	-205	-327	-113	-738	-852
2015	-504	-575	-1079	-397	-263	-661	-85	-170	-255	-22	-142	-164
2016	-778	-1071	-1850	-569	-311	-880	-123	-201	-324	-86	-559	-645
2017	-1313	-1977	-3290	-913	-409	-1323	-199	-267	-466	-200	-1301	-1501
2018	-437	-86	-523	-404	-257	-661	-84	-161	-245	51	332	383
2019	188	1013	1201	-7	-137	-144	6	-79	-73	189	1229	1418
2020	-955	-1391	-2346	-679	-333	-1012	-145	-211	-356	-130	-847	-977
2021	-1104	-1515	-2619	-793	-363	-1156	-169	-231	-400	-142	-921	-1063
2022	-1233	-1591	-2824	-895	-391	-1286	-191	-248	-439	-147	-952	-1099
2023	-732	-479	-1211	-609	-304	-913	-126	-188	-313	2	13	14
2024	52	978	1031	-120	-158	-278	-16	-87	-103	188	1223	1412
2025	-395	-119	-515	-363	-227	-589	-70	-134	-204	37	241	278
2026	-383	-155	-538	-347	-220	-567	-66	-128	-194	30	193	223
2027	-1516	-2337	-3853	-1041	-422	-1462	-221	-265	-486	-254	-1651	-1905
2028	549	1862	2411	195	-56	139	57	-15	42	298	1932	2230
2029	-889	-1237	-2126	-641	-300	-941	-131	-181	-312	-117	-757	-873
2030	-963	-1239	-2202	-706	-316	-1022	-145	-191	-336	-113	-732	-844
2031	-952	-1089	-2041	-717	-317	-1034	-146	-191	-337	-89	-580	-670
2032	-895	-882	-1777	-694	-309	-1003	-140	-184	-324	-60	-390	-450
2033	-176	531	355	-258	-178	-436	-42	-94	-136	124	804	928
2034	-282	159	-123	-299	-189	-488	-51	-101	-152	69	449	518
2035	-1498	-2232	-3730	-1038	-404	-1442	-216	-247	-463	-244	-1581	-1825
2036	-238	434	196	-299	-185	-483	-50	-97	-146	110	716	826
2037	-954	-1070	-2024	-720	-307	-1027	-144	-180	-323	-90	-584	-674
2038	-330	203	-127	-348	-195	-543	-60	-103	-163	77	501	578

