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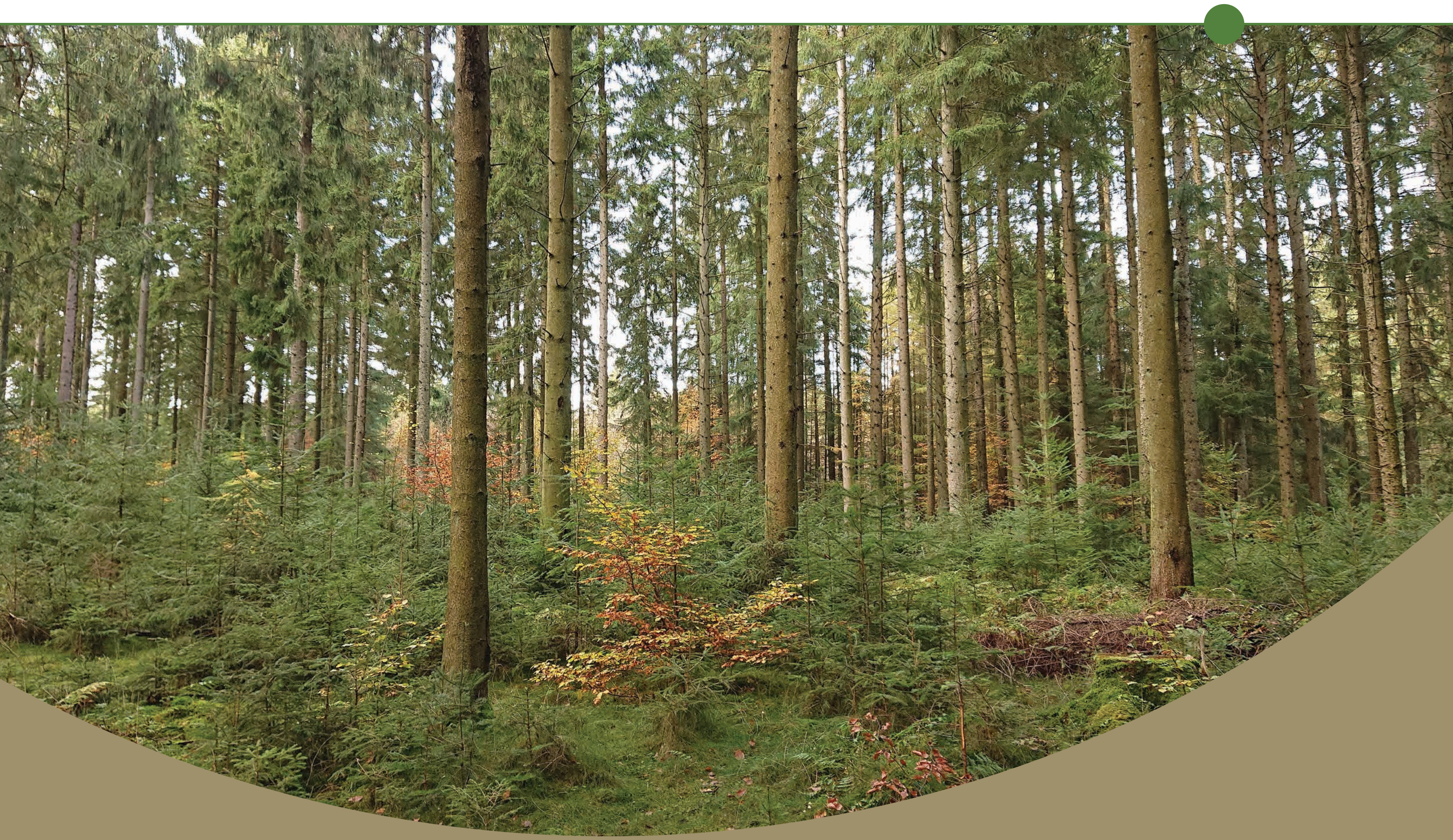
Publication date:
2019

Document version
Publisher's PDF, also known as Version of record

Citation for published version (APA):
Johannsen, V. K., Nord-Larsen, T., Bentsen, N. S., & Vesterdal, L. (2019). *Danish National Forest Accounting Plan 2021-2030 - resubmission 2019*. (1 ed.) Frederiksberg: Institut for Geovidenskab og Naturforvaltning, Københavns Universitet. IGN Rapport

UNIVERSITY OF COPENHAGEN
DEPARTMENT OF GEOSCIENCES AND
NATURAL RESOURCE MANAGEMENT



Danish National Forest Accounting Plan 2021-2030 – resubmission 2019

Vivian Kvist Johannsen, Thomas Nord-Larsen, Niclas Scott Bentsen,
and Lars Vesterdal

IGN Report
December 2019

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Responsible under the press law
Claus Beier

Citation
Johannsen, Vivian Kvist, Nord-Larsen, Thomas, Bentsen, Niclas Scott
and Vesterdal, Lars (2019): Danish National Forest Accounting Plan
2021-2030 – resubmission 2019. IGN report, December 2019.
Department of Geosciences and Resource Management, University of
Copenhagen, Frederiksberg. 112 p. ill.

ISBN
978-87-7903-817-2

Cover layout
Jette Alsing Larsen

Cover photo
Vivian Kvist Johannsen

The report is available electronically from
www.ign.ku.dk > Publications > Reports

Preface

This report is in accordance with the regulation EU 2018/841 of the European Parliament and of the Council on the inclusion of greenhouse gas emissions and removals from land-use, land-use change, and forestry in the 2030 climate and energy framework, and amending Regulation (EU) No 525/2013 and Decision No 529/2013/EU.

The report provide a description of the accounting for greenhouse gasses related to forestry. The perspective on sustainable forest management is described by forest regulation and policies, as well as by providing an overview of key indicators for sustainable forest management in Denmark. The main product is the Forest Reference Level, based on the requirements given in the Regulation (EU 2018) and based on the available data. The Forest Reference Level is hereby a prediction of the expected emissions/uptake by the forests of Denmark in the period 2021-2030, based on the data from the reference period 2000-2009. This will subsequently be utilised as baseline (reference level) for the Danish accounting for forests.

The report is produced by the Department of Geosciences and Natural Resource Management (IGN) as part of the SINKS2 project, funded by The Danish Ministry of Climate, Energy and Utilities, Denmark and for the same ministry. Data from the Danish National Forest Inventory is utilised and is funded by the Ministry of Environment and Food.

The report has been commented on by representatives from by Erik Tang (The Danish Ministry of Climate, Energy and Utilities) and Christian Lundmark Jensen (The Ministry of Environment and Food as well as a number of researchers (Henrik Meilby and Jette Bredahl, Department of Food and Resource Economics, Copenhagen University, Steen Gyldenkærne, DCE, Aarhus University).

First version was submitted by 31st of January 2019.

Following review comments from EU process, this is a revised version to be submitted by December 2019.

Section for Forest, Nature and Biomass, Department of Geosciences and Natural Resource Management,
University of Copenhagen, Denmark.

December 2019

Content

Abbreviations

FRL	Forest Reference Level (EU 2018 Regulation)
FMRL	Forest Management Reference Level (Kyoto Reporting period)
HWP	Harvested Wood Products (includes sawn wood, wood panels and paper)
KP1	Kyoto Protocol - first commitment period 2008-2012
KP2	Kyoto Protocol - second commitment period - 2013-2020
NFI	National Forest Inventory - Danmarks Skovstatistik
IPCC	Intergovernmental Panel on Climate Change - ipcc.ch
UNFCCC	United Nations Framework Convention on Climate Change - unfccc.int
CO_2 eq.	$CO_2eq = \frac{44}{12} \times C)$
AGB	Above-ground biomass
BGB	Below-ground biomass
DW	Dead Wood
FF	Forest Floor
OC	Organic Carbon

1 Executive summary

The Regulation (EU) 2018/841 addresses the inclusion of greenhouse gas (GHG) emissions and removals from land-use, land-use change and forestry in the 2030 Climate and Energy Framework, with the endorsed binding target of at least 40 % domestic reduction in economy-wide greenhouse gas emissions by 2030, compared to 1990 (EU, 2018: 1). This report is the Danish National Forestry Accounting Plan, prepared by the Department of Geosciences and Natural Resource Management (IGN) following the Regulation (EU 2018) as a task under the SINKS2 project, for The Danish Ministry of Climate, Energy and Utilities.

The key regulation of the Danish forest area is given in the Forest Act (Miljø- og Fødevareministeriet 2018a). In addition to this, a number of national laws, international commitments and a series of policy initiatives influence the current forest regulation and policies.

With a forest area of less than 15 % of the land area, of which 2/3 are established by afforestation within the last 100 years, the structure, status, and development of the Danish forests are fundamental elements of sustainable forest management, and set the base for construction of the Forest Reference Level and the future development of the forests. The distribution of the forests across the country reflects a mixture of natural conditions and cultural history. This also significantly influences the current state of biodiversity in the forests as reflected in indicators of biodiversity and other ecosystem services.

The estimation of the Forest Reference Level is based on National Forest Inventory (NFI) data from the initiation of the NFI in 2002 and until 2017, with a focus on the reference period 2000-2009 and utilizing 2010 as the baseline year for the estimation of Forest Reference Level (FRL).

The principal method chosen for the FRL of the Forest land is 'stock change' and is in line with national reporting of greenhouse gas (GHG) emissions from forests. This method is based on assessment of carbon stock at two given points in time and provides estimates of change over time as the difference between the two estimates or inventories of carbon stocks. The increment, mortality and harvest are not modelled when using the stock change method. The Regulation opens for either a 20-year or a 30-year transition period. In a Danish context a 30-year transition period is in line with the IPCC guidelines (IPCC 2006) and both a 20 and a 30 year transition time is provided in this report for the Danish FRL. The annual rate of afforestation in the period 2021-2030 affects the estimated emissions separate from the reference level.

Harvested Wood Products (HWP) based on predicted future harvests and projection of the future fraction of domestic harvest allocated to energy and use-wood respectfully, provides estimates of the contribution of HWP to the FRL estimation.

The Forest Reference level, excluding HWP and with a 20-year transition period is 545 kt $CO_{2\ eq}$ yr^{-1}- for 2021-2025 and 510 kt $CO_{2\ eq}$ yr^{-1} for 2026-2030. When including HWP and with a 20 year transition period the FRL is 354 for 2021-2025 kt $CO_{2\ eq}$ yr^{-1} and 358 kt $CO_{2\ eq}$ yr^{-1} for 2025-2030.

The forest reference level, excluding HWP and with a 30-year transition period is 1048 kt $CO_{2\ eq}$ yr^{-1} for 2021-2025 and 1017 kt $CO_{2\ eq}$ yr^{-1} for 2026-2030. When including HWP and with a 30 year transition period the FRL is 856 kt $CO_{2\ eq}$ yr^{-1} for 2021-2025 and 865 kt $CO_{2\ eq}$ yr^{-1} for 2025-2030.

2 General description

The Regulation (EU) 2018/841 addresses the inclusion of greenhouse gas (GHG) emissions and removals from land-use, land-use change and forestry in the 2030 Climate and Energy Framework, with the endorsed binding target of at least 40% domestic reduction in economy-wide GHG emissions by 2030, compared to 1990 (EU, 2018: 1). The Regulation specifically acknowledges that the land-use, land-use change and forestry (LULUCF) sector has the potential to provide mitigation and thereby contribute to the European Union GHG emissions reduction targets, as well as to the long-term climate goals of the Paris Agreement. Furthermore, the Regulation stresses that the LULUCF sector provides biomaterials that can substitute fossil- or carbon-intensive materials and therefore plays an important role in the transition to a low GHG-emitting economy (EU, 2018: 5). Since the entire LULUCF sector is characterized by long time perspectives, and at the same time development of sustainable and innovative practices and technologies, it is essential to ensure transparent and coherent accounting and reporting for the entire sector. The Regulation stresses the aim to adhere to the IPCC guidelines (IPCC 2006, 2013) for the accounting methodologies and reporting (EU 2018).

Forestry is characterised by very long time perspective regarding influence on emissions and removals. The accounts depend on a number of natural circumstances, dynamic age-related forest characteristics, as well as on past and present management practices and uses of the forest and forest products. The overarching aim of the Regulation (EU) 2018/841 is to ensure continued sustainable forest management, as adopted at the Ministerial Conference on the Protection of Forest in Europe (Forest Europe 2015) while achieving the objectives of the Paris Agreement and meeting the GHG emission reduction target of the Union.

For documentation of the accounting for the forest sector, each Member State shall submit a National Forestry Accounting Plan (NFAP), including a Forest Reference Level (FRL) regarding the future expected GHG emissions for the forest sector, including Harvested Wood Products (HWP) (EU 2018: 17-29). The NFAP will be reviewed by the Commission in consultation with experts appointed by the Member States according to a procedure given in the Regulation. The NFAP should build on good practice and be determined in accordance with the criteria and requirements set out in the Regulation (EU 2018/841).

This report is the Danish National Forestry Accounting Plan, prepared by IGN following the Regulation (EU 2018) as a task under the SINKS2 project, for the Ministry of Energy, Utilities and Climate.

2.1 Criteria in the Regulation

The Regulation (EU 2018) addresses all land-use classes: forest, cropland, grassland, wetlands, and the changes between them including afforestation and deforestation (Article 2) with land-use changes reported as new land-use for 20 years after the conversion (Article 5). For afforestation and deforestation, the reporting will address the estimated emissions and removals in the reporting period (Article 5 & 6). Denmark has opted for a period of 30 years after conversion is applied to afforestation, before transferring to forest land (Article 6). The justification based on the IPCC (2006, 2013) guidelines, is provided in Chapter 9.5.1. Danish LULUCF reporting to the EU and UNFCCC has so far been based on a 20-year transition period, and in order to enable comparisons between the proposed FRL the revised NFAP also provides figures for the FRL and other parameters based on a 20-year transition period.

For managed forest-land, the emissions and removals will be compared to the reference level FRL (Article 8), based on a reference period of 2000-2009. The FRL is intended to estimate the average expected annual net emissions or removals from managed forest-land in Denmark, expressed in tonnes of CO_2 equivalent per year ($CO_{2\,eq}$ yr^{-1}) based on the criteria given in the Regulation.

Figure 1 below gives the basic principles for the Forest Reference Level with example data for illustrative purposes only.

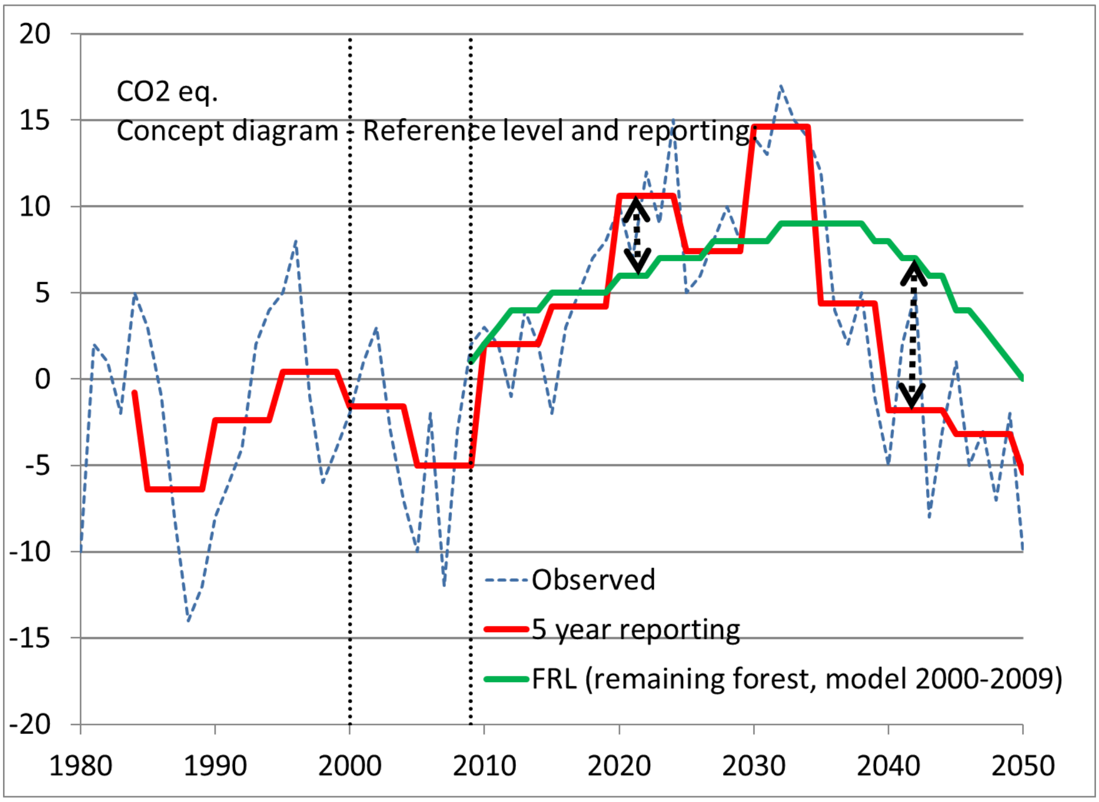

Figure 1 Concept figure on the Forest Reference Level (FRL) and the relation to reporting based on example data for illustration purpose. The blue dotted line indicates observed annual emissions (positive) or uptake (negative). The red full line indicates 5 year reporting values. The green full line indicates the results of a FRL for the remaining forest, based on the Reference period 2000-2009 (vertical dotted lines). The thick dotted arrows indicate the reported contribution from the forest area, being the difference between the projection and the reported value, and can either be an emission (reporting higher than expected by the FRL) or an uptake (reporting lower values than expected by the FRL).

By including the effect of transferring afforestation older than e.g. 30 years will influence the FRL as indicated in the next concept figure. The area of forest turning 30 in a given reporting year will subsequently be included in the FRL and no longer contribute to the afforestation pool.

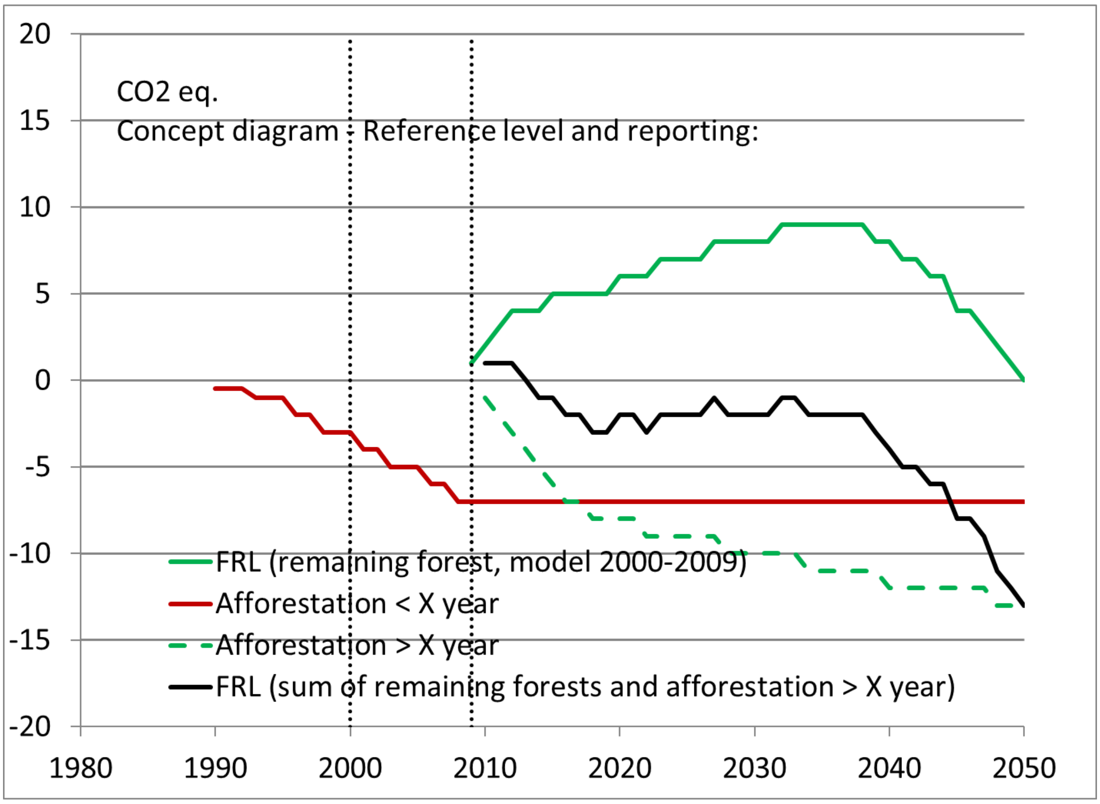

Figure 2 Since the Forest Reference Level (FRL) will include afforestation over a certain age (X - 20 or 30 years) this concept figure indicates the components of this. The green full line indicates the results of a FRL for the remaining forest, based on the reference period 2000-2009. The dotted green line indicates FRL for the afforestation older than X years. The full black line represents the overall FRL combining remaining forest and afforestation - in total referred to as 'managed forest land' in Article 8 (EU 2018). The red full line indicates the contribution of the afforestation younger than X years, which will be reported separately from the FRL. Reference period 2000-2009 is indicated by vertical dotted lines.

In the accounting for other land uses than forests, i.e. managed cropland, grassland, and wetlands, the reported emissions and removals are to be reported, minus the average annual emissions and removals, in the reference period from 2005 to 2009 for these land uses. This is expected to document changes compared to the reference period.

The main criteria of the Regulation, for the FRL, relate to Article 8 and 9, as well as the related Annex IV and V. These are be summarised in the following main points.

1. A continuation of sustainable forest management practices, as documented in the period from 2000-2009,
2. Take into account the dynamic age-related forest characteristics in national forests,
3. Use of the best available data,
4. Accounting for the future impact of dynamic age-related forest characteristics in order not to unduly constrain forest management intensity as a core element of sustainable forest management,
5. Maintaining or strengthening long-term carbon sinks, and
6. Demonstration of consistency between methods and data used for the FRL and the reported values for managed forest-land.

The specific criteria and elements for establishment of the FRL are given in the Annex IV of the Regulation (EU 2018). A summary of how and where each of the many criteria and elements in the Regulation are addressed in the Danish NFAP is provided in Annex9.1 " Cross reference - EU Regulation & DK-NFAP", Table 13 on page 79.

Furthermore, the FRL will include Harvested Wood Products (HWP) as set out in Article 9, including the pools: paper, wood panels, and sawn wood. The Regulation contains further guidelines in annexes V (EU 2018) on the construction of the FRL including HWP, which will be addressed in the subsequent paragraphs.

The removals, resulting from the forest sector accounting, are limited by a maximum of 3.5 % of the emissions in the base year 1990. Exempt from this are the pools of dead wood, wood panels, and sawn wood. There is no limitation to the emissions from forest accounting (Article 8: 1-2). However, there is a general flexibility for the accounting, given in Article 13, depending on national values (Annex VII) and the overall land-use accounting in Denmark and in EU (Article 13: 2 and 3).

2.2 The National Forest Accounting Plan

The National Forest Accounting Plan (NFAP) shall contain the following elements:

1. Identification and justification for inclusion and omissions of carbon pools, and their consistency.
2. Description of adopted national policies.
3. Documentary information on sustainable forest management practices and intensity in the reference period 2000-2009 given for forestry.
4. General description of the determination of the FRL, including elements of influence on the FRL (area, HWP, forest characteristics and harvesting rates, disaggregated between energy and non-energy uses), as specified in Annex 4: A, and including estimates of the FRL for 2020-2025 and 2026-2030.
5. Description on how the criteria from the Regulation were taken into account.
6. Description of approaches, methods and models used to determine the FRL.
7. Documentation of the consistency with recently submitted national inventory reports.
8. Information on expected harvesting rates under different policy scenarios.

The report addresses the points above as follows:

Chapter 3: "Carbon pools and greenhouse gasses", addresses point one above.

Chapter 4: "Forest regulation and policies" addresses point two.

Chapter 5: "Danish Sustainable Forest Management" addresses point three.

Chapter 6: "Forest Reference Level" addresses the remaining points from the list, for each of the categories: Forest land (0), Afforested land (6.2), Harvested Wood Products (6.3) and Deforestation (6.4). The sections on forest-land and HWP, will address the different policy scenarios and how they may influence harvesting rates.

A condensed summary and key figures are provided in Chapter 7 "Conclusion and summary" and the cross reference to full specification in the Regulation are given in Annex 9.1 "Cross reference - EU Regulation & DK-NFAP".

3 Carbon pools and greenhouse gasses

This chapter provides key information on the carbon pools and GHGs included in the Danish FRL, based on the Regulation, Article 2 and Annex 1. The Regulation 2018/841 also refers to the prior Regulation 2013/525 (EU 2013), specifically Article 7 of the new Regulation give guidance on accounting and specifications.

3.1 Greenhouse gasses

The following GHGs are included in the FRL, where the values for global warming potential given (in a 100-year time horizon), in accordance with the IPCC and their Fourth Assessment Report (IPCC 2007, Nielsen et al 2018).

3.1.1 Carbon dioxide (CO_2)

The changes in pools are converted into carbon dioxide equivalents, by multiplying estimated carbon amounts with the ratio of the molar mass of carbon dioxide to the molar mass of carbon, i.e. 44/12.

3.1.2 Methane (CH_4)

The emissions of methane, as they are estimated to occur from soil organic matter, are affected by drained and rewetted organic soils, and are transferred into carbon dioxide equivalents by the Global Warming Potential (GWP), i.e. a GWP of 25 for 1 mole of CH_4 molecule (IPCC 2007).

Due to lack of national data for methane emissions from soil organic matter under different conditions and drainage status, the default values given by Tier 1 in the accounting guidelines are applied (see Chapter 6 for values).

3.1.3 Nitrous oxide (N_2O)

The emissions of nitrous oxide, as they are estimated to occur from drained organic soils, are transferred into carbon dioxide equivalents by the Global Warming Potential, i.e. a GWP of 298 for 1 mode of N_2O.

Due to lack of national data for the nitrous oxide emissions from drained soils under different conditions and drainage status, the default values given by Tier 1 accounting guidelines, are applied (see Chapter 6 for values).

3.2 Carbon pools

This section addresses the carbon pools included in the FRL, as referred to in Article 5(4) and Annex 1. The section provides key information on the basic definitions and distinctions of the pools, as described in Nord-Larsen & Johannsen (2016) and reported in Nielsen et al. (2018). In general, for the pools addressed, biomass is converted to carbon using a factor of 0.47 g C/g dry matter.

3.2.1 Above-ground biomass

Above-ground biomass is defined as the living part of the trees above the ground level. This pool is based on trees measured in the Danish National Forest Inventory (NFI) sample plots. The Danish NFI is a continuous, sample-based inventory, with partial replacement of sample plots based on a 2 x 2-km grid. The sampling provides data for analysis and reporting on the status and development of the Danish forests, following the indicators of Sustainable Forest Management, as agreed upon by the pan-European initiative (Forest Europe 2015, Nord-Larsen & Johannsen 2016, Nord-Larsen et al 2017).

For calculation of forest biomass and carbon pools, national tree species specific biomass functions are applied, along with basic density for different tree species, converting volume in m^3 to dry mass and subsequently converting dry mass to carbon amount (Nord-Larsen & Johannsen 2016, pg. 16 ff.).

3.2.2 Below-ground biomass

The below-ground biomass is the roots of the trees. The estimation of this carbon pool is based on the trees measured on the NFI sample plots and use of biomass models and expansion factors, and converting dry mass to carbon amount (Nord-Larsen & Johannsen 2016, pg. 16 ff.).

3.2.3 Litter layer (forest floor)

The amount of carbon in the litter layer depends on layer thickness and composition. Fine woody debris (smaller than 10 cm lying dead wood) are included in the litter layer. Litter layer thickness is measured in the NFI plots. The average litter layer carbon pools on the individual plots are calculated from the litter layer thickness, multiplied with the average density of the litter layer, and the average carbon concentration of the litter layer. The density of the litter layer is related to the main tree species present at the sampling site (Nord-Larsen & Johannsen 2016, pg. 27 ff.).

3.2.4 Dead wood

The dead wood carbon pool is calculated for both lying and standing dead wood, with a diameter of min. 10 cm and 4 cm respectively. The carbon content is estimated based on the volume, species and decay stage specific basic densities and expansion factors (Nord-Larsen & Johannsen 2016, pg. 25).

3.2.5 Soil organic carbon

Based on literature there is little evidence to support that the soil C pool in forest remaining forest would be changing to an extent that could be detectable by sampling with decadal frequency. This is further substantiated by the soil inventory, where no overall changes in soil organic carbon stock to 1 m depth were detectable in mineral soils between 1990 and 2007-9 (Callesen et al., 2015).

The NFI monitoring is supplemented by an additional forest soil inventory (Callesen et al., 2015). The detailed measurements of the soil inventory further contributes to distinguishing mineral soils from organic soils (by a topsoil carbon concentration of 12 % organic carbon (OC) in the 0-25 cm soil layer below the O-horizon) and hereby the calculations of carbon stocks and the area of mineral soils and organic soils, respectively. Based on this criterion, organic forest soils represent 5 % of the forest area. This fraction is consistent with the map classification of organic soils using the Digital Geological Map of Denmark (1:25,000 and 1:200,000). The results of the soil inventory give mineral soil C stocks in forest remaining forest an estimated of 155 t C ha^{-1} to 1 m depth for soils with <12 % C in 0-25 cm and 142 t C ha^{-1} for the soils with < 6 % C in 0-25 cm.

For drained organic soils, the default carbon emission factor of 2.6 t C ha^{-1} yr^{-1} was used (Wetland supplement, 2013, Table 2.1). In the mapping of the forest area there are no data on forest soils with 6-12 % OC available as for Crop land and Grassland and hence only emissions from organic forest soils >12 % OC are reported.

For afforestation, a gradual transition from the former land use cropland to the weighted average value for the land use forest is expected to occur. Danish research projects using afforestation chronosequences sites as well as repeated sampling, have indicated that mineral soils are small sinks for CO_2 following afforestation of former cropland. This is because forest floors start to sequester carbon immediately, but there is usually a lag period of up to 3 decades before afforested mineral soils become sinks for carbon (Vesterdal et al. 2002, 2007, Bárcena et al. 2014). Based on an assumed transition time of 100 years, the weighted soil C stocks from soil inventories in forests and cropland were used to estimate the rates of soil carbon stock change for cropland to forest conversion (0.21 tC ha^{-1} yr^{-1} over 100 years) (Nielsen et al., 2018, 6.2.2.2). In the FRL this rate of C sequestration was assumed constant or increasing - but set to 0, as there are not yet sufficient nationally representative data and analyses to document the rate of soil carbon sequestration.

3.2.6 Harvested wood products

The Harvested wood products (HWP) are included in the assessment for wood originating from the land accounting categories of afforested land and managed forest land. Carbon in the HWP pool is accounted for based on the semi-finished wood product categories: sawn wood, wood-based panels and paper and paper products with default half-lives of 35, 25 and 2 years, respectively, as suggested by the Regulation (EU 2018, Annex V) and stipulated by the Intergovernmental Panel on Climate Change (IPCC 2014) as Denmark do not have country-specific methodologies or data to support other half-life values. HWP originating from imported wood are excluded from the accounting, while exported HWP originating from domestic harvest are included. HWP originating from deforestation activities are accounted for on the basis of instantaneous oxidation, according to the IPCC guidelines (avoiding any credits being generated from deforestation). HWP contribution for each year is the amount of the total harvested volume used for semi-finished wood products in Denmark, while the share of the harvested volume used for energy purposes or exported as raw wood are accounted for on the basis of instantaneous oxidation (see more in Chapter 6.3).

3.3 Land-use mapping

The definition of 'forest' adopted in the Danish NFI is identical to the definition used by the Food and Agricultural Organization (FAO 2012) and corresponding to the values given in the Regulation, Annex II (EU 2018) namely "Land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use" and of "a width of more than 20 meters". Temporarily non-wooded areas, firebreaks and other small open areas, that are an integrated part of the forest, are also included. Areas with Christmas tree production are included in the forest area, as it fulfills the forest definition. The temporarily un-stocked areas make up 3 % and auxiliary areas 2 % of the total forest area. The temporarily un-stocked areas can be caused by e.g. clear cutting and wind throw and is generally required to be reforested within a 10-year period according to the Forest Act of Denmark (Miljø-og Fødevareministeriet 2018a). The Forest Act applies to the Forest reserved areas, which covers approx. 70 % of the entire forest area. Harvesting and regeneration by clear cutting is a common forest management practice in Danish forestry, with typical size of clear cut areas being 2-10 ha (and often smaller) and acknowledged in the national criteria's for sustainable forest management.

With the objective to obtain time consistent and precise estimates of forest areas to report to the United Nations Framework Convention on Climate Change (UNFCCC) and under the Kyoto protocol, two projects have aimed at mapping the forest area in Denmark based on satellite images from 1990, 2005, and 2011 (Levin et al. 2014). Based on the land-use matrix in 1990, 2005, and 2011, a linear trend of land-use change was assumed during the periods 1990 to 2005 and 2005 to 2011. From 2011 and onwards, the land-use matrix is updated annually with data from different data suppliers, with the Cropland Registry and the cadastral information being among the main sources of information. Some of these data are not updated annually, and thus a time lag in the implementation of the land-use changes may occur in some areas. A change to annual updates may result in more fluctuating area changes than in the previous years (Nielsen et al., 2018, chapter 6.1) as well as there are some uncertainties in the change estimates (Johannsen et al 2018). It should be noted that the estimation of the carbon pools related to above- and below-ground biomass, litter and dead wood in the reporting are based on direct measurements by the NFI, and not based on the land use matrix.

The EU-Regulation recommends including all stable forests in the FRL, and land-use mapping is a key element, when examining the transition period for areas. The default time for transition in the IPCC guidelines is 20 years (IPCC 2006), se also Annex 9.5.1 for further details. However, for the forest soils the transition period is expected to be 100 years and have been reported as 50 years in the first Kyoto Commitment and as 100 in the second Kyoto Commitment period (Nielsen et al., 2018, chapter 6.2.2.2). The Danish Government have decided to opt for a 30 year transition period for afforestation cf. Article 6 (2) of the Regulation (EU 2018). Accordingly, this report contains figures and information for a 30-year transition period. As requested in the Commission Technical recommendations figures for a 20 year transition period have also been included in order to enable comparisons with historic LULUCF reporting from Denmark.

In relation to the FRL, the choice of transition period will have significant impact on the area included in the FRL and the expected development of the carbon pools and Green House Gas (GHG) emissions. The forest area in the afforestation category will not be included in the FRL and changes in the pools will contribute directly to annual accounts of emissions and removals.

Deforestation may occur and the loss of carbon from the pools in this case would be estimated directly based on mapped biomass resources, derived from Lidar mapping of Denmark (Schumacher et al 2014, Nord-Larsen et al., 2017). Future updates can be based on the new continuously collected Lidar data for Denmark, if the funding for this can be achieved.

The EU regulation (EU 2018, Article 10) gives an option to exclude effects of natural disturbances such as wind or insects. This has not been included in the establishment of the FRL.

3.4 Consistency

The carbon pools mentioned above (Above- and below-ground biomass, litter layer, dead wood, soil organic carbon and HWP) ensure that all pools are included in the FRL as well as in the accounting, and that double accounting is avoided. The same estimation and calculation procedures are applied to FRL as well as to accounting.

4 Forest regulation and policies

The Danish territories are regulated by a number of Acts and regulations, and have been so for centuries. In addition, national policies and international regulations and agreements influence the management of land, forests, cropland, as well as nature and urban areas in Denmark.

4.1 Forest act

The key regulation of the Danish forest area is given in the Forest Act (Miljø- og Fødevareministeriet 2018a). The first dedicated Act on forest management was issued in 1781, with the first major national protection of the forest area given by the Forest Act in 1805. The latest major revision was adopted in 2005, with a number of subsequent minor revisions and adjustments (latest in June 2018). The purpose of the Forest Act is given in §1[1] "The purpose of the Act is to preserve and protect the forests of the country and further increase the forest area." This is further detailed by requiring sustainable forest management with focus on robustness, long term productivity, biodiversity and a range of ecosystem services (landscape level, natural and cultural history, environmental protection and recreation). For publicly owned forests, special focus is put on biodiversity and ecosystem services. The increase of the forest area has been a focus in a number of other planning and regulatory incentives, and subsidies for afforestation of cropland are given as an incentive to land owners. This has resulted in an increase in the forest area of Denmark since the year of the first Forest Act (1805), when the forest area was only 2-3 % of the land area. In 2016 the forest area had increased to 14.5 % of the land area. The increasing forest area, older than 30 years, will have significant implications for the FRL.

The Forest Act applies to areas designated as “forest reserve land”, constituting approximately 70 % of the current forest area. The main requirement for forest reserve land is that the area must be stocked with trees, which form, or have the potential to form, a closed canopy forest of high-boled trees within a reasonable period of time. Moreover, harvesting operations apart from thinning, may not be carried out before the stand or the individual tree has reached the stage of maturity for harvest. The conditions described above must be established no later than 10 years after harvesting of a stand. Exceptions from the main requirement are that up to 10 % of the forest reserve land may be used for Christmas tree production and greenery in short rotation as well as up to 10 % for open nature areas, and up to 10 % for coppice and grazing.

The Forest Act ensures protection of biodiversity on designated areas according to e.g. local conservation decisions and designation of forest habitat areas according to the Habitat Directive of nature types and species (EU 1992), and the Birds Directive (EU 2009b). On the majority of the forest area there are, however, no restrictions on species choice, cutting cycle, regeneration strategy, etc. in the forest in general. See more below, in the paragraph on legislation and regulations related specifically to biodiversity.

The Forest Act also forms the legal basis for statutory orders laying down rules for administration of EU-FLEGT and EUTR (EU 2010). Mandatory rules govern public procurement by the central government (Ministries & agencies). They are obliged to seek to safeguard that wood and wood products are sustainable. The rules define “sustainable timber” and apply to wood for construction, furniture and paper (not wood for energy). Voluntary guidelines are also developed for the encouragement for other public

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[1] Original text: §1 "Loven har til formål at bevare og værne landets skove og hertil forøge skovarealet"

entities to safeguard sustainable timber on a voluntary basis, as well as provide inspiration for private entities (e.g. EFI 2018)

The development of policies related to forest management have been guided by national processes, including a National Forest Program in 2002 (Skov- og Naturstyrelsen 2002), followed by policy input from a broadly composed group of stakeholders in the set of recommendations given in 'Fremtidens skov - anbefalinger fra Skovpolitisk udvalg 2011' (Skovpolitisk udvalg 2011). During recent years, a number of workshops have been conducted and a new National Forest Program has been published in October 2018 (Miljø- og Fødevareministeriet 2018d). The program sets out a vision for Danish forests, two long term goals, 13 strategic orientation lines and a number of concrete actions, all aiming at a sustainable and multifunctional development of Danish forests. The vision, goals and strategic orientation lines are outlined in Annex 9.2.

4.2 Afforestation

The promotion of afforestation has been an ongoing policy for many decades and has been an effort also for private initiatives, including the initiation of the Danish HedeDanmark company at a meeting on 28th March 1866. Since 1989 afforestation has been promoted through grant schemes for afforestation on private lands and support for public afforestation as well as through other means, including active rural planning. In the National Forest Program in 2002 (Skov- og Naturstyrelsen 2002) the goal was to increase the forest area to an extent that 'forest landscapes cover 20-25 % of the Danish land area within a tree generation (80-100 years)'. Since 1990 the planning has designated areas where afforestation was desired (for multiple reasons) and areas where afforestation was not wanted. The aim was to support the administration of subsidies for afforestation based on application from the land owners. This is still a significant guideline for where afforestation is desired or not wanted as confirmed with the recent update of the legislation on planning (Planloven, Retsinformation, 2016), managed at the municipal level. The current key focus of the incentives to establish new private forests is to reduce leaching of nutrients and pesticides to the surface and ground water. Hence, applications for support are prioritized based on the sensitivity of the soil and water bodies in different areas (Miljø- og Fødevareministeriet 2018c). This is expected to increase the rate of afforestation compared to the last decade (Miljø- og Fødevareministeriet 2018d).

The subsidy schemes have focused on establishment of robust forests, with a high share of domestic species and varied structures and forest edges. For afforestation as part of the State forests and municipal forests, particular focus has been on robust forests, forests to protect groundwater and forests close to urban areas, to provide options for recreation. Private afforestation established without subsidies has been extensive and have generally a higher share of non-native species, including coniferous trees. Through a number of evaluations of the new forests it has been found that large parts have indeed been located adjacent to urban areas (Lassen & Præstholm 2010, Lassen & Larsen 2013, Goldberg et al 2013), but also that the composition and growth differs from the remaining forest area (Schou et al 2014). The soil types and the species composition of the new forests vary over time, depending on the forest owner and management purpose. Subsidies for afforestation to private land owners have covered approximately 30 % of the afforested area since 1990, while the remaining 70 % have been promoted and established through other means, mainly private afforestation.

By 2016, afforestation since 1990 constitutes almost 20 % of the current forest area. This will have significant implications for the FRL, as forests older than 30 years will be included in the FRL, with a changing forest area as consequence. To reflect the overall development of the forest area in 2021-2030 two different rates (low and high) of afforestation are included in the prediction to demonstrate the sensitivity of the predictions, accounting for the influence on area and carbon pools not included in the FRL, but indicating scenarios for reporting.

4.3 Renewable energy

Renewable energy, including wood for energy, plays an important role in the transition towards a fossil free society. There are a number of legislations and regulations on this area, where the EU-Renewable Energy directive (EU 2009a as revised 2018) and the Governance Regulation also adopted in 2018 (EFKM 2018) sets some of the key provisions. This was supplemented in 2016 by a voluntary agreement between/within the Energy sector to apply common criteria for Sustainable Biomass Production (Dansk Energi & Dansk Fjernvarme 2016). This is expected to ensure focus on the sustainable procurement of biomass for energy. In relation to the FRL this will have impact on the share of wood used for energy from Danish and foreign forests which has been increasing since 1990. See also Chapter 6.3 for further details on the development of wood for energy from the Danish forests.

The overall focus on reducing fossil fuel consumption is expected to generally increase the amount of wood marketed and used for energy. The amount of imported wood for energy has not been included in the mapping of wood flows due to lack of estimates of carbon content (statistics focus on value or estimated energy content, but not on carbon content). It could give supplementary information to the FRL as suggested by the Regulation (EU 2018) and the Harvested Wood Products (HWP) component (Chapter 6.3).

4.4 Biodiversity

The conservation of biodiversity has gained increasing focus since the first designation of forest areas in 1918 to secure species and habitats. The current legislation includes the Nature Protection Act (Miljø- og Fødevareministeriet 2018b), where the purpose is given as follows in § 1 "The Act shall contribute to protecting the nature and environment of the country, to ensure a sustainable development of the society, while giving respect to human livelihoods and the conservation of fauna and flora." For the forests of Denmark the Nature Protection Act governs parts of them, especially the lakes, bogs, heaths and open grasslands (especially according to §3) surrounded by areas with forest cover.

The Natura 2000 includes areas designated under the EU Habitat Directive and the Bird Directive, as well as the Ramsar treaty, and ensures focus on designated areas, especially the forest habitat types. In conjunction with the Forest Act and the Nature Protection act, this provides protection of these areas and restricts forest management, especially with regards to e.g. regeneration methods and the choice of species in plantings, which have to be approved by the authorities before implementation (Miljø- og Fødevareministeriet 2018a, §14-28).

In 2016 the Danish Parliament agreed on 'Naturpakken' (Nature package) setting aims for designation of 13,300 ha forest areas in State owned forests for primarily biodiversity purposes. The final designation includes 13,800 ha. A major part of this area will be "set aside as forest land not available for wood supply", and, after a transition period of 10-50 years, it will only be managed for biodiversity purposes. Parts of the forests will be managed for nature protection, with no focus on wood production. In total an area of 22,800 ha has been designated for biodiversity in the State forests (Naturstyrelsen 2018). Hence the majority of these areas will not be available for wood production in the commitment period of the EU-LULUCF Regulation for 2021-2030 (EU 2018).

Significant nature restoration projects have been undertaken in the recent 10-20 years. Most often, these have focused on restoring wetlands and open nature areas such as heathlands, which is an example of the management influenced landscapes currently under pressure due to other land-uses and airborne pollution/deposition of nutrients. In some of the restoration projects, formerly forested land is cleared actively or the trees die due to an increasing water level. The effect of these restoration projects are reported as deforestation since the tree cover is removed. The changed hydrology, e.g. ceased drainage, leads to higher spatial variability within the forests, including rewetting of some areas. These changes influence the reporting of GHG emissions for the rewetted areas of the forest as well as the restored open nature areas.

5 Danish Sustainable Forest Management

With a forest area constituted of 90-95 % afforestation of less than 200 years old (and approx. 60 % less than 100 years old), the structure, status and development of the Danish forests are fundamental elements of sustainable forest management and setting the base for construction of the Forest Reference Level and the future development of the forests. The Danish National Forest Inventory produces annual reports on the status and development of the Danish forests, following the indicators of Sustainable Forest Management as agreed upon by the pan European initiative Forest Europe. The text in this chapter is based mainly on these publications, with the latest being 'Skove og plantager 2016' (Nord-Larsen et al 2017) with a focus on the current state of the Danish forests. Data for the reference period for the FRL are given in Chapter 6.

5.1 Forest area, history and owner structure

The current forest area (2017) is estimated to approx. 625.000 ha or 14.5 % of the land area. With a mapping of forest area based on satellites, the forest area has increased with more than 80,000 ha since 1990, equaling an average increase of almost 3,000 ha/year. Since 1990 deforestation has varied from year to year with an average of approx. 250 ha/year, depending on expansion of settlements and nature restoration projects as the two main drivers of deforestation in some specific years. The area of Other Wooded Land (OWL), including mainly naturally reforested heathlands, meadows, and bogs, is estimated to approx. 44,000 ha or 1.0 % of the land area. Overall, the Danish forest area has more than tripled since the first forest survey published in 1881 (Figure 3 - Indicator 1.1 Forest Europe, Nord-Larsen et al 2017).