2039	225	1135	1360	11	-88	-76	21	-30	-9	193	1253	1446
2040	-1142	-1696	-2839	-799	-324	-1124	-161	-191	-352	-182	-1181	-1363
2041	-477	-224	-701	-417	-210	-628	-75	-113	-187	15	99	114
2042	-1228	-1670	-2898	-877	-344	-1221	-177	-203	-380	-173	-1124	-1297
2043	301	1414	1715	41	-72	-31	29	-17	12	232	1503	1735
2044	-511	-425	-936	-420	-206	-626	-75	-109	-184	-17	-110	-127
2045	-1100	-1523	-2622	-785	-312	-1097	-156	-180	-337	-159	-1030	-1189
2046	-947	-1046	-1993	-716	-290	-1006	-140	-165	-305	-91	-592	-683
2047	-678	-440	-1117	-563	-243	-806	-105	-133	-237	-10	-64	-74
2048	-458	-29	-487	-426	-202	-628	-74	-104	-178	42	276	318
2049	-1243	-1579	-2822	-902	-340	-1242	-180	-198	-378	-160	-1041	-1201
2050	-16	919	903	-168	-123	-291	-15	-49	-64	168	1091	1259
2051	-963	-1095	-2058	-723	-284	-1007	-140	-159	-299	-100	-652	-752
2052	-830	-734	-1565	-656	-263	-919	-124	-144	-268	-50	-326	-377
2053	-1367	-1698	-3065	-994	-361	-1356	-199	-211	-410	-173	-1126	-1300
2054	-687	-218	-905	-601	-244	-845	-110	-130	-240	24	157	181
2055	117	1244	1361	-97	-95	-191	3	-28	-25	211	1367	1578
2056	-544	-286	-830	-467	-202	-669	-80	-102	-182	3	18	21
2057	189	1076	1264	-11	-67	-78	22	-10	12	177	1152	1330
2058	-691	-817	-1508	-522	-216	-738	-93	-112	-205	-75	-490	-565
2059	-845	-1024	-1869	-629	-246	-876	-117	-132	-249	-99	-646	-745
2060	-483	-227	-710	-420	-184	-604	-70	-89	-159	7	45	52
2061	-919	-1072	-1991	-687	-261	-948	-129	-142	-271	-103	-669	-772
2062	-945	-1004	-1948	-718	-269	-987	-136	-147	-282	-91	-588	-679
2063	-1579	-2100	-3678	-1124	-387	-1511	-226	-227	-452	-229	-1486	-1715
2064	-1187	-1092	-2279	-918	-326	-1244	-179	-184	-362	-90	-583	-673
2065	-478	331	-147	-493	-199	-692	-83	-97	-180	97	628	725
2066	170	1407	1577	-71	-74	-146	12	-12	-1	230	1494	1724
2067	73	913	987	-89	-79	-168	7	-16	-9	155	1008	1163
2068	-596	-558	-1155	-474	-191	-665	-80	-93	-172	-42	-275	-317
2069	-112	396	284	-180	-103	-283	-14	-33	-47	82	532	614
2070	-353	-174	-527	-314	-141	-455	-44	-60	-104	4	27	32
2071	-1660	-2650	-4310	-1120	-377	-1497	-224	-220	-445	-316	-2052	-2368
2072	-614	-293	-907	-525	-202	-727	-90	-100	-190	1	9	10
2073	-1154	-1328	-2482	-856	-298	-1155	-164	-165	-329	-133	-865	-998
2074	-1368	-1582	-2950	-1010	-342	-1352	-198	-195	-392	-161	-1045	-1206
2075	-1052	-804	-1856	-839	-291	-1130	-158	-159	-318	-54	-354	-408
2076	-479	318	-161	-491	-188	-679	-80	-89	-169	92	595	687
2077	375	1787	2162	57	-26	30	42	21	63	276	1792	2068
2078	-353	47	-306	-344	-143	-487	-48	-59	-107	38	250	288
2079	-252	174	-78	-273	-121	-394	-32	-45	-77	52	341	393
2080	-353	-95	-448	-324	-136	-460	-44	-55	-99	15	96	111
2081	-1106	-1542	-2648	-785	-271	-1056	-147	-147	-294	-173	-1125	-1298
2082	-702	-574	-1276	-563	-204	-768	-97	-102	-199	-41	-268	-309

2083	-791	-706	-1498	-624	-221	-845	-110	-113	-223	-57	-372	-429
2084	-468	-42	-511	-431	-164	-596	-67	-74	-141	30	196	226
2085	-693	-521	-1214	-563	-202	-765	-97	-100	-197	-34	-218	-252
2086	-421	18	-403	-398	-153	-551	-60	-66	-126	37	238	274
2087	-519	-228	-747	-450	-168	-618	-71	-77	-148	2	16	18
2088	-510	-229	-739	-442	-164	-606	-70	-75	-144	2	10	11
2089	-200	338	138	-248	-107	-354	-26	-35	-62	74	480	554
2090	-364	-79	-443	-335	-132	-466	-46	-53	-99	16	106	122
2091	-142	308	166	-192	-89	-281	-14	-24	-39	65	421	486
2092	-1019	-1438	-2456	-722	-244	-966	-133	-130	-263	-164	-1063	-1227
2093	-135	424	289	-201	-91	-292	-16	-25	-42	83	540	623
2094	275	1078	1354	69	-10	58	44	28	72	163	1060	1224
2095	362	1024	1386	152	15	166	61	45	106	149	965	1114
2096	-878	-1505	-2383	-589	-202	-791	-105	-104	-209	-185	-1198	-1383
2097	-2326	-4003	-6330	-1515	-474	-1990	-312	-289	-601	-499	-3240	-3739
2098	633	2190	2824	232	40	271	80	62	143	322	2088	2410
2099	-1464	-2183	-3647	-1008	-324	-1332	-198	-186	-384	-258	-1673	-1931
2100	-651	-341	-992	-548	-188	-736	-94	-93	-187	-9	-59	-69

Table 3 Table demonstrating historical and future harvesting rates disaggregated between energy and non-energy uses