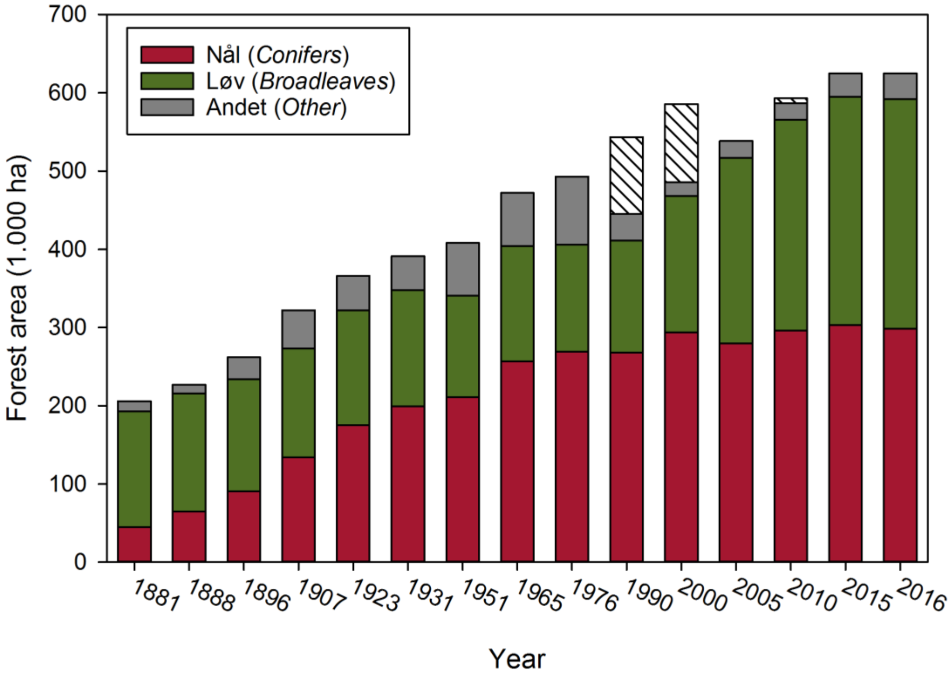

Figure 3 Forest Area development in Denmark 1881-2016. The forest area is distributed to broadleaves, conifers and other. "Other" includes unstocked areas in forests and areas where the species is unknown. Before 2005, the estimates are based on questionnaire surveys. The three hatched areas show the total forest area estimated from satellite imagery in 1990, 2000 and 2011. Historically, forest area mapping has been based on different sources, and methods and definitions have varied between mappings and hence estimates of change reported in different sources may deviate.

The distribution of the forests across the country reflects a mixture of natural conditions (based on soil and climate) and cultural history (Figure 4). The large forest area north of Copenhagen has been influenced by the ownership of the Royal Family of Denmark, whilst the large forest areas in the mid and western parts of Jutland are a result of degraded land being reforested in the period 1750-1950 and owned by a mix of owners. The number of forest owners in Denmark is close to 23,000, of which 88 % own less than 20 ha. Approximately 70 % of forests are privately owned; while State forests constitute 18 % of the forest area and other public bodies own 12-13 % (Figure 5 - Indicator 6.1 Forest Europe).

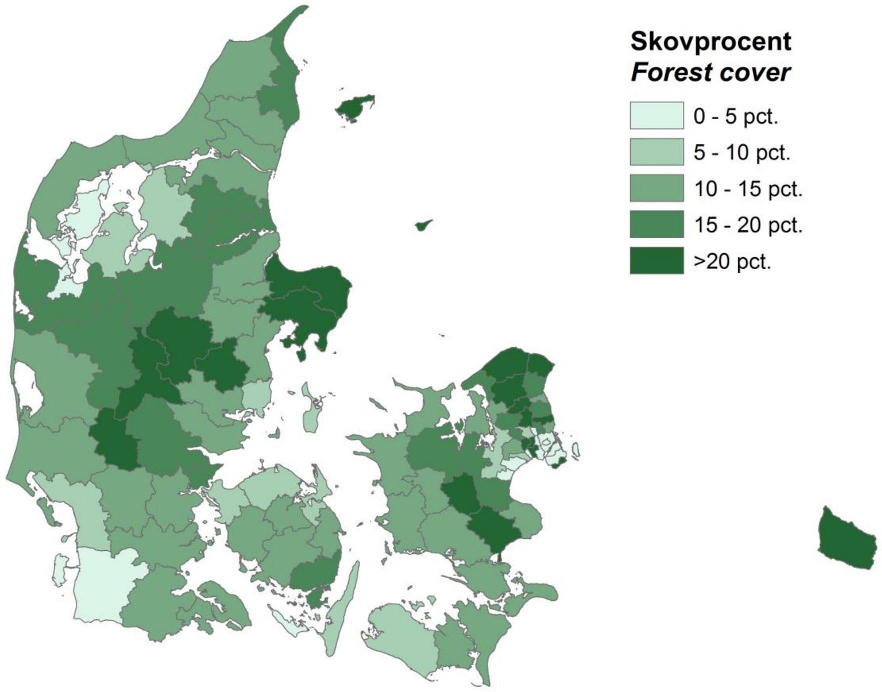

Figure 4 Forest area percentage for individual municipalities.

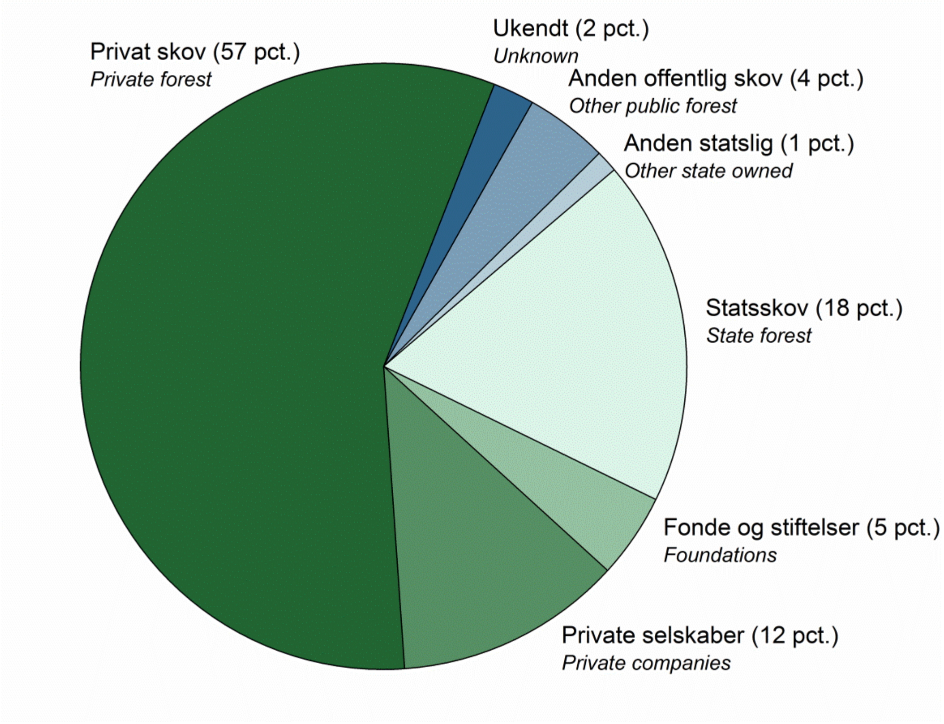

Figure 5 Distribution of forest area by types of ownership.

The forest area has been steadily increasing through efforts to support afforestation during more than 200 years, with a targeted effort since 1990. Some of the biodiversity objectives have resulted in some deforestation, for the benefit of restoration of open nature types.

The impact on the FRL of the forest area is primarily related to continued afforestation, especially as afforestation older than 30 years is expected to be included in the FRL (see also sections 3.2 and 6.2 for further on this issue). This will lead to a continuously changing area included in the FRL. This is a result of decisions and actions implemented in the period 1990 - 2010 with effect for the commitment period 2021-2030. In contrast to this, the reporting to the Kyoto Protocol (KP1 and KP2) asked for a reference level only for the forest area established before 1990, being a constant area, influenced by structure and composition decided before 1990. The afforestation after 1990, and its full carbon pools, was reported in full, without having a reference level as basis for the reporting.

Furthermore, the variability in the growing conditions, the ownership and hence the species composition and management will influence the FRL and the subsequent reporting.

5.2 Species, age, and dimension characteristics

The natural vegetation in Denmark, in the absence of human influence, would be mixed deciduous forests. However, increasing population, agriculture, and settlements have altered the vegetation of Denmark. Today most of the forests are a result of afforestation over more than 200 years. This is reflected in the species composition, where 57 species have been recorded by the NFI in the period 2012-2016. Of these, many are non-native to Denmark (e.g. Norway spruce, larch and Nordmann fir), and some have their natural habitats in continents outside Europe (e.g. Sitka spruce, Douglas fir and grand fir). In total, approximately 43 % of the forest area is covered by non-native tree species (Forest Europe Indicator 4.4). The species composition by area, results in approximately 50/50 distribution of broadleaved and coniferous forests (Figure 6 Indicator 4.1 Forest Europe).

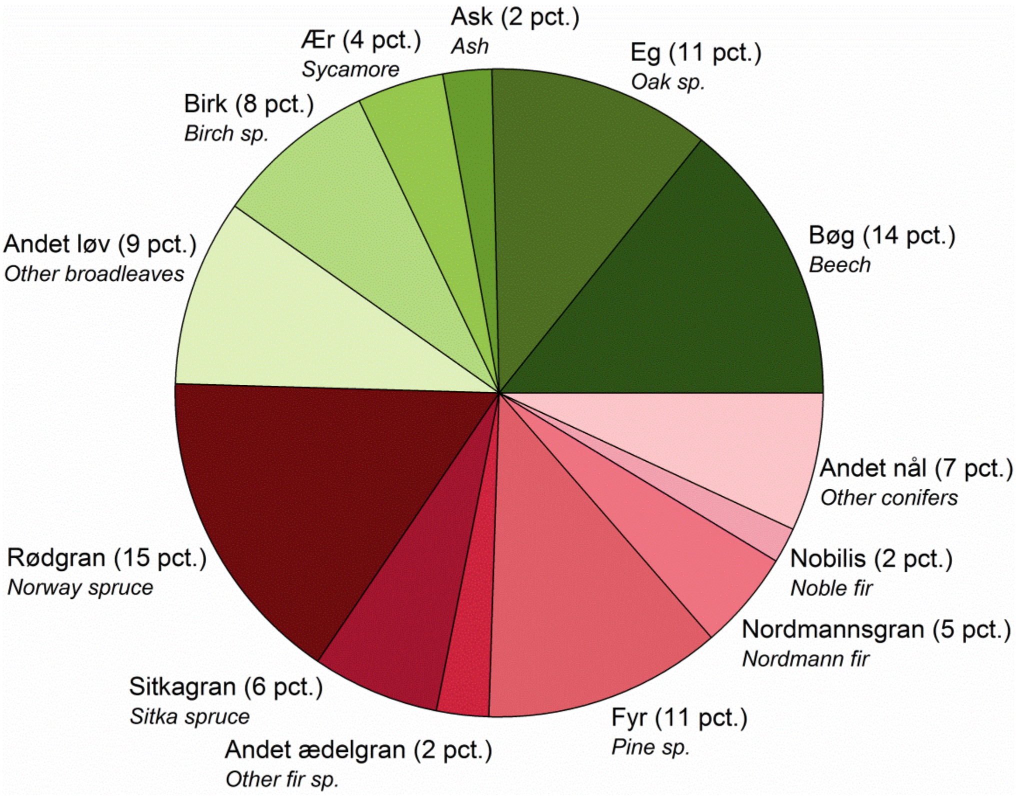

Figure 6 Distribution of the forest area by tree species. Percentages refer to the species share of the total forest area. In addition to this, unstocked areas account for 4.7 % of the area and areas with unknown species account for 0.5 %.

The species composition and the forest management vary among forest owners and across the country. The forests in the middle and northern part of Jutland are dominated by coniferous trees that are able to thrive in the sandy soils there, whereas broadleaved trees dominate in the loamy eastern parts of Denmark, especially on most of the areas in Zealand and Funen (Figure 7). This influences the growing stock of the forests (Figure 8).

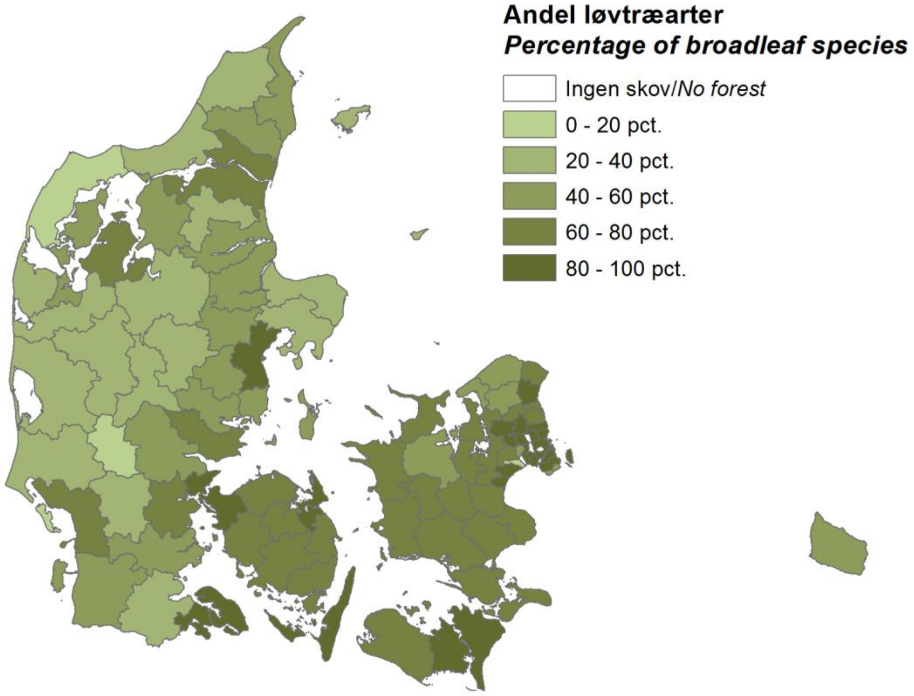

Figure 7 Percentage of broadleaved forest cover for individual municipalities. While broadleaved dominate the forests in the eastern parts of the country, conifers dominate in the western parts.

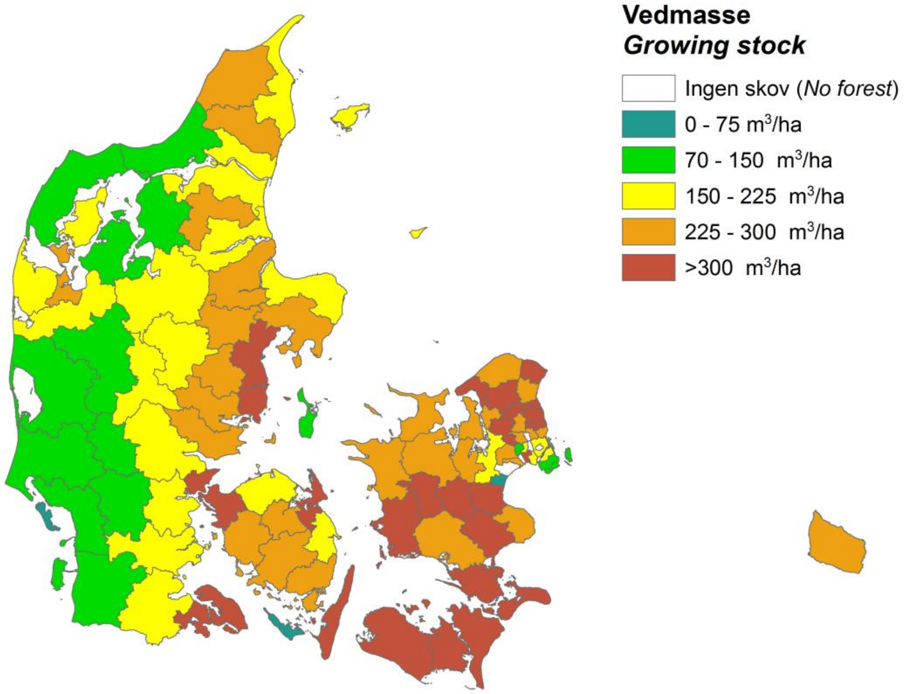

Figure 8 Average growing stock per hectare for different municipalities. Municipalities where no forest was observed within the sample plots are marked as "No forest".

The age distribution of the forests reflects both the history of the forests and the management during decades (Indicator 1.3 Forest Europe). For beech, the age class distribution reveals that more than a fourth of the area is allocated to trees older than 100 years. In addition, a share of 15 % of the beech area has not been assigned an age class, but they are typically large, older stands, so in practice the share of large, old beech trees is higher than indicated in the age class distribution. At the same time, the area of regeneration is fairly low compared to an even age distribution, indicating that large areas may be expected to be regenerated in the near future (Figure 9). The use of natural succession in beech stands involve retaining some large trees for a period, which would also result in harvest of these when the regeneration is well established. When market prices on beech logs improve, this harvest of large, old trees will increase, benefiting regeneration, but resulting in a decline in living biomass in the beech forests.

For oak the picture is more or less reversed, with a majority of the area being allocated to age classes younger than 50 years and only 7 % of the area for trees older than 100 years. This reflects that a large share of the subsidized afforestation has been established using oak as the primary tree species (Figure 9).

For Norway spruce, the age distribution is more even, with some low levels of area in the youngest age classes, reflecting a declining rate of regeneration with Norway spruce. This will in time lead to a lower production of Norway spruce timber (Figure 9). For most of the conifers, the majority of the area is in age classes ‘less than 65 years’. For Nordmann fir, which is used for Christmas tree production, the majority of the area is in the very first age classes of age 5-20 years.

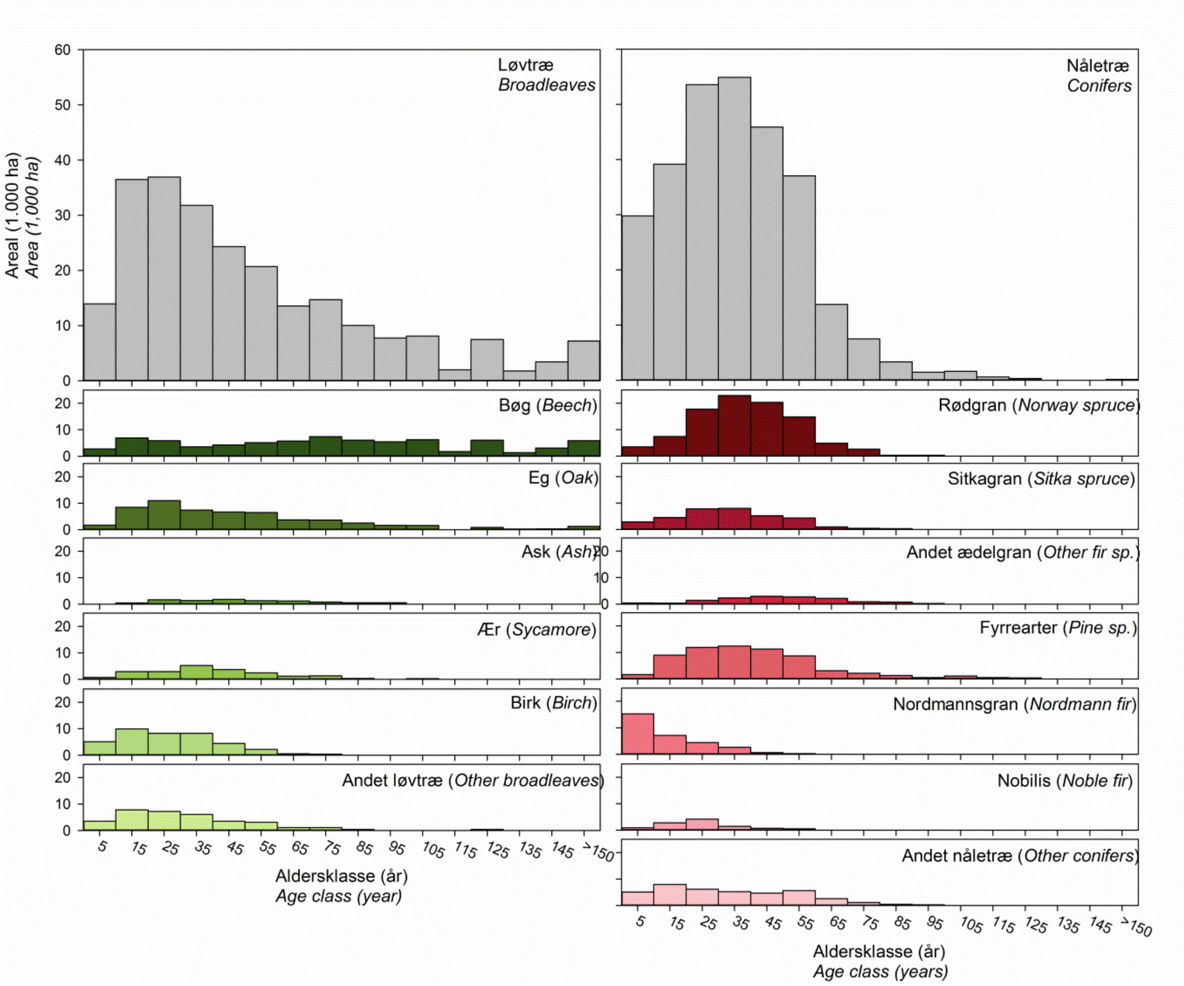

Figure 9 Age class distribution for broadleaves and conifers (in 1,000 ha).

Furthermore, the distribution of volume to diameter classes gives an indication of the current structure of the forest area (Figure 10). A significant share (1/3) of the volume for broadleaved, especially beech, is found with diameters larger than 60 cm. This indicates, as well as the age class distribution, an accumulation of volume in old, large trees. This has most likely been caused by low prices on beech logs for the last decade. The trend is slightly decreasing in the last couple of inventory assessments. For the oak however, the volume is largest for the 20-40 cm diameter classes, reflecting both a harvest of the oldest trees but also an increasing area with oak. For the conifers the main part of the volume is less than 40 cm, reflecting both age and size limitations on timber.

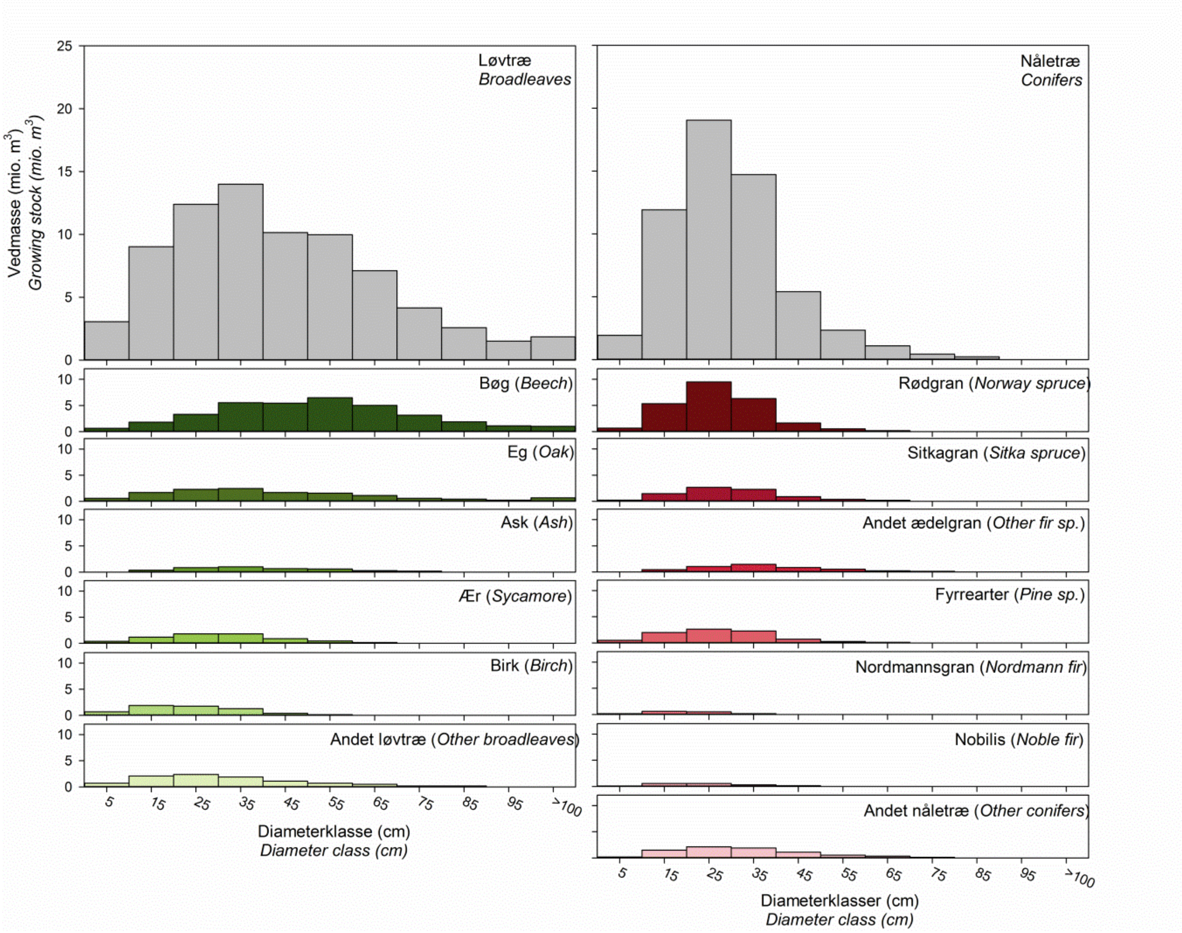

Figure 10 Distribution of growing stock (mio. m³) to diameter classes (cm) according to tree breast height diameter for different tree species and tree species groups.

The carbon stock in the forests and the distribution of the carbon stock of the living biomass is closely related to the volume of the trees. Hence the distribution over the country reflects the forest area, the species composition, and the management (Figure 11).

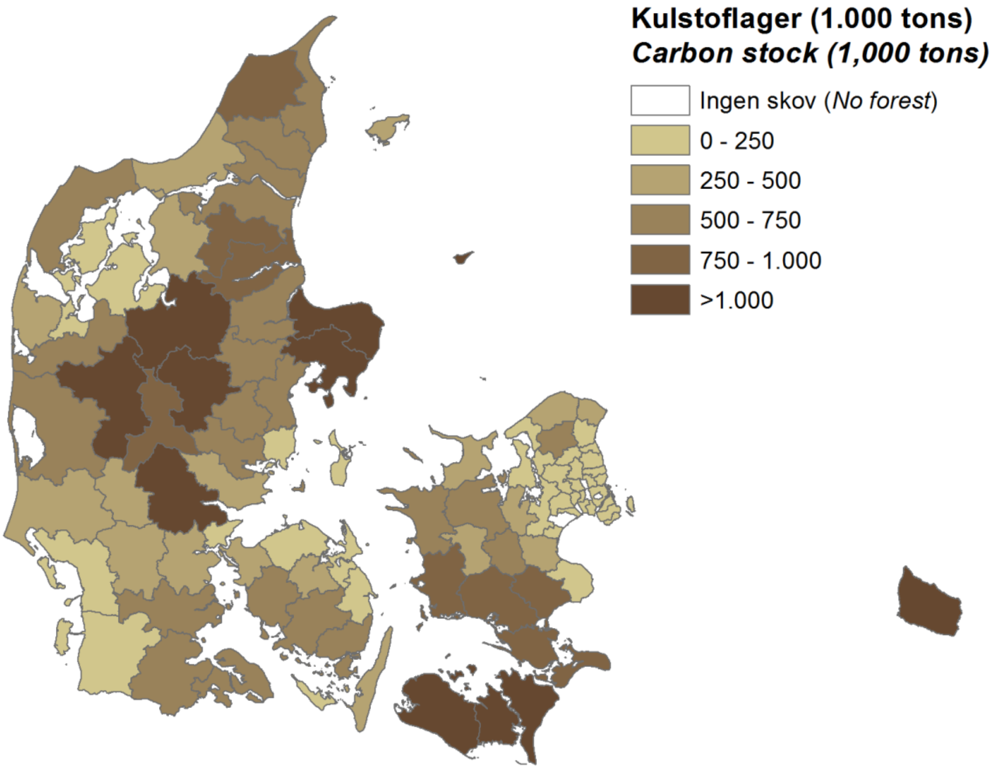

Figure 11 Geographical distribution of carbon stocks in living biomass (in 1,000 t).

The continued maintenance of growing stock, and carbon stocks in the forests, requires a continuous process of young, small trees getting established and growing to become mature trees in the forest. The age and diameter distribution is both a snapshot of the current structure, but also an indication of which development can be expected. A large pool of volume in old and large trees indicates a forest management which has been accumulating volume. This may result in regeneration of this area with old trees, and over a period of time, lead to a decrease in stock, with a subsequent increase in uptake as the young trees gain growth.

The diameter and age of the trees may influence their health and stability. For example large old spruce trees are more prone to storm damage than small young trees.

The development of growing stock over the last 10 years (the period with NFI) has been somewhat stable, with average growing stocks per ha remaining largely unchanged (Figure 12) with average growing stocks being 199, 204, 211, 211 m^3ha^{-1} in the period 2005-2016. The increase in area recorded has influenced the overall stock estimates. The estimates for 2005 area are based on the first NFI cycle, and are less precise than the later estimates, especially as the sample in 2002-2007 did not have a 100 % coverage of the scheduled sample plots.

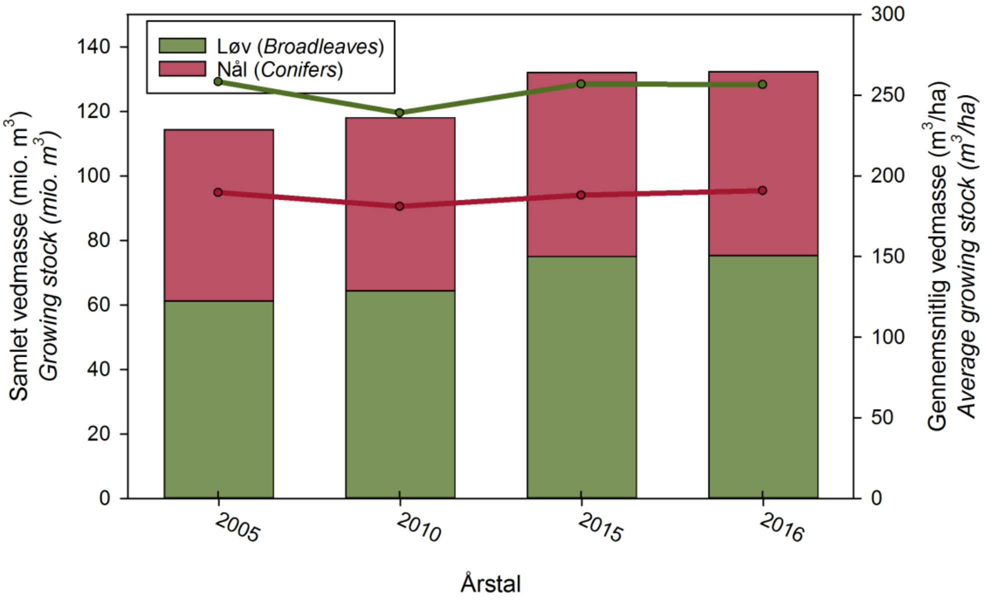

Figure 12 Development in growing stock (bars) and average growing stock per hectare (lines), distributed to broadleaves and conifers.

The overall impact on FRL is related to the development of the forests, as indicated by the age and diameter distribution. The choice of species at the time of afforestation or regeneration, by planting or natural regeneration, set the key parameter for the future growth and development of both volume and carbon stocks.

5.3 Increment and rotation lengths

The increment of the forest stocks is assessed by the NFI (Indicator 3.1 Forest Europe). For the period 2006-2016 the gross increment has been 9.6 m^3ha^{-1} yr^{-1}, with total removals (harvested, wind throw, dead, and missing) of 7.3 m^3 ha^{-1} yr^{-1}, resulting in a net increment of 2.3 m^3ha^{-1} yr^{-1}. The Gross increment varies over the country with a minimum of 8.9 m^3ha^{-1} yr^{-1} in Central Jutland and a maximum of 12.5 m^3ha^{-1} yr^{-1} on Zealand. The net increment varies from 0 in the Capital region to 4 m^3 ha^{-1} yr^{-1} on Zealand. The positive net increment so far leads to a continued accumulation of volume and carbon stock in the forests as a whole. The increment is a product of site, species, and the structure of the forest - i.e. the size, age and volume of the trees in the forest and the applied forest management.

The results from the NFI confirm the findings from long term field experiments that have been followed for 20-150 years (IGN 2018) in terms of increment rates and variation with species and site conditions. The NFI gives additional information on the species composition, the age structure, and the actual coverage of the forests, which often ranges from 10-100 % with a mean crown cover of 80-85 %.

The increment and its development over time is one of the key factors in determining rotation lengths of forests managed for production of wood products. Other factors are dimension, primarily diameter of the trees, and the prices of the different assortments that at a given time can be produced and sold. This also includes the expectations to future market prices and demands, as well as the owners need for savings or cash flow. The rotation time to obtain a certain target diameter can be influenced both by the direct interplay of site and species and by the management of the forests. For example, the use of intermediate thinning can allocate the total increment of an area to fewer trees and hereby obtaining a certain target diameter faster than in the absence of thinning. All these factors influence both the theoretical rotation lengths for the forests, as well as the realized rotation lengths, as decided by each individual forest owner and forest manager. As can be seen from Figure 9, the majority of the conifers are cut at an age of approximately 60-70 years indicated by a reduction in area in age classes above this age. Similarly for broadleaved, but less distinct, the approximate rotation age is 100-120 years. If indicated by diameter, as seen from Figure 10, the diameter limit for broadleaved is 60-70 cm and 40-50 cm for conifers.

The relation to the FRL is significant as the increment and harvesting reflects the carbon capture and emissions of the forests, respectively. Both components are driven by the composition of the forest and the applied forest management.

5.4 Harvest rates and assortments

The total volume of removals[2] including harvested, wind thrown, dead, and missing trees, is to 7.3 m^3 ha^{-1} yr^{-1}. The harvest rates vary among regions, spanning from 5.2-7.1 m^3 ha^{-1} with the maximum in the Capital region and the lowest value in the northern part of Jutland. On average, the harvest rates are 5.8 m^3ha^{-1} (Indicator 3.1 Forest Europe).

In total, the NFI estimates the total harvest to be 3.5 mill. m^3yr^{-1} and the missing volume to be 0.4 mill. m^3yr^{-1}. Assuming that the missing volume has been harvested, this amounts to 3.9 mill. m^3yr^{-1}, which is comparable to the harvest assessment performed by Statistics Denmark, reporting an annual total harvest of 3.9 mill. m^3yr^{-1} based upon questionnaires to forest owners on wood products sold from the forests. The consistency between the NFI and the Statistics Denmark assessment of harvest is valid for years after 2014. Before this year, some systematic differences caused the values of harvest estimated by Statistics Denmark to be lower than observed by the NFI. The uncertainties include errors in the upscaling of the survey to the full forest area (harvest data only collected for a subset of forest owners) and uncertainty in the transformation of the sold volume to full harvested volume (relation between residues and reported sold volume). Both factors would result in Statistics Denmark providing an underestimation of the actual harvest in the Danish forests.

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[2] Terminology: Total removals: all felled and dead trees, Harvested trees: Felled by man, Wind thrown: Felled by wind, Dead: Natural mortality, in most cases remaining on site, Missing trees: By re-measurement of permanent plots, the reason for it's removal (by man, wind or mortality) cannot be determined, but the tree is removed. This terminology does not consider the usage of the removed trees, e.g. for use wood or for energy production.

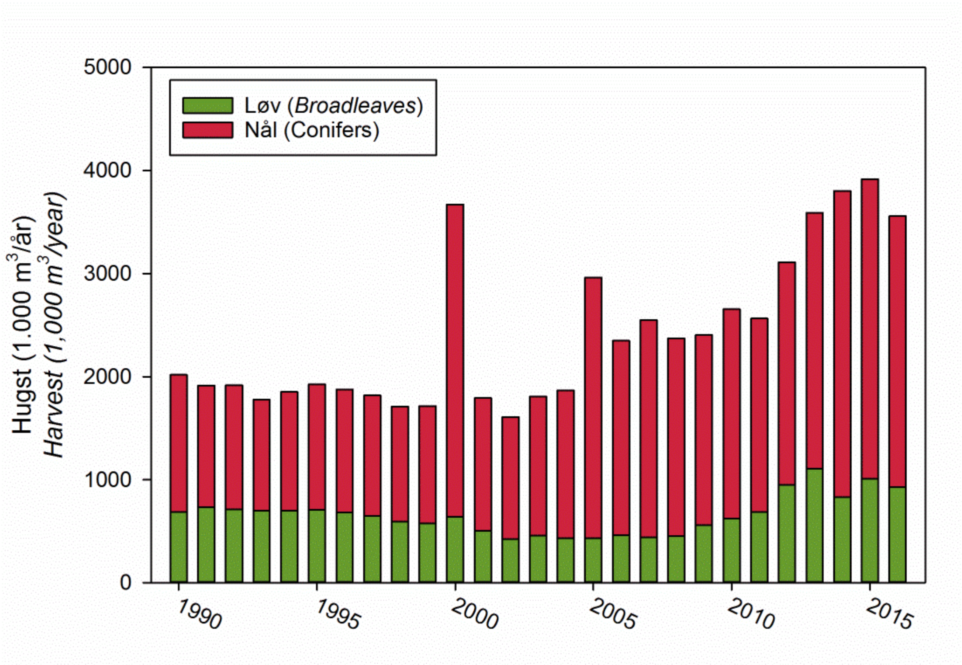

Figure 13 Total harvested volume of broadleaves and conifers reported as sold from the forests (Statistics Denmark: Statistikbanken.dk/SKOV6). Note that the development both reflects a change in completeness in the survey (increasing number of respondents from 2000 an onwards) as well as a change of method from 2012 (including also small forest owners in the total estimate).

The overall harvest rates have been increasing in the past years (Figure 13), reflecting an increasing share of the forest area being old enough to reach rotation ages but also more intensive utilization of the felling residues, through a use of branches and tops for fuel wood production (chipped wood). It is important to note, that the harvest rates reported by Statistics Denmark are based on questionnaires collecting information on sold products from the forests. Where previously a larger share of branches and wood with small dimensions were left in the forest for natural decay or collection by private persons for household heating, they are now utilized for wood energy and included in the reporting based on questionnaires. This is supported by the statistics on energy and use of wood for decentralized heating (EA energianalyse 2016), where the amount of firewood originating from forests in total amounts equals the harvest of firewood reported by Statistics Denmark from 2011-2016. Some of the initial analyses (2005-2009) of firewood for decentralized heating indicated higher amounts of firewood originating from forests and there is a continuous high supply of firewood reported originating from trees outside the forest area. The trees outside forests are not expected to influence the estimation of the FRL.

The increasing production of fuel wood is evident from the more or less stable production of round wood, alongside a dramatic increase in the fuel wood production (Figure 14). With the increasing demand for wood for energy, as a consequence of policies on renewable energy (see also 4.3), prices, as well as production, are expected to increase in the years to come. This will, however, be influenced by demand for round wood and the basic structure and development of the forests.

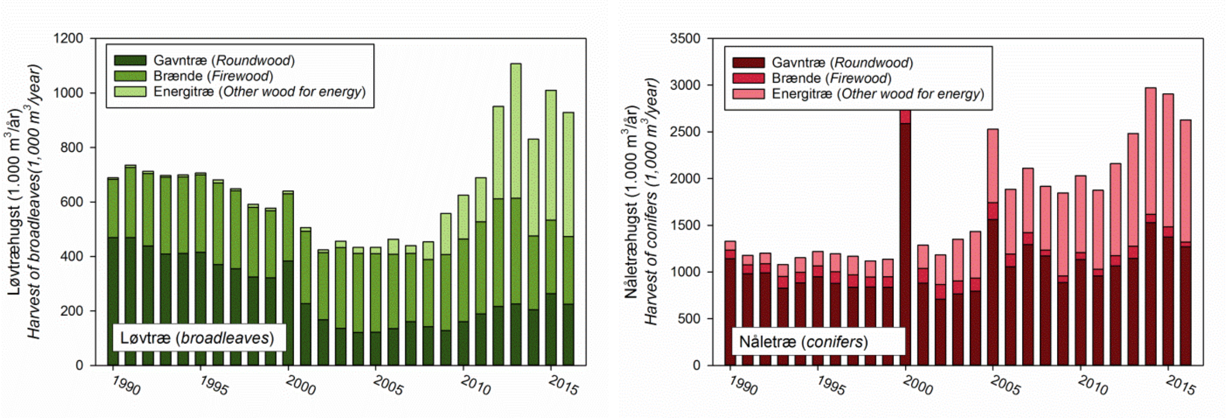

Figure 14 Total harvested volume of broadleaves (green) and conifers (red) distributed to different assortments (Statistikbanken.dk/SKOV6). Note also here the changes in population and method mentioned earlier applies, as well as the basis for the graphs being traded products from the forests.

The forest management practices applied to the Danish forests varies with owners, with the type of forest and with the aim of the forest. In the plantations of mainly coniferous tree species, a system of intensive planting, followed by intermediate thinning leads to the final harvest of the crop. All the trees felled in the intermediate thinning are utilized, mainly for fuel wood with wood chips being the main product. Some broadleaved forests are managed in a similar way, with more frequent intermediate thinnings. The products include chipped wood from the first thinnings, followed by a gradual higher share of round wood for the sawmilling industry. Generally the later years have resulted in a higher utilization of harvest residues from the harvested trees for energy (Nord-Larsen et al., 2017).

Depending on species and site, a supported natural regeneration can be utilized for the broadleaved species, instead of planting. This is most commonly used for beech. The forest management practices are reflected in the growing stock and its diameter and age distribution.

Initiatives in 2005, following the Forest Program (see section 4.1) introduced close to nature forest management as a method to obtain a better integration of multiple ecosystem services while allowing for a differentiation of management actions, depending on the local site and species composition. This is being implemented in State forests, giving a higher focus to multi-aged stands and a focus on natural regeneration. The transition will follow the development of the forests, to allow for a gradual transition to a new silvicultural system. The harvest rates from these forests may change over time, but the timing and degree are not known. The decision to designate 13,800 ha with biodiversity as the primary purpose (see section 4.4), will result in normal harvest in these areas for the next 10 years (50 years for the coniferous forest areas), with a focus on establishing best possible options/habitats for biodiversity when the forests are left without wood production. Some guidelines for this are given by Møller et al. (2018), including guidelines for conservation of old, large trees, removal of non-native tree species, establishment of grazing forest and open pastures. The cessation of harvest from these areas will enter into effect by 2026 for the majority of the area, with 3.300 ha coniferous plantations stopping harvest by 2066.

Overall, the harvest rates of the last decades reflect changes and development of the forest structure as well as a development in the demands and policies of society. This will form the basis for the FRL. But the changes in the forests and the demands of society will still change faster than the forests are regenerated.

The increasing demand for renewable energy will probably influence the assortments of the harvest, and possibly the harvest rates. One of the main drivers for this is the Danish national agreement on energy in 2012 and the recent update of this in 2018, which supports a transition to renewable energy, including biomass. The increasing demand will on the other hand also influence the management of the forests, e.g. in the choice of species for planting and the density of the plants in the regeneration and in the afforestation, as increasing number of plants initially may give increasing increment that can be harvested at the first intermediate thinning (e.g. planting of nurse trees - pre-crop trees). At the same time initiative for the benefit of biodiversity may reduce harvest rates for parts of the forest area (Graudal et al 2013).

In the FRL both the intensity of the harvest as well as the allocation to use wood or wood for energy in the reference period of 2000-2009 play a central role for the HWP component of the FRL. But, the future development and hence the accounting will be highly influenced by the technical development in the harvest systems and the use of the harvest.

5.5 Biodiversity and water

A sustainable forest management encompasses ecosystem services related to securing habitats for species, genetic variation as well as protection of water resources. In Forest Europe, several indicators are utilized to monitor the state and development of important ecosystem services, among these, species and age distribution (as described in 5.2).

The history of the Danish forest area, with continued afforestation (see chapter 5.1), influences the current state of biodiversity in the forests as reflected in species composition and management. The species mixtures with two or more tree species are found on 63 % of the forest area (Forest Europe Indicator 4.1) while more than 70 % of the trees are planted (Forest Europe Indicator 4.2). At the same time, more than 70 % of the forest area is managed as even-aged forests (Forest Europe Indicator 4.3, Figure 15). The share of forests where biodiversity is the focus of management is approximately 6 % and uneven-aged management 10 %. There are some minor differences in these indicators between ownership in the current state of the forests. But this may change in the decades to come, especially as the policy for the State forests, aiming for more focus on biodiversity and supporting uneven-aged forest management or no management, gradually influences the state of the forests more.

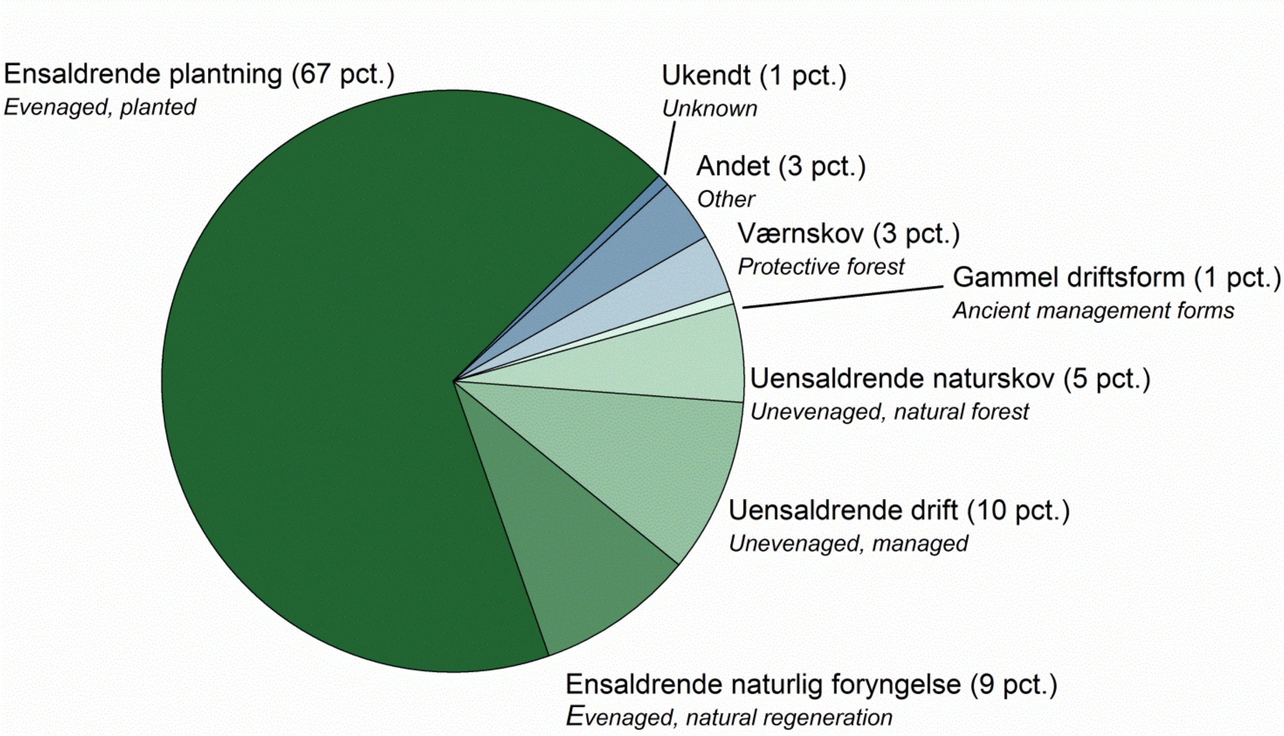

Figure 15 Distribution of the forest area to management types. The percentages are of the total forest area, excluding the 2 % auxiliary areas. Temporarily unstocked areas are part of the even-aged, planted area.