Year	HWP (Mg C)	Energy use (Mg C)	Energy use/HWP ratio
2000	1 553 835	166 691	0.107
2001	1 514 889	739 059	0.488
2002	1 453 611	328 111	0.226
2003	1 468 399	207 749	0.141
2004	1 554 595	402 271	0.259
2005	1 547 559	148 456	0.096
2006	1 527 935	901 324	0.590
2007	1 483 283	471 446	0.318
2008	1 377 638	373 581	0.271
2009	1 169 644	1 174 124	1.004
2010	1 252 168	385 182	0.308
2011	1 139 026	350 378	0.308
2012	2 588 410	796 226	0.308
2013	2 024 690	622 819	0.308
2014	1 872 786	576 091	0.308
2015	2 056 162	632 500	0.308
2016	2 418 192	743 865	0.308
2017	1 917 650	589 892	0.308
2018	1 520 234	467 642	0.308
2019	2 206 264	678 673	0.308
2020	2 335 200	718 335	0.308
2021	2 455 478	755 334	0.308
2022	2 181 234	670 974	0.308
2023	1 695 674	521 610	0.308
2024	1 945 106	598 338	0.308
2025	1 936 158	595 585	0.308
2026	2 650 576	815 349	0.308

2027	1 411 475	434 186	0.308
2028	2 260 232	695 274	0.308
2029	2 338 779	719 436	0.308
2030	2 363 999	727 194	0.308
2031	2 355 682	724 636	0.308
2032	1 924 219	591 913	0.308
2033	1 972 068	606 632	0.308
2034	2 731 072	840 110	0.308
2035	1 998 002	614 609	0.308
2036	2 433 779	748 659	0.308
2037	2 068 271	636 225	0.308
2038	1 709 215	525 775	0.308
2039	2 535 474	779 942	0.308
2040	2 162 209	665 121	0.308
2041	2 639 268	811 870	0.308
2042	1 720 604	529 278	0.308
2043	2 189 646	673 561	0.308
2044	2 570 395	790 684	0.308
2045	2 515 641	773 841	0.308
2046	2 373 961	730 259	0.308
2047	2 245 647	690 788	0.308
2048	2 739 732	842 774	0.308
2049	2 009 514	618 151	0.308
2050	2 578 326	793 124	0.308
2051	2 524 603	776 598	0.308
2052	2 882 522	886 698	0.308
2053	2 501 451	769 476	0.308
2054	1 999 199	614 977	0.308
2055	2 378 535	731 666	0.308
2056	1 922 967	591 528	0.308
2057	2 444 464	751 946	0.308
2058	2 564 141	788 760	0.308
2059	2 363 502	727 042	0.308
2060	2 643 843	813 278	0.308
2061	2 689 735	827 395	0.308
2062	3 117 597	959 010	0.308
2063	2 930 547	901 471	0.308
2064	2 514 744	773 565	0.308
2065	2 095 172	644 500	0.308
2066	2 114 563	650 465	0.308
2067	2 509 301	771 891	0.308
2068	2 218 760	682 517	0.308
2069	2 358 324	725 448	0.308
2070	3 186 481	980 200	0.308
2071	2 602 713	800 625	0.308
2072	2 950 934	907 742	0.308
2073	3 124 206	961 043	0.308
2074	2 970 306	913 702	0.308
2075	2 632 296	809 726	0.308
2076	2 084 061	641 082	0.308
2077	2 490 859	766 218	0.308
2078	2 425 330	746 061	0.308
2079	2 483 281	763 887	0.308
2080	2 960 069	910 552	0.308
2081	2 749 249	845 702	0.308

2082	2 822 161	868 130	0.308
2083	2 638 643	811 678	0.308
2084	2 781 399	855 592	0.308
2085	2 624 635	807 369	0.308
2086	2 685 530	826 101	0.308
2087	2 686 043	826 259	0.308
2088	2 497 023	768 114	0.308
2089	2 590 450	796 853	0.308
2090	2 451 991	754 262	0.308
2091	2 996 018	921 611	0.308
2092	2 479 780	762 810	0.308
2093	2 208 402	679 331	0.308
2094	2 122 271	652 836	0.308
2095	2 874 102	884 108	0.308
2096	3 830 702	1 178 370	0.308
2097	2 079 940	639 815	0.308
2098	3 339 151	1 027 163	0.308
2099	2 889 923	888 975	0.308
2100	2 179 912	670 567	0.308