The high share of even-aged forest, is also reflected in the number of large, old trees and in the amount of dead wood, which compared to most other European countries is low (Forest Europe Indicator 4.5). The uncertainty of such small pools is relatively high, and will be influenced by a number of factors, varying with silvicultural system and harvest intensity.

The protection of biodiversity in the forest is supported by the current legislation, mainly with focus on some specific targets. Beside formal protection focusing on either agreements from 1910-today on specific designated areas (a total of approx. 21,000 ha. - based on structure and/or species), the Natura 2000 gives some regulation for the management of the Forest Habitat types within the Habitat areas (a total of approx. 20,000 ha - Forest Europe Indicator 4.9) (Johannsen et al., 2013). Here, the forest management needs to ensure the continued existence and conservation/improvement of the state of the forest habitat types. This is ensured by notification to the Ministry of Environment and Food, who evaluates the proposed activities. In total there are some 35,000 ha of forest area with biodiversity as the primary management objective, as there is some overlap between the formal protection and the habitat types.

The area is further supplemented during 2018, with new areas of 13,800 ha in State forests designated for biodiversity, resulting in a total of 22,800 ha in the State forests (Naturstyrelsen 2018, Møller et al., 2018). The protection of biodiversity in the forest area is also partly supported by the Nature Protection Law, especially lakes, streams and bogs (§ 3 of the Nature Protection Law) as well as the Natura 2000 framework (Habitat and Bird directive as well as the Ramsar treaty).

Of the forest area, more than 1/3 is located in areas designated for drinking water supply (Forest Europe Indicator 5.1). In the subsidy schemes for afforestation and in the planning of location of new afforestation, the positive impact on ground water protection has been prioritized. In the most recent years, the focus on potentials for reduced leaching of nutrients to surface water, have given focus to afforestation on cropland with high risks of leaching (Miljø- og Fødevareministeriet 2018c). The establishment of forest on these soils will reduce leaching.

The FRL will be based on the state in the reference period 2000-2009. For the development of the full GHG accounts of the forests, the development of forest areas for biodiversity will influence the future reporting and accounting. The carbon storage will be different from the managed forests, changed water management regimes with rewetting of some areas, unknown interplay of grazing, mortality and regeneration. Generally, change of species will be limited as well as harvest will be very restricted or not take place at all. It is expected that the amount of dead wood, standing and lying, will increase in the designated areas. The forests located on drinking water reserves will develop similar to the rest of the forest area.

5.6 Societal functions

The societal functions of the forests are naturally to contribute to the economic value for the forest owners and for society as a whole. With forestry, being a small part of the Danish industry, the contribution to the GDP is small (< 0.1%), but the wood production, the production of Christmas trees and greenery together with the wood industry still play a role. In addition to this, the hunting for game provides significant income to the forest owners. The forest sector has been steady in terms of jobs for the primary production, but the number of jobs in the related industry of sawmills and carpentry has diminished (Figure 16).

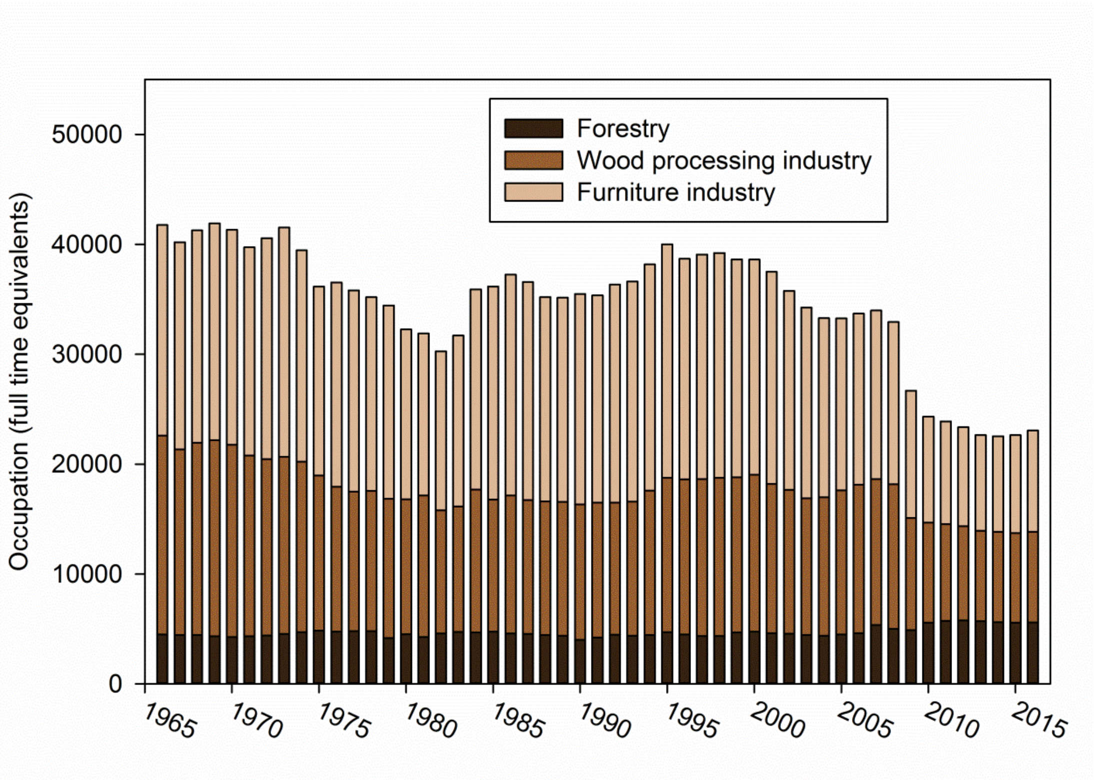

Figure 16 Occupation in the forestry sector and associated industry 1966-2016 (Statistikbanken.dk/NABB117).

One of the main recreational activities for the Danish population includes visits to forest areas. It is estimated that 90 % of the population visit forests at least once a year and that the number of annual visits is approximately 70 mill. based on questionnaires (Forest Europe Indicator 6.10). For comparison, the population of Denmark is 5.8 mill. people.

Forests hold a large number of archeological and cultural sites, especially related to former land-use and older markings (Forest Europe Indicator 6.11). In the case of Denmark, 14.5 % of forest areas hold 40 % of such recorded sites.

The societal functions will have limited influence on the FRL, however, HWP coincide with jobs in the wood processing industry.

6 Forest Reference Level

To increase transparency and documentation, construction of the FRL is categorised in four parts, each addressing fundamental elements of FRL estimation:

1. *Forest land*. Land area identified as forest before 1990 in the land-use mapping (Levin et al. 2014), previously forming the basis for the FMRL in the Kyoto commitment period.
2. *Afforested land*. Land area afforested after 1990. The FRL includes only afforestation that has reached steady state in terms of carbon uptake and emissions. The reference age for which afforestation carbon pools are assumed to have reached a stable level is, in Denmark, set at 30 years, as duly justified in the IPCC guidelines. This publication further includes estimates at a reference age of 20 years, which is the default given by the regulation. Only the share of afforestation older than the reference age is included in the estimation of the FRL. Hence, afforestation younger than the reference age is outside the FRL.
3. *Harvested Wood Products (HWP)*. The carbon pool captured in forest products that are in use in buildings or paper. Historic development and use of wood determines the outflow through the half-time degradation of the total pool of woody products. The inflow is determined by the harvest in the forest, the forest industry, and international trade.
4. *Deforestation*. Change in forest-land occurring after 1990. Wood harvested from deforestation does not contribute to the HWP pool according to the IPCC Guidelines (IPCC 2014). An estimation of deforestation is included in the report, but is not included in the FRL estimate. Occurring deforestation in the period 2021-2030 will be reported as a technical correction, to ensure correct accounting.

The report will draw upon analyses and reviews in the Danish report on the subject from July 2017 (Johannsen et al., 2017), former reporting (e.g. Nielsen et al., 2018) and calculations based on the NFI. The forest area included in the report refers to the forest definition given by the NFI, which is in line with other international reporting and indicated in Annex II (EU 2018).

The report aims to follow the IPCC Good Practice Guidance for LULUCF (IPCC 2006, 2007, 2014) by adhering to the following key points 1) Transparency, 2) Completeness, 3) Consistency, 4) Comparability and 5) Accuracy. A key point of the Regulation (EU 2018) is use of data from the reference period 2000-2009 and using 2010 as the base year for the FRL. Multiple analyses have been conducted during the process of developing the FRL, to identify the most robust and transparent method.

Table 1 provides the main results, with a 20-year transition period while Table 2 provides the results for a 30-year transition period. The annual rate of afforestation in the period 2021-2030 affects the estimated emissions separate from the reference level. In the tables below an annual afforestation rate of 1.900 ha/year is expected. In Annex 9.4.3 similar tables are presented applying an annual afforestation rate of 3.200 ha/year. The data, stratification, methods, sub results and validation are described in the subsequent sections.

Table 1 Summary of Forest Reference Level - FRL - annual average values for each period, base year 2010, transfer at 20 years, afforestation 1.900 ha/yr. Positive changes indicate emissions, while negative changes indicate uptake.

	2011-2015	**2016-2020**	**2021-2025**	**2026-2030**	**2031-2035**	**2036-2040**	**2041-2045**	**2046-2050**
I: FRF - from before 1990								
Area* (ha)	529,085	529,085	529,085	529,085	529,085	529,085	529,085	529,085
Carbon stock* (AG+BG+DW+FF) (kt $CO_{2\ eq}$)	150,382	144,602	139.382	133.754	130.842	129.571	128.330	128.359
Stock change** (AG+BG+DW+FF) (kt $CO_{2\ eq}\ YR^{-1}$)	769	1.156	1.044	1.126	582	254	248	-6
CO2 from drained soils (kt $CO_{2\ eq}\ yr^{-1}$)	123	123	123	123	123	123	123	123
N2O drained organic soils (kt $CO_{2\ eq}\ yr^{-1}$)	17	17	17	17	17	17	17	17
CH4 drained and rewetted organic soils (kt $CO_{2\ eq}\ yr^{-1}$)	28	28	28	28	28	28	28	28
$\sum$ soils emissions (kt $CO_{2\ eq}\ yr^{-1}$)	168	168	168	168	168	168	168	168
Stock change + $\sum$ soils emissions ** (kt $CO_{2\ eq}\ yr^{-1}$)	**937**	**1,324**	**1,212**	**1,293**	**750**	**422**	**416**	**162**
Afforestation - after 1990								
II: Older than 20								
Area* (ha)	22,068	40,458	58,907	77,594	88,761	98,261	107,761	117,261
Carbon stock* (AG+BG+DW+FF) (kt $CO_{2\ eq}$)	2,622	7,339	12,138	17,564	22,475	27,003	31,446	35,878
Stock change** (AG+BG+DW+FF) (kt $CO_{2\ eq}\ yr^{-1}$)	-328	-943	-960	-1,085	-982	-906	-888	-886
Carbon stock transfer**$^{\#}$ (AG+BG+DW+FF) (kt $CO_{2\ eq}\ yr^{-1}$)	278	278	280	283	141	144	144	144
Carbon accumulation - soil (kt $CO_{2\ eq}\ yr^{-1}$)	-11	-19	-28	-37	-43	-47	-52	-56
CO2 from drained soils (kt $CO_{2\ eq}\ yr^{-1}$)	11	24	36	48	57	62	67	72
N2O drained organic soils (kt $CO_{2\ eq}\ yr^{-1}$)	2	3	5	7	8	8	9	10
CH4 drained and rewetted organic soils (kt $CO_{2\ eq}\ yr^{-1}$)	0	0	1	1	1	1	1	1
$\sum$ soils emissions (kt $CO_{2\ eq}\ yr^{-1}$)	3	8	13	19	23	24	25	27
Stock change +$\sum$ soils emissions + transfer (kt $CO_{2\ eq}\ yr^{-1}r$)**	**-47**	**-657**	**-666**	**-784**	**-818**	**-738**	**-719**	**-716**

	2011-2015	**2016-2020**	**2021-2025**	**2026-2030**	**2031-2035**	**2036-2040**	**2041-2045**	**2046-2050**
III: Younger than 20								
Area* (ha)	66,694	57,804	48,854	39,667	38,000	38,000	38,000	38,000
Carbon stock* (AG+BG+DW+FF) (kt C $CO_{2\,eq}$)	3,320	3,033	2,593	1,934	1,780	1,780	1,780	1,780
Stock change** (kt $CO_{2\,eq}$ yr^{-1})	45	57	88	132	31	0	0	0
Carbon stock transfer** # (AG+BG+DW+FF) (kt $CO_{2\,eq}$ yr^{-1})	-278	-278	-280	-283	-141	-144	-144	-144
Carbon loss from conversion (kt $CO_{2\,eq}$ yr^{-1}) ##	49	42	42	42	42	42	42	42
Carbon accumulation - soil (kt $CO_{2\,eq}$ yr^{-1})	-32	-28	-23	-19	-18	-18	-18	-18
CO2 from drained soils (kt $CO_{2\,eq}$ yr^{-1})	35	27	20	12	9	9	9	9
N2O drained organic soils (kt $CO_{2\,eq}$ yr^{-1})	5	4	3	2	1	1	1	1
CH4 drained and rewetted organic soils (kt $CO_{2\,eq}$ yr^{-1})	1	1	0	0	0	0	0	0
$\sum$ soils emissions (kt $CO_{2\,eq}$ yr^{-1})	50	46	41	37	34	34	34	34
Stock change + $\sum$ soils emissions + transfer(kt $CO_{2\,eq}$ yr^{-1})**	**-183**	**-175**	**-151**	**-114**	**-77**	**-110**	**-110**	**-110**
IV: Deforestation								
Area**(ha)	2.251	116	116	116	116	116	116	116
Carbon stock (AG+BG+DW+FF) (kt $CO_{2\,eq}$ yr^{-1})**	**499**	**26**	**26**	**26**	**26**	**26**	**26**	**26**
V: Harvested Wood Products								
HWP (kt $CO_{2\,eq}$ yr^{-1})**	**-118**	**-241**	**-192**	**-152**	**-152**	**-152**	**-152**	**-152**
Forest Reference Level 20 year								
I + II (kt $CO_{2\,eq}$ yr^{-1})**	**889**	**667**	**545**	**510**	**-68**	**-316**	**-303**	**-554**
I+II +V ** (kt $CO_{2\,eq}$ yr^{-1})	**772**	**425**	**354**	**358**	**-220**	**-468**	**-456**	**-706**
Total Forest sector								
I+II+III+IV+V** (kt $CO_{2\,eq}$ yr^{-1})	**1,095**	**276**	**228**	**269**	**-271**	**-552**	**-540**	**-791**

* Refer to the state at the end of the period

** Refer to the average for the 5-year period

The full effect of growth/harvest/mortality for the age class 20 is assigned to the afforestation before transferring the area to the forest land. Therefore, the stock of age class 20 remains in the afforestation until the end of the year (December 31) and is transferred by the beginning of the next year (January 1).

Emissions from removal of crop biomass before afforestation. For change from crop land to forest this is estimated to be 22 t CO2 eq ha^{-1} equaling a loss of 12 t of biomass per ha.

Table 2 Summary of Forest Reference Level - FRL - annual average values for each period, base year 2010, transfer at 30 years, afforestation 1.900 ha/yr. Positive changes indicate emissions, while negative changes indicate uptake.

	2011-2015	**2016-2020**	**2021-2025**	**2026-2030**	**2031-2035**	**2036-2040**	**2041-2045**	**2046-2050**
I: FRF - from before 1990								
Area* (ha)	529,085	529,085	529,085	529,085	529,085	529,085	529,085	529,085
Carbon stock* (AG+BG+DW+FF) (kt CO$_{2\,eq}$)	150,382	144,602	139.382	133.754	130.842	129.571	128.330	128.359
Stock change ** (AG+BG+DW+FF) (kt CO$_{2\,eq}$ yr^{-1})	769	1.156	1.044	1.126	582	254	248	-6
CO2 from drained soils (kt CO$_{2\,eq}$ yr^{-1})	123	123	123	123	123	123	123	123
N2O drained organic soils (kt CO$_{2\,eq}$ yr^{-1})	17	17	17	17	17	17	17	17
CH4 drained and rewetted organic soils (kt CO$_{2\,eq}$ yr^{-1})	28	28	28	28	28	28	28	28
$\sum$ soils emissions (kt CO$_{2\,eq}$ yr^{-1})	168	168	168	168	168	168	168	168
Stock change + $\sum$ soils emissions ** (kt CO$_{2\,eq}$ yr^{-1})	**937**	**1,324**	**1,212**	**1,293**	**750**	**422**	**416**	**162**
Afforestation - after 1990								
II: Older than 30								
Area* (ha)	0	3,678	22,068	40,458	58,907	77,594	88,761	98,261
Carbon stock* (AG+BG+DW+FF) (kt CO$_{2\,eq}$)	0	878	5,671	11,049	16,930	23,282	28,108	32,540
Stock change ** (AG+BG+DW+FF) (kt CO$_{2\,eq}$ yr^{-1})	0	-176	-958	-1,076	-1,176	-1,270	-965	-886
Carbon stock transfer ** $^{\#}$ (AG+BG+DW+FF) (kt CO$_{2\,eq}$ yr^{-1})	0	314	786	786	791	798	399	406
Carbon accumulation - soil (kt CO$_{2\,eq}$ yr^{-1})	0	-2	-11	-19	-28	-37	-43	-47
CO2 from drained soils (kt CO$_{2\,eq}$ yr^{-1})	0	5	17	29	41	56	62	67
N2O drained organic soils (kt CO$_{2\,eq}$ yr^{-1})	0	1	2	4	6	8	9	9
CH4 drained and rewetted organic soils (kt CO$_{2\,eq}$ yr^{-1})	0	0	0	1	1	1	1	1
$\sum$ soils emissions (kt CO$_{2\,eq}$ yr^{-1})	0	4	9	14	20	27	29	31
Stock change +$\sum$ soils emissions + transfer ** (kt CO$_{2\,eq}$ yr^{-1})	**0**	**142**	**-164**	**-276**	**-366**	**-445**	**-537**	**-450**

	2011-2015	2016-2020	2021-2025	2026-2030	2031-2035	2036-2040	2041-2045	2046-2050
III: Younger than 30								
Area* (ha)	88,761	94,583	85,694	76,804	67,854	58,667	57,000	57,000
Carbon stock* (AG+BG+DW+FF) (kt $CO_{2\,eq}$)	5,943	9,494	9,061	8,449	7,325	5,502	5,118	5,118
Stock change** (kt $CO_{2\,eq}$ yr^{-1})	-283	-710	87	122	225	365	77	0
Carbon stock transfer** # (AG+BG+DW+FF) (kt $CO_{2\,eq}$ yr^{-1})	0	-314	-786	-786	-791	-798	-399	-406
Carbon loss from conversion (kt $CO_{2\,eq}$ yr^{-1})##	49	42	42	42	42	42	42	42
Carbon accumulation - soil (kt $CO_{2\,eq}$ yr^{-1})	-43	-45	-41	-37	-33	-28	-27	-27
CO2 from drained soils (kt $CO_{2\,eq}$ yr^{-1})	46	46	39	32	24	15	13	13
N2O drained organic soils (kt $CO_{2\,eq}$ yr^{-1})	6	6	5	4	3	2	2	2
CH4 drained and rewetted organic soils (kt $CO_{2\,eq}$ yr^{-1})	1	1	1	1	1	0	0	0
$\sum$ soils emissions (kt $CO_{2\,eq}$ yr^{-1})	52	50	46	42	37	31	30	30
Stock change + $\sum$ soils emissions s + transfer (kt $CO_{2\,eq}$ yr^{-1})**	**-230**	**-975**	**-653**	**-622**	**-529**	**-402**	**-292**	**-376**
IV: Deforestation								
Area** (ha)	2.251	116	116	116	116	116	116	116
Carbon stock (AG+BG+DW+FF) (kt $CO_{2\,eq}$ yr^{-1})**	**499**	**26**	**26**	**26**	**26**	**26**	**26**	**26**
V: Harvested Wood Products								
HWP (kt $CO_{2\,eq}$ yr^{-1})**	**-118**	**-241**	**-192**	**-152**	**-152**	**-152**	**-152**	**-152**
Forest Reference Level 30 year								
I + II ** (kt $CO_{2\,eq}$ yr^{-1})	**937**	**1,466**	**1,048**	**1,017**	**384**	**-23**	**-121**	**-288**
I + II + V ** (kt $CO_{2\,eq}$ yr^{-1})	**819**	**1,224**	**856**	**865**	**232**	**-176**	**-274**	**-440**
Total forest sector								
I+II+III+IV+V** (kt $CO_{2\,eq}$ yr^{-1})	**1,095**	**276**	**228**	**269**	**-271**	**-552**	**-540**	**-791**

* Refer to the state at the end of the period

** Refer to the average for the 5-year period

The full effect of growth/harvest/mortality for the age class 30 is assigned to the afforestation before transferring the area to the forest land. Therefore, the stock of age class 30 remains in the afforestation until the end of the year (December 31) and is transferred by the beginning of the next year (January 1).

Emissions from removal of crop biomass before afforestation. For change from crop land to forest this is estimated to be 22 t CO2 eq ha^{-1} equaling a loss of 12 t of biomass per ha.

6.1 Forest land

Forest land identified as forest prior to 1990 comprised 85 % of the total forest area at the reference year for the FRL projections (2010). The diverse species and age structure of forest land (as described in chapter 5) is a product of historical circumstances, including the large afforestation projects initiated after the first forest act in 1805. However, in relation to the FRL, forest land is considered one entity.

The principal method chosen for the FRL of the forest land is 'stock change' and is in line with national reporting of GHG emissions from forests. This method is based on assessment of carbon stock at two given points in time and provides estimates of change over time as the difference between the two estimates or inventories of carbon stocks.

The principles of the stock change method are illustrated in Figure 17 and in Table 3. In the following paragraphs and in Annex 9.6 further details are given on the estimation and application of the stock change method for the Danish FRL.

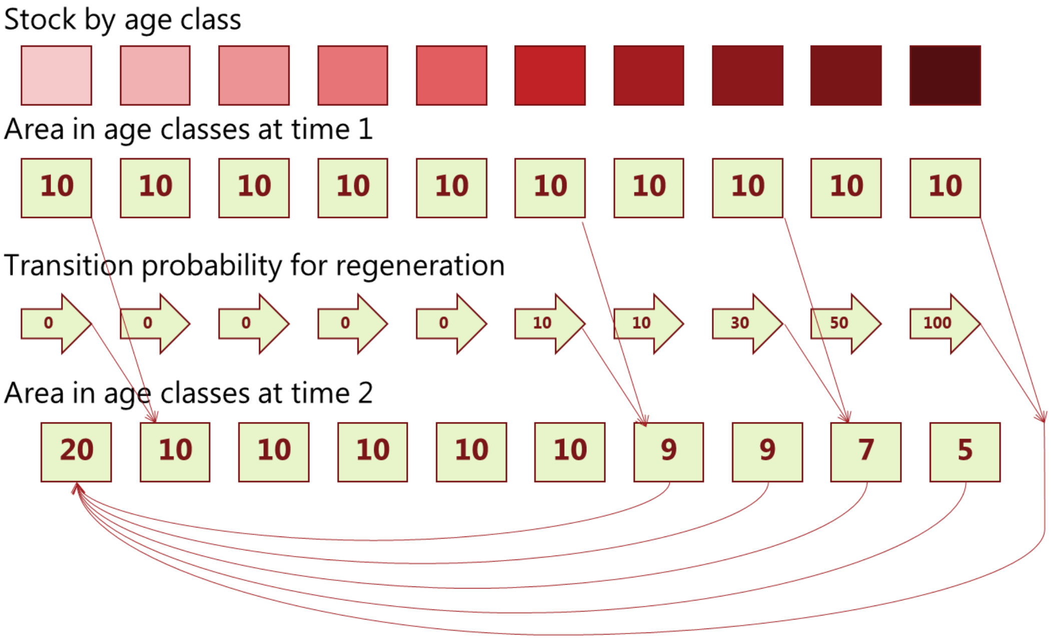

Figure 17 Principles of the stock change method. Current management is reflected in the stock by age classes. Current state is given by area in age classes at time 1. Transition probabilities indicate the probability for regeneration, leading to harvest and new age class (youngest) of a share of the area in an age class. In summary, this gives a distribution of the total area by age classes at time 2.

Table 3 Principles of stock change method with example data for an area of 100 ha with 10 age classes. Transition probabilities and the stock in each age class in summary reflect the management observed prior to the prognosis. The resulting area distribution and summary stock are given for selected years, based on annual simulation.

Age class	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**		
Transition probability	0	0	0	0	0	10	10	30	50	100		
Stock m^3/ha	5	10	20	40	60	80	90	95	100	120		
Year Area (ha)	ha										**Sum area (ha)**	**Sum stock (m^3)**
2017	10	10	10	10	10	10	10	10	10	10	100	6.200
2018	20	10	10	10	10	10	9	9	7	5	100	5.165
2027	13	11	11	10	10	10	10	11	11	3	100	5.593
2037	13	13	12	11	11	10	9	9	8	4	100	5.312
2047	12	12	12	12	12	11	10	9	7	4	100	5.267
2057	12	12	12	12	12	12	10	9	6	3	100	5.342
2067	11	12	12	12	12	12	11	9	6	3	100	5.417
2077	12	11	12	12	12	12	11	10	7	3	100	5.445
2087	12	12	12	12	12	12	11	10	7	3	100	5.439
2097	12	12	12	12	12	12	11	10	7	3	100	5.423

6.1.1 Data

The National Forest Inventory (NFI) provides data for estimation of the FRL for forest land. The basic design of the NFI and the calculation methods are briefly described in Chapter 3, and more thoroughly by Nord-Larsen & Johannsen (2016).

Estimation of the FRL is based on NFI data from the initiation of the NFI in 2002 and until 2017. The reference period 2000-2009 poses some challenges, as the time interval for repeated measurement of permanent plots is every 5 years, and hence the Danish NFI only now (in 2017) is on the third cycle, offering a maximum of 2 repeated measurements in each permanent plot. Still, the usage of the full NFI data from 2002 - 2017 for estimation of the survival of the forests, puts the focus on the data from the period 2002-2012 (the first two cycles representing the reference period 2000-2009), as the primary input for estimation of survival models. The distribution of NFI data with repeated measurements to the years of first observation are given in Table 4 and in Figure 41 page 102. For each plot the state at the initial observation determines the usage of the plot. 67 % of the data are from the period 2000-2009, while the rest is from 2010-2012. The first years of the NFI (2002-2003) are characterized by a lower number of data, due to the starting phase of the NFI. Of the full set of repeated measurements (4886) some do not have age class information (446) leaving a total of 4440 plots with repeated measurements and age class information available for the estimation of transition probabilities. The state of cut or no-cut is the only information determined by the subsequent measurement, regardless of when in the 5 year period until the repeated measurement the event occurs.

The full datasets used for the estimation are provided in Annex 9.3 and further details on the methodologies and sensitivity can be found in Annex 9.6.

Table 4 Number of re-measurements from the NFI by year of first measurement and availability of age class information. State of cut are determined by the re-measurement 5 years later.

	With age class information			No age class information			ALL
Year of first observation	**Not cut**	**cut**	**total**	**Not cut**	**cut**	**total**	
2002	159	22	**181**	37	2	39	**220**
2003	258	25	**283**	82	6	88	**371**
2004	275	30	**305**	50	8	58	**363**
2005	398	41	**439**	36	6	42	**481**
2006	372	60	**432**	30	9	39	**471**
2007	348	21	**369**	40	2	42	**411**
2008	464	25	**489**	35	2	37	**526**
2009	451	37	**488**	36		36	**524**
2010	452	44	**496**	25	4	29	**525**
2011	439	33	**472**	32		32	**504**
2012	455	31	**486**	4		4	**490**
Sum	**4071**	**369**	**4440**	**407**	**39**	**446**	**4886**

Data from the NFI are extracted with information on growth region (Jutland or the Islands), species group (conifers, broadleaved or Christmas trees), supplemented with information on age class, height, volume, and carbon stocks for all the pools (as described in Chapter 3). For each plot, the management related to regeneration is recorded and hereby provide information on the forest management practices in the observed period. Each permanent plot is re-inventoried every 5 years and hence the changes observed refer to 5-year intervals.

The different operations (such as clear cut, pre-seeding harvest, planting, regeneration etc.) are jointly regarded as an ‘end of life’ event and the age until an event the ‘survival time’. The dataset 9.3.1 contains the input data and Figure 18 below provides a representation of the number of plots available for the estimation and their distribution to age classes, and the frequency of forest management actions, which occur on 10 % of the coniferous plots and on 6 % of the broadleaved plots within a 5-year period. The key parameter in the forest management is the age of the forest stands and the survival of the stands. Thereby the data influencing the survival models are mainly the total area in each age class ('survival time'), more than the frequency of 'end of life' events.

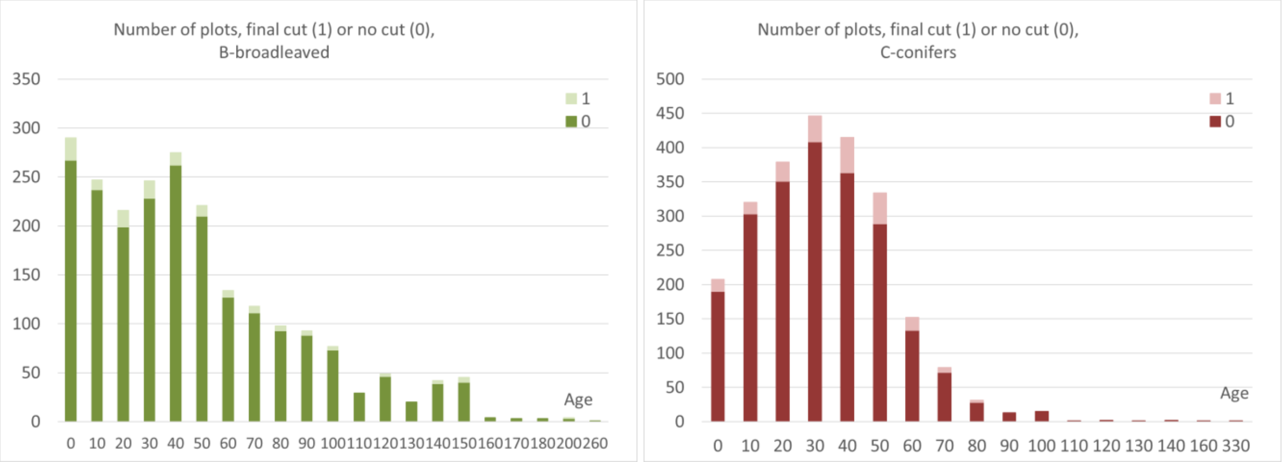

Figure 18 Data available for estimation of the survival model. NFI data for the time of initial observation in 2002 - 2012, 2250 observation for the conifers and 2012 for the broadleaved (and 178 observations for Christmas trees).The 440 plots with no age class information are 150 conifer, 289 broadleaved and 7 Christmas trees reflecting that determination of age Is most difficult for broadleaved plots.

Stratification of NFI data

Table 5 show the stratification classes of the forest area, to handle the forest management practices in the modelling of the forest reference level. This stratification ensures forest area of common growth and management regimes and secures a minimum number of sample plots for use as basis for the initialisation of the FRL estimation.

Table 5 Stratification of the Danish forest area used for the Forest Reference Level estimation

Classification	**Levels**	**Number of levels**
Region	Jutland; Islands	2
Species type	Broadleaved; Conifers, Christmas trees	3

Baseline estimate

The state of the forest area by 2010 is used as the baseline for the expected development. The baseline forest structure of forest land was estimated from data collected in the Danish NFI during the five-year rotation 2006-2010, in line with ordinary procedures for national and international reporting of forest resources (Nord-Larsen and Johannsen, 2016). An area of 506.623 ha are stocked while 22.462 ha are unstocked and without carbon stocks giving a total area of 529.085 ha in the forest land remaining forest land.

The baseline estimate was tested for different resolutions e.g. in age classes (1, 5 or 10 year age classes, span of 35 - 200 year). The choice of age class width of 5 years reflects a combination of need for iterating in 5-year time steps, to interval of NFI remeasurements on permanent plots and the availability of data. The selected resolution resulted in the models with the lowest uncertainty, with the requirements of the reference period and the baseline for predictions being 2010.

The baseline provides the forest area and carbon stock distribution to growth region, species group, and 5-year age classes. The dataset 9.3.2 contains the baseline data and the age class distribution by 2010 is given in Figure 19. The management classes are the same as used to model transition probabilities for making the

FRL, based on data from the permanent plots, providing the information on the forest management practices and how they are expected to influence the future development of the forest area and the related GHG accounts.

Transition probabilities

The reference period for modelling transition probabilities in accordance with Regulation is 2000-2009. Our initial analyses indicated several interrelated problems regarding the use of the statutory reference period:

1) The Danish NFI was initiated in 2002, which left only a 7-year reference period and only approximately 3/5 of a full rotation of NFI measurements for estimation transition probabilities
2) Only 1/3 of Danish NFI sample plots are permanent and thus allows for modelling of transition probabilities
3) Measurements during the first years of the NFI were incomplete due to problems with training, logistics, and data capture infrastructure. Hence the number of repeated observations was less than indicted above
4) The span of data with respect to growing conditions, forest management practices, species, and forest stand ages was too wide to be captured within the prescribed reference period
5) The requirements to resolution of the data into growth regions, species, and age classes left too few observations in each class for producing robust and transparent estimation (elements of this described in Knudsen, 2018).

Because of the initial analyses, the data used for estimating transition probabilities for modelling the FRL included NFI data collected in 2002-2017, covering three cycles of NFI measurements or two observations transition probabilities. The data available for the estimation totaled 4,440 plots. Of these, regeneration activities occurred on less than 400 plots, i.e. less than 10 % of the plots.

For further information on the principal methods of estimating the transition probabilities by estimation of the survival curves, we refer the reader to annex 9.6.1.

Management class biomass carbon stocks

Biomass carbon stocks in individual forest management classes were estimated from data collected by the Danish NFI during 2006-2010, in line with ordinary procedures for national and international reporting of forest resources (Nord-Larsen & Johannsen, 2016).

The biomass carbon stock in each forest management class is the combined result of influences by regeneration success, the growth of the trees, climate influence, natural mortality, silvicultural methods, and harvest intensity (including fuel wood harvest and their potential effects on remaining stock in the forest stands) occurring in each management class, i.e. the result of the forest management practices. The data reflects the forest management practices, as implemented until 2010. Hereby the basis for the accounting and the FRL is in line with the suggestions of Article 8 of the Regulation (EU 2018), with focus on a continuation of the forest management practices from the reference period. Furthermore, the approach ensures consistency with the accounting and reporting methods and data (reported data are given in dataset 9.3.2) and visualised in Figure 19 and Figure 20. It should be noted that the number of plots are low in the high age classes, as also indicated by the low area estimates for these age classes. This increases the variability in estimated volume m^3ha^{-1} in old age classes.

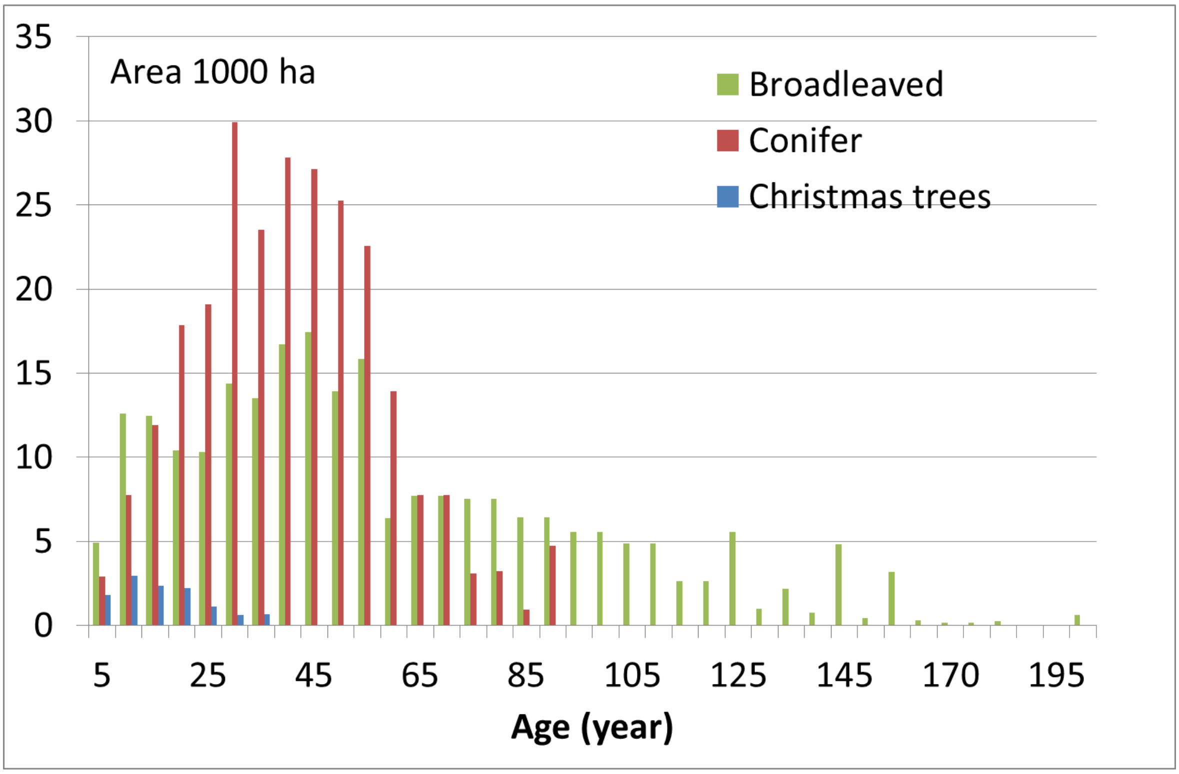

Figure 19 Age class distribution of the forest land area by 2010, by broadleaved, conifers and Christmas trees.

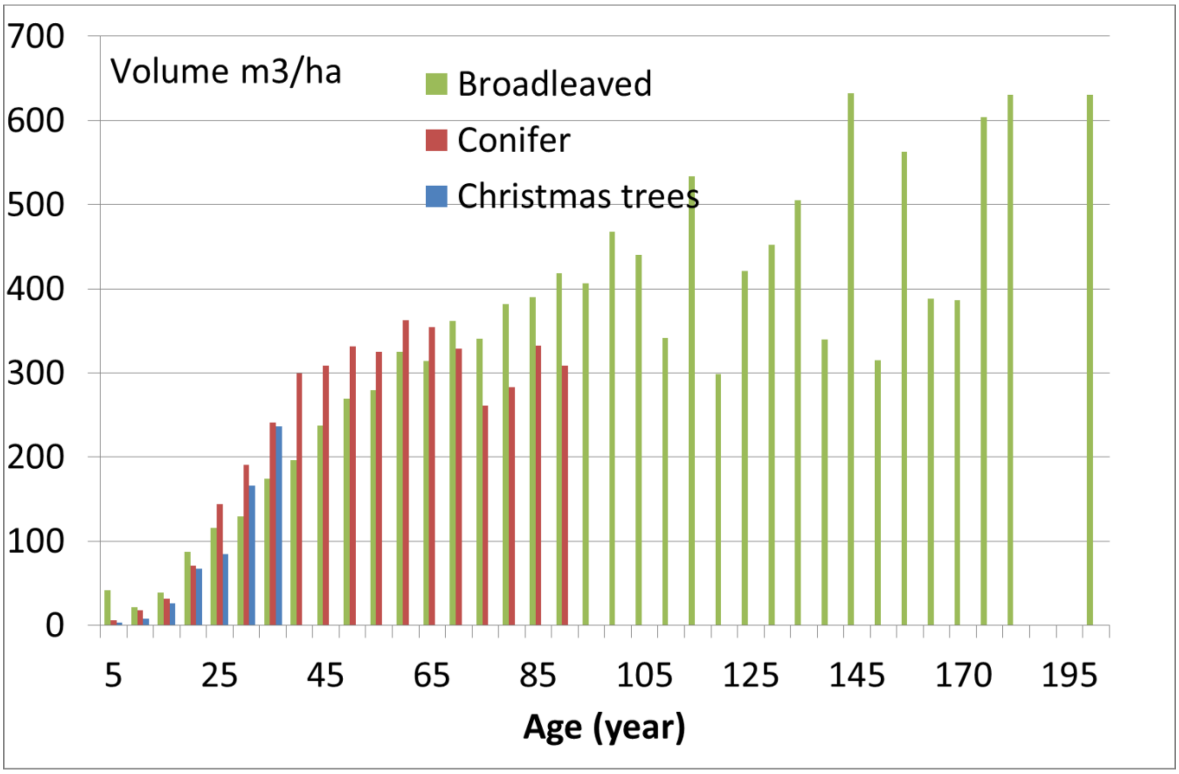

Figure 20 Growing stock (above-ground biomass m^3 ha^{-1}) by age class distribution by 2010, for broadleaved, conifers and Christmas trees.

6.1.2 Methods

The principal method chosen for the FRL of the forest land is 'stock change' and is in line with national reporting of GHG emissions from forests. This method is based on assessment of carbon stock at two given points in time and provides estimates of change over time as the difference between the two estimates or inventories of carbon stocks. The increment, mortality and harvest are not modelled when using the stock change method. The observed stock at the stratification of the forest area and by age classes gives the integrated effect of increment, regeneration, mortality and harvest, as all these processes results in changes in stock of living and dead biomass. The principles of the 'stock change' method are illustrated in the start of this chapter and further elaborated in the annexes, especially 9.6. The description of stock over age classes have been utilized in forest management since 1780's in form of yield tables.

When applying the stock change approach, it is essential to ensure that stocks are measured consistently for consecutive intervals. Challenges relate to certainty of total carbon stock estimates and hence the effect on change estimates. This approach is utilised for accounting of the biomass carbon pools in the Danish forests (Nielsen et al. 2018, Nord-Larsen & Johannsen 2016). The uncertainties related to stock change methods are analysed in detail in Johannsen et al. (2017). The strength of this method is the actual measurements by the NFI at two points in time and the reporting intervals of 5 years, as this allows for more accurate change estimates than alternative methods available with the data for the Danish forests.

Projection of biomass carbon stocks and stock changes

Projections of biomass carbon stocks and stock changes are based on the following main elements (see also Figure 17 and in Table 3) – assuming the forest remaining forest as a constant area:

- A projection of the forest area distribution to growth region, species and age-classes over time
- Estimated biomass carbon stocks and their distribution to growth region, species and age classes at the starting year of the FRL in 2010.

The area distribution to species and age-classes in 2010-2050 is projected in 5-year time intervals, assuming that the forest area in each species and age class, that has not been regenerated, progress into the subsequent age class after each iteration. Furthermore, the area regenerated in each iteration is re-assigned to the first age class of the same species class. The probability that the forest area is transferred to the subsequent age class after iteration is termed the transition probability, whereas the net flow to or from the species classes is termed the conversion probability. For the FRL, the conversion probability is assumed zero, as the species composition in the reference period did not indicate significant changes.

Transition probabilities are estimated based on the survival models estimated from the repeated measurements of permanent plots in the NFI, using the PROC PHREG[3] of the SAS Institute (Cox 1972, 1975). The survival model is estimated based on the Cox model, by maximising the partial likelihood and computes the baseline survivor function, by using the Breslow (1972) estimates. The estimation allows for censored data, i.e. the fact that the dataset only contains a small subset (reference period of 10 years) of the entire lifespan of forest stands (60-200+ years). The results give the predicted survival for all forest strata, as given in Figure 21. Initial analyses included other factors for classification of the forest area such as e.g. owner, soil types, and more detailed site classifications. However, these additional factors did not contribute to the

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[3] The PROC PHREG procedure performs regression analysis of survival data based on the Cox proportional hazards model. Cox's semiparametric model is widely used in the analysis of survival data to explain the effect of explanatory variables on hazard rates. The partial likelihood of Cox also allows time-dependent explanatory variables, like age.

overall accuracy in predicting the survival models and were not included in the final model. It is relevant to note, that the survival modelling not only relies on the sample in the separate age classes, but estimate a model that describes the full population over all the age classes.

When projecting carbon stocks, the species and age-class distributions originating from the transition/survival probabilities in each iteration is coupled with species and age-class specific estimates of biomass carbon stocks. In cases where projections result in species and age-classes not represented in the NFI data, estimates are obtained by species-specific interpolation between adjacent age-classes.

Projection of dead wood, litter and soil carbon stocks and stock changes
The data for the carbon pools in dead wood, litter and soil indicate no statistically significant changes across age-classes. Furthermore, dead wood pools are highly variable, recorded only on 1/3 of the plots in the NFI with a low overall average volume (3-5 m^3ha^{-1}). Hence, dead wood carbon pools are assumed constant within individual regions (Islands and Jutland) at the 2010 level.

Changes in litter layer and soil carbon pools are slow and trends across age classes are not detectable based on the data from the NFI in the given reference period 2000-2009. Hence, litter and mineral soil carbon pools are assumed constant within individual regions (Islands and Jutland) at the 2010 level.

The temporal change in drained and rewetted soil area was assessed based on current trends in forest management. A change in these soil categories was made in 2008, based on expert assessment of observed trends in the past 20 years of active maintenance of pre-existing ditches in forests. For further information, see 6.2.2.4 in Nielsen et al (2018).

CO_2: The expected emission of carbon dioxide from forest soils is estimated to 123 kt $CO_{2\,eq}\,yr^{-1}$. This is expected to be constant for the entire period 2013-2040. The estimate is based on an assumption of the area of drained organic soils (50 % of the organic soils - approx. 13,000 ha) being constant in the period, with an annual emission of 9.5 ton $CO_{2\,eq}\,yr^{-1}$ (IPCC 2014: Wetland supplement, Chapter 2, Table 2.1).

N_2O: The emissions of nitrous oxide from the forest soils, with the amount of drained organic soils, are expected to result in an annual emission of 0.05 kt N_2O yr^{-1}, corresponding to 4.4 kg N_2O $ha^{-1}yr^{-1}$. With the GWP of 298 this equals an annual emission of 17 kt $CO_{2\,eq}\,yr^{-1}$ (IPCC 2014: Wetland supplement Chapter 2, Table 2.5 negligible if water table shallower than 20 cm).

CH_4: Emissions of methane are estimated based on the changes in drainage status of the forest organic soils. For the organic drained soils the emission is 2.5 kg CH_4 $ha^{-1}yr^{-1}$ and for the ditches (2.5 % of the area) on organic drained soils the emission is 217 kg CH_4 $ha^{-1}yr^{-1}$. On rewetted organic soils assumed to be distributed 50/50 to poor and rich soils (infertile and fertile soils respectively), the emissions are 122.7 kg CH_4 $ha^{-1}yr^{-1}$ for poor soils and 288.0 kg CH_4 ha^{-1} yr^{-1} for rich soils. The total annual emissions amounts to 1.13 kt CH_4 yr^{-1} with a GWP of 25 equivalent to an annual emission of 28 kt $CO_{2\,eq}\,yr^{-1}$ (IPCC 2014: Wetland supplement, Table 2, 2.3-2.5 and 3.3).

6.1.3 Results

The predictor variables included in the survival model were all significant (see resulting model estimates in 9.4.1). The survival model reflects the expected higher probability of regeneration with age (Figure 21). For the species group of Christmas trees, the very short rotation ages are clearly shown by the resulting models. The estimation of survival probability also indicated the maximum age classes with sufficient data to estimate the survival, resulting in broadleaved having 200 years as upper limit, conifers 90 years and Christmas trees only 35 years.

The modelling approach reveals shorter rotation ages of conifers compared to broadleaves. The observed trends are in line with previous studies (Nord-Larsen and Suadicani, 2010) and supposedly reflect the higher growth rates, the lesser industry requirements of stem size, and general shorter longevity of conifers compared to broadleaves. Furthermore, the analyses revealed a shorter rotation age of conifers grown on the Islands compared conifers grown in Jutland, reflecting the better soil properties and related faster growth on the Islands compared to general soil conditions in Jutland. For broadleaved however, the rotation ages in Jutland were shorter than on the Islands, which most likely reflects differences in owner composition and aims of forest ownership.

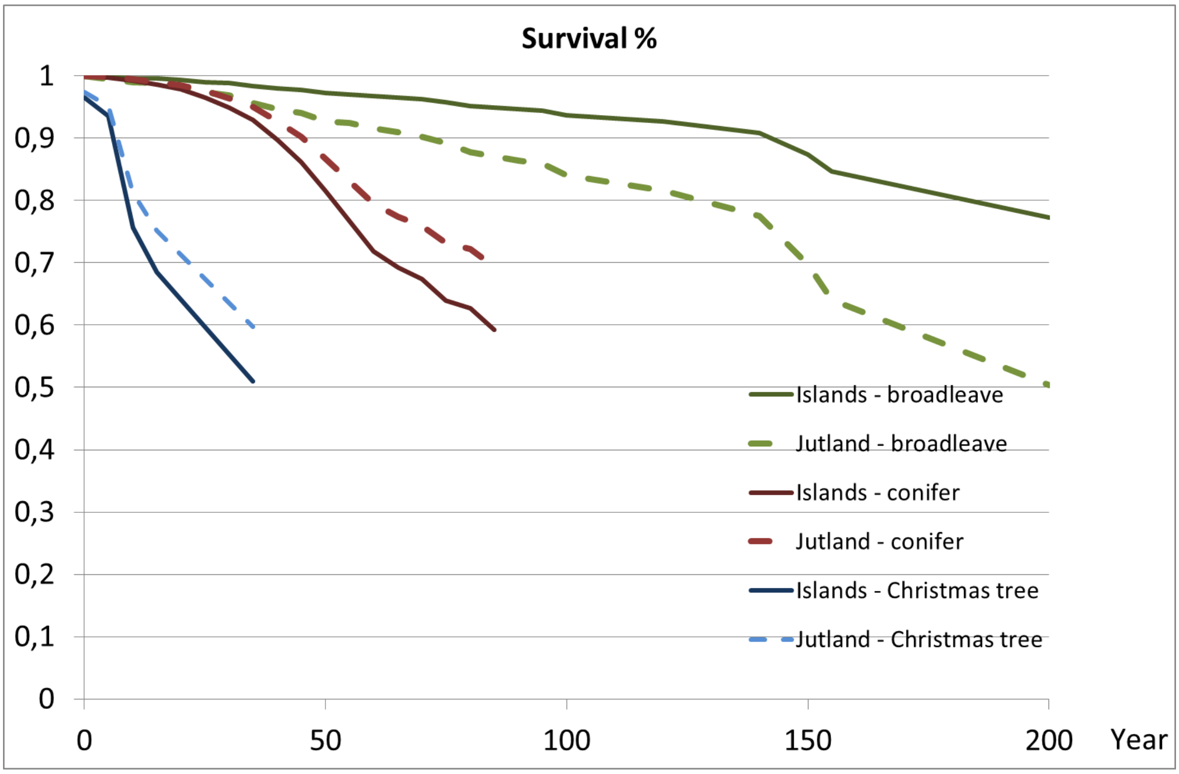

Figure 21 Survival curves for forest strata.

The procedure yielded estimates of standard error for the survival probability resulting in a low and high estimate. In Figure 22, the low and high values for broadleaved on the Islands and for conifers in Jutland indicate reasonable certainty in the estimation. For further information on the sensitivity of the survival models see Annex 9.6.1.

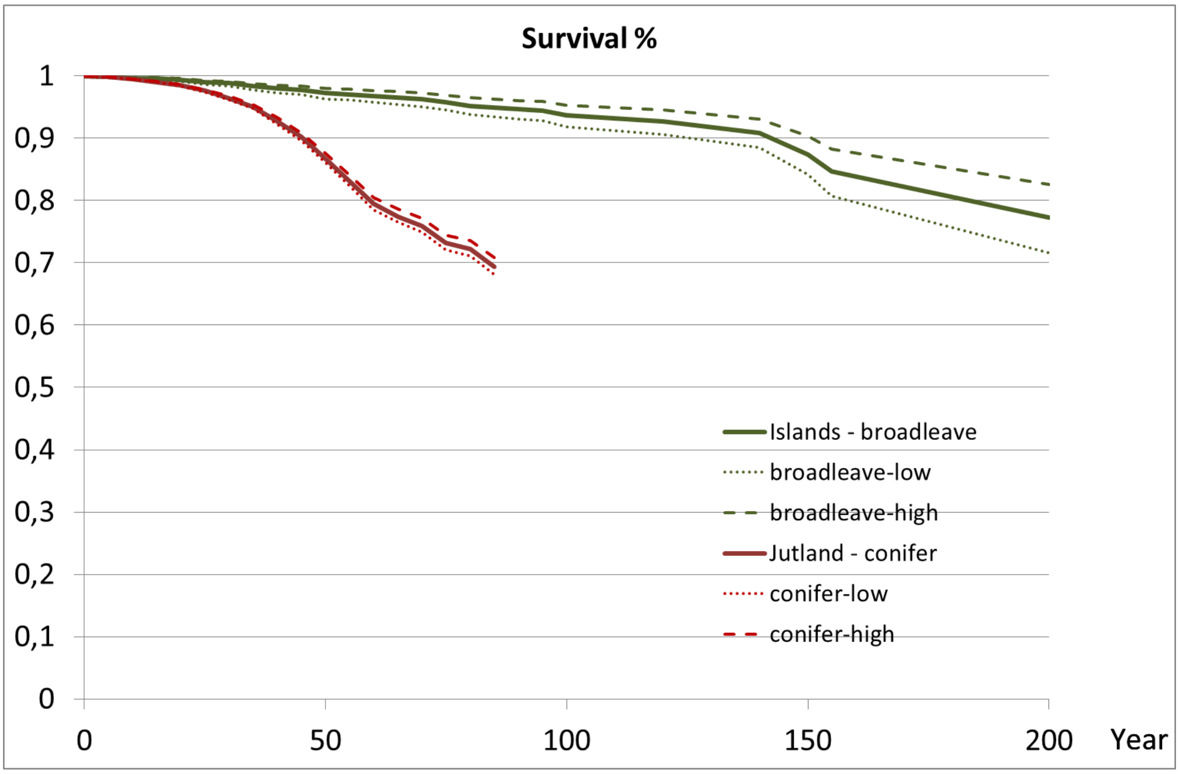

Figure 22 Predicted survival probabilities and their uncertainties as result of growth region, tree species and age classes.

Drawing on the baseline from 2010, and the models estimated for survival probabilities based on the reference period 2000-2009, the development of the forest carbon pools in the above- and below-ground biomass, dead wood and litter layer/forest floor are summarised in Table 6, and visualized in Figure 23 (see full data in 9.4.2 for 20 and 30 year transition). It is important to note that the area included in Table 6 only addresses forest land remaining forest land. As such it is not influenced by afforestation rate or age of transition. The increment and the harvest are not modelled when using the stock change method. However, the regeneration of the forest area involves harvest of the older and volume dense age classes and this is expected to lead to a slight increase in the harvested volume. This is further addressed in Chapter 6.3.

Table 6 Predicted development in stocks of the forest land (kt CO2 eq) for the year 2010 - 2050 in 5-year intervals. Note it is a constant forest area remaining forest. Note also that in comparison with NIR reporting this area includes Christmas trees.

YEAR	Above- ground Biomass	Below ground Biomass	Dead Wood	Forest Floor	TOTAL
	kt $CO_{2\ eq}$	kt $CO_{2\ eq}$	kt $CO_{2\ eq}$	kt $CO_{2\ eq}$	kt $CO_{2\ eq}$
2010	105.703	23.300	1.797	23.429	154.228
2015	102.577	22.580	1.797	23.429	150.382
2020	97.815	21.562	1.797	23.429	144.602
2025	93.520	20.637	1.797	23.429	139.382
2030	88.902	19.627	1.797	23.429	133.754
2035	86.514	19.103	1.797	23.429	130.842
2040	85.471	18.874	1.797	23.429	129.571
2045	84.451	18.654	1.797	23.429	128.330
2050	84.470	18.664	1.797	23.429	128.359

Figure 23. Predicted development of forest land carbon stocks (kt CO2 eq) for the year 2010 - 2050 in 5-year intervals - based on Table 6. The figure does not include mineral soil carbon stocks and assumes a constant area.

The overall trend is a decline in the carbon pools of the forest area established before 1990. This is because old stands make up a large share of the current forest area. The survival probability for these old stands is low, resulting in an increasing regeneration rate and hence a reduction in the standing stock. The survival models reflect the full age class distribution, and not only the oldest age classes. With simulations for another 100 years (Figure 24), the level of the stock remains at levels reached after 30-40 years of simulation, confirming that the current structure of the forests represents a deviation from the common rotation ages for the forest stands. The share of area regenerated in each year of the predictions to 2100 amounts to 1.8-2.0 % of the full forest area, which reflects the rotation time/survival times for the stands on average. This is comparable to the area reported as regenerated based on the NFI (Nord-Larsen et al 2017). The survival models have been tested for different stratification of the forest area (species and age stratification), with similar results, indicating robustness of the model.

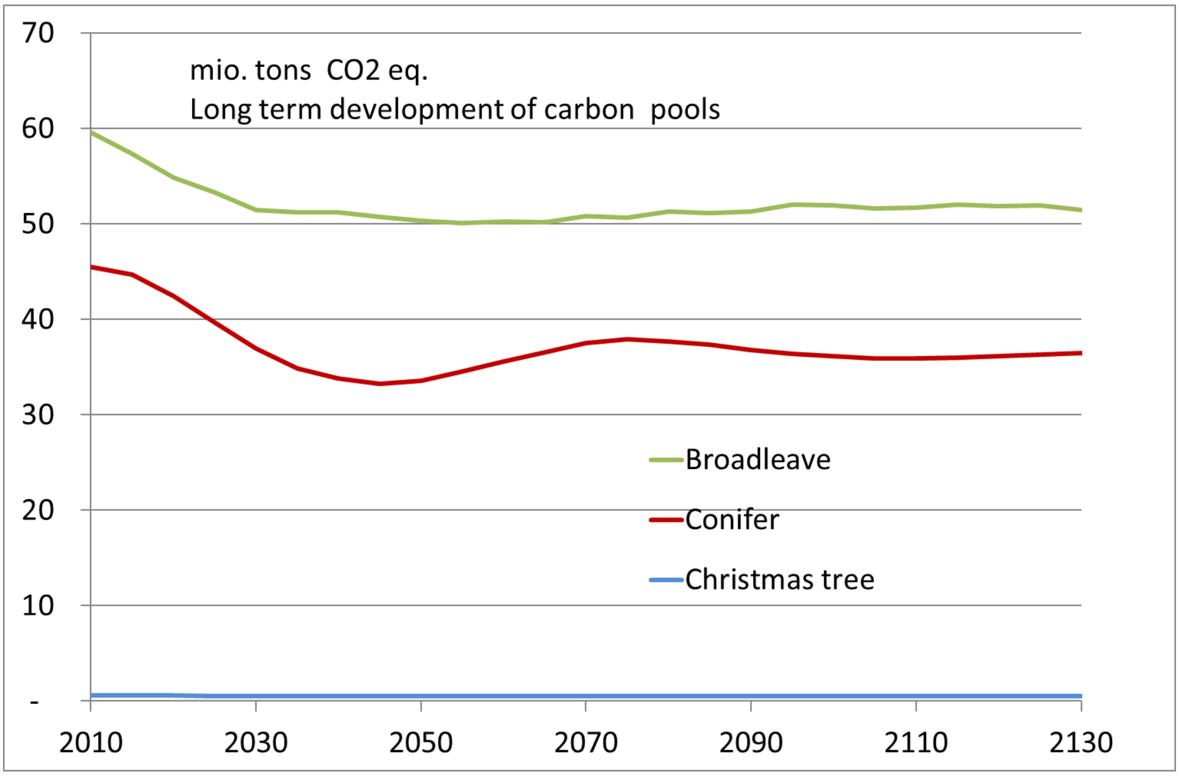

Figure 24 Long term development (2010-2130) of the carbon pool in above-ground biomass of existing forest.

The contribution of the forest land to the FRL are given by the sum of the stock changes estimated as described above and the projections of the annual emissions from soil GHG.

The FRL contributions from "forest land" existing before 1990 is given in Table 2 (I) and are an emission of 1.212 kt $CO_{2\ eq}$ yr^{-1} in 2021-2025 and an emission of 1.293 kt $CO_{2\ eq}$ yr^{-1} in 2026-2030.

6.1.4 Validation

Since the predictions are starting in year 2010, it is possible to compare the prediction for 2015 with the emission data reported for 2015. The comparisons showed significant deviations between predicted and observed stocks and consequently between predicted and observed emissions (Table 7). Deviations between observed and predicted forest carbon pools ranged 2-21 %, the largest deviation being for dead wood. Notably, forest land was predicted to be a net source of emissions in 2010-2015, while it was actually observed to be a net sink.

Table 7 Predicted (FRL) and Reported (NIR) stocks (kt CO2 eq) for the year 2015. Note NIR numbers are subsets of total reporting for the specific pools and that these numbers only refer to the fixed forest area existing before 1990 including Christmas trees. The numbers are not influenced by afforestation and transition age.

	Above-ground biomass	Below Ground Biomass	Dead Wood	Forest Floor	TOTAL
2010-FRL kt CO_2 eq	105,703	23,300	1,797	23,429	154,228
2010-NIR kt CO_2 eq	105,498	22,785	1,846	24,096	154,225
Deviation %	-0,2%	-2,3%	2,7%	2,8%	0,0%
2015-FRL kt CO_2 eq	102,577	22,580	1,797	23,429	150,382
2015-NIR kt CO_2 eq	118,357	25,585	2,285	23,907	170,134
Deviation %	13%	12%	21%	2%	12%
Change-FRL kt CO_2 eq	3,126	720	0	0	3,845
Change-NIR kt CO_2 eq	-12,859	-2,800	-439	189	-15,909

The deviations in 2010 are explained by the fact that the calculations of the FRL require a slightly different approach to the calculations than applied in the reporting, due to the age class allocation in the FRL estimation. For the 2015 data, the deviation is larger. The fact that the FRL deviates from the subsequent reported development in the National Inventory Reporting (Nielsen et al 2017), is a result of a number of reasons, including:

1) Short reference period compared to forest growth,
2) Temporal changes in forest management practices,
3) Uncertainty in the sampling of large pools (addressed in the next paragraph).

A longer reference period would strengthen the estimation of the survival models (point 1). However, for Denmark the NFI only started in 2002, so the data would in any case be limited. The absolute deviations are primarily related to the above- and below-ground biomass, whereas the pools for dead wood and forest floor only have minor absolute deviations. For dead wood, it is worth noting, that even though the deviation is relatively large (21 %), the uncertainty in the estimates of the dead wood pool is very high, due to the very scattered occurrence and the deviation is not statistically significant. A potential cause of the high level of dead wood in 2015 can be the wind throw events in 2013. From the most recent national report (Nord-Larsen et al. 2019), it is seen that the amount of dead wood (primarily standing dead conifers) was higher in 2014-2015, most likely a temporary effect of the wind throw. It is important to remember that survival models reflect the full age class in all strata, and not only the limited 'end of life' events in the reference period, allowing a dynamic age-related prediction rather than a simple average of increment and harvest.

Point 2) could be one of the main drivers for the deviation and can be introduced by e.g. low wood prices, retention of old stands, or other causes leading to reduced felling of older/larger stands. Both these factors are expected to have influenced the forest management practices in the period after the reference period 2000-2009, due to changes in policy and the general economic development. In relation to the harvest, the product statistics from the forest sector (see Chapter 5.4) indicate a higher harvest , but is more likely to reflect a change in degree of utilisation of the felled trees, yielding a higher amount of energy wood (especially wood chips) produced from harvest residues, that were previously left in the forest. This applies both to large trees and early and intermediate thinnings, which were previously not utilized. This is supported by the most recent publication on the Danish forests, where a declining trend is noted for the dead wood pool, especially standing dead coniferous wood (Nord-Larsen et al 2019). When comparing to the data for harvest to the HWP (Chapter 6.3) it is worth noting, that the amount of input to the Danish industry since 2011 has been based on direct collection of information from the industry, and not on harvest data from Statistics Denmark. Furthermore, there has been a change in the overall estimation of the harvest by Statistics Denmark since 2012 (as commented in Chapter 5.4). All in all the deviations between the predicted and reported values for 2015 reveal the challenges of basing the FRL on the reference period 2000-2009.

6.1.5 Uncertainty

The general uncertainty of reporting the forest carbon pools are described in detail in Johannsen et al (2017), specifically in Chapter 6.4. A key finding is that reporting of changes is more uncertain for shorter time intervals. For year-to-year changes, a bootstrap analysis showed uncertainty levels of standard error corresponding to 113 % of the mean for the forest area and 60-86 % of the mean for the carbon stock. Similar analysis of five year change intervals showed standard error of approximately 15 % of the mean (Johannsen et al. 2017). This supports the present method, with 5-year intervals in the estimation of the FRL and the subsequent full reporting periods 2020-2025 and 2026-2030.

The sensitivity of the survival models and the influence on the resulting estimation of FRL is tested in Annex 9.6.1. The result of the sensitivity analysis indicates an uncertainty of the full stock within +/- 6 % compared to the reference values. For the annual change in stock, the uncertainty is higher, ranging from 0 to +/- 60 % of the annual change of the reference numbers. The uncertainty of the annual change is in all cases less than 5 % of the full carbon stock in the above ground biomass. This reflects that even with a reference value within a 95 % interval (based on the survival curves) the uncertainty of the annual changes may be high. The same pattern was also reported based on analysis of reporting data based on the NFI data (Johannsen et al 2017).

The sensitivity to baseline year has been tested, applying baseline data from 2015 and 2017 as alternative starting points for the estimation of FRL. Even though there are differences in the numbers, the overall pattern in annual changes are similar regardless of baseline year (Figure 25). The variation based on baseline year is less than the potential variation caused by variation in survival rates. In comparison with the reported numbers for annual change (5 year mean) in the period 2005 – 2015 a sink have been reported. This is also reflected in the data in Table 7, with higher total stock in 2015 than predicted with the FRL. The detailed analysis addressing point 1, raised under the validation, is provided in Annex 9.6.2.

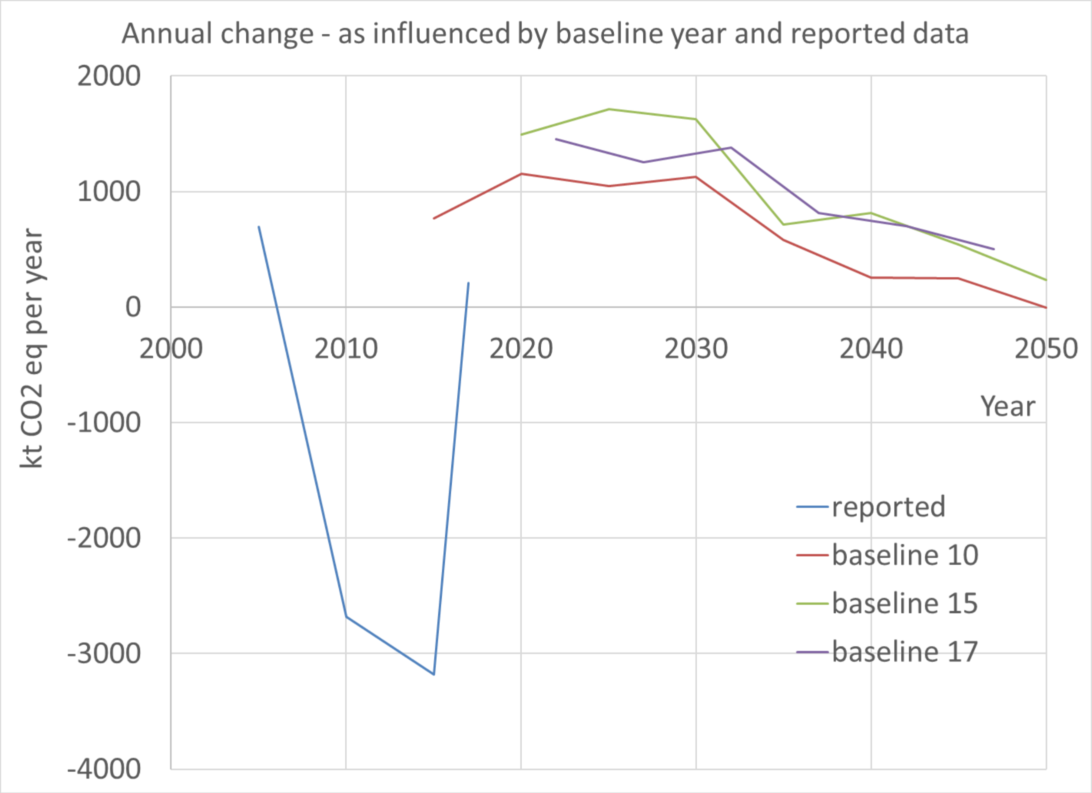

Figure 25 Annual change of stock (above and below ground, dead wood and forest floor) based on baseline year 2010, 2015 or 2017. The reported data from 2005 – 2017 are included for reference. See more details in 9.6.2.

Potential impacts of different silvicultural practices, such as change in species composition, breeding, harvest rates, or set aside forest were analysed by Graudal et al (2014). Annex 9.6.3 provides a summary of the effect of a range of different silvicultural practices and their influence on both carbon stock in above ground biomass and on harvest volume (in comparison with a business as usual scenario, equaling the forest reference level approach). These addresses point 2 raised under the validation and the potential causes for differences between the FRL and the reported data for 2015.

6.2 Afforested land

Focus in this part is on the 15 % of the forest area established after 1990 and the afforestation expected to occur from the 2010 baseline and until 2050. In relation to FRL this area is only of importance, when it is transferred to forest land at the reference age of 20 or 30 years. Because the Regulation opens for either a 20-year or a 30-year transition period, the IPCC (2006) guidelines for this issue have been reviewed (focus on Volume 4, chapter 4.3). A more detailed review of the guidelines are provided in Annex 9.5.1. The Danish Government has opted for a 30-year transition period, which is in line with the IPCC guidelines (IPCC 2006). In order to enable comparisons between the proposed FRL and historic LULUCF reporting based on a 20-year transition period FRL-figures for both 20 and 30-year transition periods are provided in this revised NFAP. Due to the 30-year transition period selected by Denmark, only historic figures up till year 2001 have an impact on the calculation on the Danish FRL. Yet, in order to enable comparisons with historic LULUCF reporting a FRL based on a 20-year transition period is also provided. This requires afforestation in the period 2001-2010 to be included in calculation of the FRL. For completeness the NFAP also contains projections of carbon pools in areas afforested from year 2011.

Another issue of investigation in the IPCC (2006) guidelines is the biomass stocks in connection with land-use conversion, in this case with afforestation on former cropland and grassland. Until now, the reporting from Denmark has included a loss of biomass carbon from former cropland of 6 t C ha^{-1} (Nielsen et al. 2018, table 6.8) equivalent to a loss of 12 t biomass per ha. This places an "emission burden" as a legacy of cropland management on afforestation activities. The examples in the IPCC (2006) guidelines (Volume 4, chapter 2.3.1.2 and chapter 4.3.1.2) are generally aimed at removal of woody vegetation (i.e. perennial vegetation carbon stocks removed when previously unmanaged forest are replaced by plantation), whereas an annual crop of wheat (harvested long before the new trees are planted or sown) does not meet the description in the guidelines. However, the guidelines are not clear on this issue. A more detailed review of the guidelines provided in Annex 9.5.2. This issue will therefore be raised during the review process, to clarify which interpretation best follows the guidelines.

6.2.1 Data

Expected afforestation was based on an assessment of the forest area development obtained in relation to the emissions reporting (Johannsen et al. 2018, Levin et al. 2014, Nielsen et al. 2018). The average afforestation rate in the period 1990 - 2005 resulted in 3,678 ha yr^{-1}, and in the period 2005-2011 in 3,737 ha yr^{-1} (see 9.3.4 for data on annual afforestation area 1990-2016).

Since 2012, the annual afforestation rate has been based on detailed field information, resulting in annual updates. In the period 2016-2035, the annual afforestation is not known, but the predictions include two scenarios: 1,900 or 3,200 ha yr^{-1}. A lower annual afforestation rate could be an effect of reduced amounts of subsidies for afforestation and a decline in the area afforested without subsidies. Economic and environmental conditions related to agriculture and other land-uses (such as changes in subsidy schemes) will influence the rate of annual afforestation. It should be noted that the areas of afforestation include areas initially established with trees for Christmas tree production (most frequently *Abies nordmaniana*), as these fulfill the definition for forest area.

The annual afforestation rate, combined with the transfer of afforestation older than 20 or 30 years to forest land, leads to a development of the afforestation area, as shown in Figure 26.

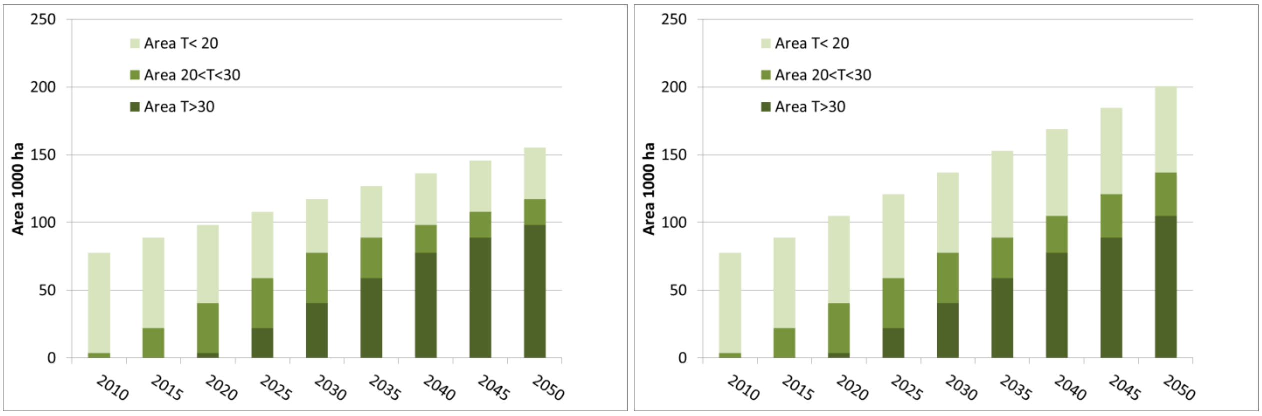

Figure 26 Total afforestation for the period 2010 - 2050 with indication of age classes (<20 yr, <30 yr and older). Afforestation of 1,900 ha yr^{-1} (left) and 3,200 ha yr^{-1} (right) from 2016 - 2050.

6.2.2 Methods

The species compositions and forest management in afforestation established in 1990-2012 was evaluated by Schou et al. (2014). They found that afforestation during this period had not resulted in the carbon accumulation expected from previous estimates for the new forests, which was attributed to a range of factors, e.g. planting density and species choice. The same patterns have resulted in the reported carbon stocks in the period 2006-2017 where the NFIs have formed the basis for the reporting. Therefore, afforestation is assumed to have a species distribution similar to that of the afforestation area during 1990-2012, resulting in the same level of carbon stocks.

The projection of afforestation carbon stocks is based on a combination of tree growth and yield models (Møller 1933, Nord-Larsen et al., 2009) for beech (site class 2), oak (site class 4), and Norway spruce (site class 2) (see 9.3.3 for details on these), reflecting the site conditions for the overall afforestation area. Based on the report by Schou et al. (2014) a mix of 30 % beech, 40 % oak and 30 % Norway spruce was used for the projection for the afforestation. The prognosis was based on a crown cover degree of 90 %.

The initial growth of the first 20 years is not directly modelled, but is assumed to follow a sigmoid growth pattern, resulting in a slow start as also identified in the previously mentioned analyses. Overall, this results in estimates of stock densities similar to the observed values in the afforestation by Schou et al. (2014) and in recent reporting, also when analyses are stratified to the different age classes of the afforestation. The magnitude of afforestation is modelled in a matrix model allowing direct estimation of carbon pools of both overall stock and an estimate of the stock of afforestation in the age class 20 or 30 separately for the use in the change estimates.

Loss of carbon from cropland has been included in the accounting in the form of the lost biomass from the previous land-use. For change from cropland to afforestation this is estimated at 6 t C ha^{-1} (Nielsen et al 2018), equivalent to a loss of 12 t of biomass per ha. An afforestation rate of 1,900 ha yr^{-1} hence results in an emission of 41.8 kt $CO_{2\ eq}$ yr^{-1} while an afforestation of 3,200 ha yr^{-1} will result in an emission of 70.4 kt $CO_{2\ eq}$ yr^{-1}. This may be changed based on the review process, as mentioned in the introduction to afforestation.

Soil emissions

In the afforestation, accumulation of carbon in the soils is expected to occur over a period of 100 years. The change is estimated to be 0.21 tC ha^{-1} yr^{-1} over 100 years. In the approx. 100,000 ha established since 1990, this accumulates to a sink of 13 kt C yr^{-1} or 48 kt $CO_{2\ eq}$ yr^{-1} (Nielsen et al 2018).

Emissions of CO_2 from drained organic soils, N_2O and CH_4 are estimated following the same principles as for forest remaining forest (see Chapter 6.1.2). In the projections, increase in afforestation area is embedded in the calculations.

CO_2: The estimate is based on the area of drained organic soils (50 % of the organic soils), with an annual emission of 9,5 t $CO_{2\ eq}$ yr^{-}. (IPCC 2014: Wetland supplement, Chapter 2 Table 2.1) results in 47 kt $CO_{2\ eq}$ yr^{-1} (as example for 2013).

N_2O: The emission of N_2O from afforested soils originating from the drained organic soils, are expected to result in an annual emission of 4.4 kg N_2O ha^{-1} yr^{-1}. With a GWP of 298, this equals an annual emission of 6 kt $CO_{2\ eq}$ yr^{-1}. (IPCC 2014: Wetland supplement Chapter 2, Table 2.5, negligible if water table shallower than 20 cm).

CH_4: The methane emissions are based on the changes in drainage status of the organic soils. For the drained organic soils the emissions are 2.5 kg CH_4 ha^{-1} yr^{-1} and for the ditches (2.5 % of the area) on organic drained soils the emissions are 217 kg CH_4 ha^{-1} yr^{-1}. On rewetted organic soils the emission is 235 kg CH_4 ha^{-1} yr^{-1}. The GWP of methane is 25 (IPCC 2014: Wetland supplement, Table 2, 2.3-2.4 and 3.3).

6.2.3 Results

Development of carbon pools and GHG for afforestation in total, and split according to transition ages of 20 and 30, are calculated to give the input for the FRL. Especially the pools for the area with age, older than the transition age, are important for the FRL, as they constitute part hereof (see also Figure 2 page 9). The overall development for the main pools is visualised in Figure 27.

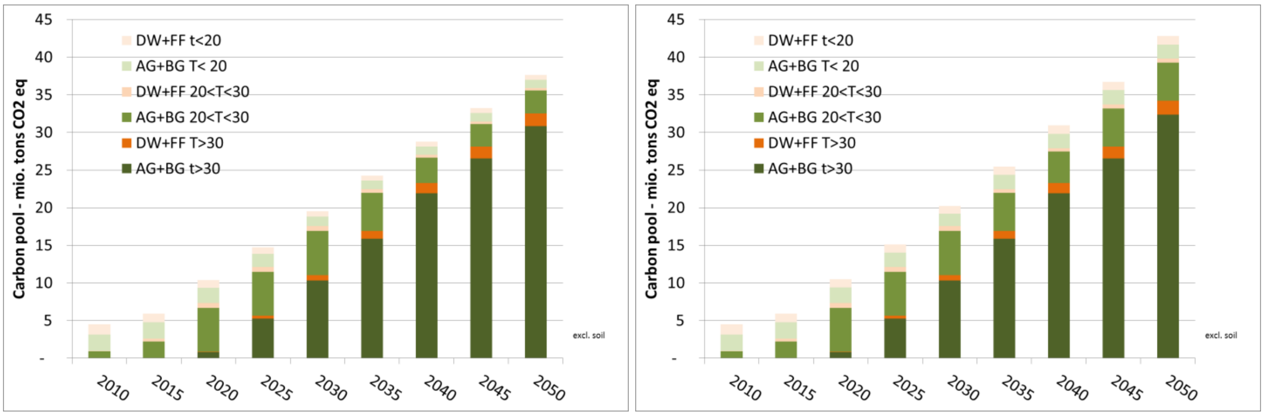

Figure 27 Development in the above-ground biomass (AG), below-ground biomass (BG), dead wood (DW) and forest floor (FF) pools of the different subdivisions of the afforestation depending on age since establishment <20, <30 or older than 30. (Afforestation rate 1,900 ha yr^{-1} left and rate 3,200 ha yr^{-1} right).

The area included in the FRL changes, when afforestation areas planted 20 or 30 years ago, are transferred to the area of "forest land" according to Article 6 (EU 2018). In the calculations of carbon emissions, the effect of growth/harvest/mortality occurring prior to the reference age is assigned to the afforestation before transferring the area to the forest land. Therefore, the stock at the transition age to be transferred to forest land remains in the afforestation until the end of the year (December 31) and is transferred by the beginning of the following year (January 1). This approach is applied in both estimation of the FRL and in the accounting (see also: Figure 1 and Figure 2 on page 9 for the conceptual description and 9.5.3 for technical description).

The contribution of the afforestation to the FRL is based on the share of the afforestation older than the reference age for transferring the area. For a transition period of 20 years, the corresponding results is a sink of -666 kt $CO_{2\ eq}$ yr^{-1} in 2021-2025 and a sink of -784 kt $CO_{2\ eq}$ yr^{-1} in 2026-2030 (item II of Table 1).

Beside this contribution to the FRL, the afforestation younger than 20 years is estimated to generate a sink of -151 kt $CO_{2\ eq}$ yr^{-1} in 2021-2025, and a sink of-114 kt $CO_{2\ eq}$ yr^{-1} in 2026-2030 (item III of Table 1).

The contribution of the afforestation to the FRL is based on the share of the afforestation older than the reference age for transferring the area. For a transition period of 30 years the corresponding results is a sink of -164 kt $CO_{2\ eq}$ yr^{-1} in 2021-2025, and a sink of -276 kt $CO_{2\ eq}$ yr^{-1} in 2026-2030 (item II of Table 2).

Beside this contribution to the FRL the afforestation younger than 30 years is estimated to generate a sink of -653 kt $CO_{2\ eq}$ yr^{-1} in 2021-2025 and a sink of-622 kt $CO_{2\ eq}$ yr^{-1} in 2026-2030 (item III of Table 2).

6.2.4 Validation

To test the predictions of the afforestation, the table below compares predicted development and reported carbon stocks in 2010 and 2015 for the afforested area. For the overall development, the models can reproduce the observed values within reasonable deviations. For the small pool of dead wood, the uncertainty is high when expressed in relative values but not when expressed in absolute values. This reflects the low and rare observations of dead wood, especially in the afforestation area.

Table 8 Predicted (FRL) and Reported (NIR) stocks (kt CO2 eq) for the year 2015 for afforestation, with a 1,900 ha/yr afforestation since 2011. Both 20 and 30-year transition period are represented. Note NIR numbers are subsets of total reporting for the specific pools.

	Above-ground biomass	Below-ground biomass	Dead wood	Forest floor	TOTAL
FRL prognosis					
Total	4,218	844	44	1,511	6,616
2015 T<20 kt CO2 eq	1,793	359	33	1,135	3,320
2015 20<T<30 kt CO2 eq	2,424	485	11	376	3,296
2015 30<T kt CO2 eq	0	0	0	0	0
NIR reporting					
Total	3,962	869	26	1,465	6,322
2015 T<20 kt CO2 eq	1,344	315	11	812	2,482
2015 20<T<30 kt CO2 eq	2,618	553	15	653	3,840
2015 30<T kt CO2 eq	0	0	0	0	0
Differences FRL-NIR					
Total	-256	25	-18	-46	-294
2015 T<20 kt CO2 eq	-449	-43	-22	-324	-838
2015 20<T<30 kt CO2 eq	194	69	4	278	544
2015 30<T kt CO2 eq	-	-	-	-	-
Differences FRL-NIR, %					
Total %	-6 %	3 %	-67 %	-3 %	-5 %
2015 T<20 %	-33 %	-14 %	-197 %	-40 %	-34 %
2015 20<T<30 %	7 %	12 %	28 %	42 %	14 %
2015 30<T %	-	-	-	-	-

Afforestation poses a specific challenge, both in terms of predicting the carbon of the young stands (less than 30 years) but even more so for the part of afforestation transferred to the forest remaining forests area. The growth models can reproduce the observed development so far, but future changes in areas utilised for afforestation and species composition may cause deviations from the predicted development.

6.2.5 Uncertainty

The uncertainty of the estimation of the FRL contribution from the afforestation is mainly related to the growth models used for the prediction of the growth, since the growth models are based mainly on data from experiments older than 20-30 years at the first observation. Furthermore, the species composition and the silviculture of afforestation may deviate from the management system applied in the growth models and thus add to the uncertainty of the growth models.

Another uncertainty originates from the reporting phase, as also addressed in Johannsen et al (2017). Since the area of afforestation constitutes a minor part of the full forest area, the confidence intervals of the change estimates will generally have relative errors of more than 15 % of the mean (see Johannsen et al 2017, Chapter 6.4-6.5).

6.3 Harvested Wood Products

6.3.1 Data

Estimation of forest reference levels 2018 - 2030 for HWP is based on data from FAO-Stat (2018), Statistics Denmark (2018), and an annual questionnaire survey of wood production in the Danish wood industry, covering the historic period, including the reference period 2000 - 2009.

To ensure consistency with the estimation of FRL for the forest carbon pools, the data for the harvest in the period 2010 – 2050, are estimated based on the same models used for estimation of the development of forest land and afforested land. The transition models estimate, of the regeneration of the forest area, gives direct estimation of the biomass in the areas. Furthermore, it is known from yield models and forest management practices, that intermediate thinnings approximately add 20 - 30 % to the final fellings for broadleaved and 80 % for conifers. Of the total harvested biomass, 85 % of the broadleaved biomass is utilized, and 90 % of the biomass for the conifers is utilised, and hence included in the harvest volumes used as input for the estimation of changes in the HWP pool.

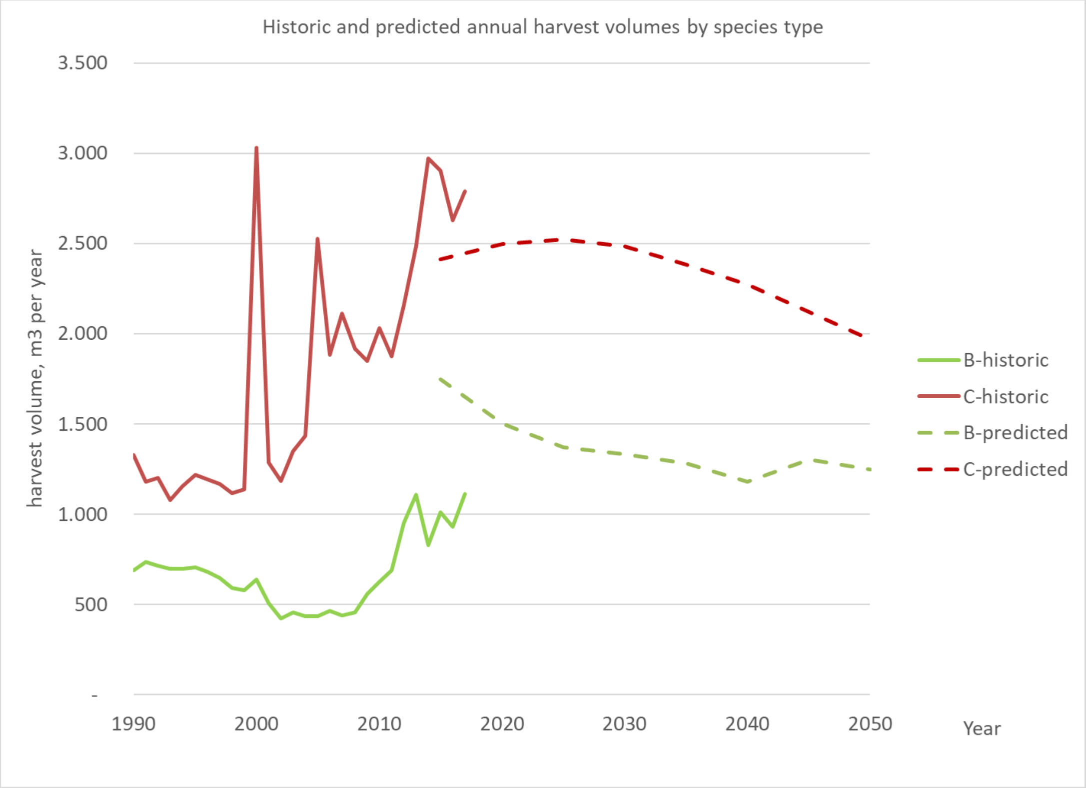

Figure 28. Historic and predicted harvest volumes by broadleaved (B) and coniferous (C) species.

Table 9 Growth and removals in the Danish forests, estimated from the remeasurement of NFI sample plots. Average annual increment and removals per hectare are provided (in shaded rows) (Nord-Larsen et al 2019). (Note 1: Data from 2012 is based on the first years of the NFI, with lower amount of data. Note 2: In the values for increment are included effect of changing area. The values of removals refer to the area at the start of the remeasurement of the NFI sample plots).

	2012	2015	2016	2017	2018
	Annual increment and removals				
Net increment (1,000 m³/year)	2.918	3.010	2.336	1.934	1.701
- ***Per year (m³/ha/year)***	1,2	2,4	2,2	2,0	1,9
Total removals (1,000 m³/year)	3.959	4.446	4.791	4.756	4.794
- ***Per year (m³/ha/year)***	7,2	7,6	8,0	7,8	7,8
Harvested *(1,000 m³/year)*	3.246	3.275	3.524	3.336	3.142
- ***Per year (m³/ha/year)***	5,9	5,6	5,9	5,5	5,1
Windthrow *(1,000 m³/year)*	35	73	124	129	200
- ***Per year (m³/ha/year)***	0,1	0,1	0,2	0,2	0,3
Dead *(1,000 m³/year)*	330	435	473	494	513
- ***Per year (m³/ha/year)***	0,6	0,7	0,8	0,8	0,8
Missing *(1,000 m³/year)*	349	663	671	797	939
- ***Per year (m³/ha/year)***	0,6	1,1	1,1	1,3	1,5
Gross increment *(1,000 m³/year)*	6.877	7.456	7.128	6.690	6.495
- ***Per year (m³/ha/year)***	8,4	10,0	10,2	9,8	9,7

From the permanent plots of the NFI it is possible to obtain some general estimates of increment and harvest for the forest area, starting with the first possible estimates in 2012 (Table 9). These numbers have been reported in the National Forest Statistics (e.g. Nord-Larsen et al. 2019). The amount of harvested volume are in good consistence with the figures reported by Statistics Denmark of the harvested volume. Furthermore, it can be noted that the Gross increment and the Net increment had maximum observed values in 2015-2016 and have declined in the two latest estimates. Observations in 2012 are based on the first years of the NFI, with lower amount of data. The observations are not in contrast to the predicted total harvest as input for the HWP estimations.

6.3.2 Methods

Projection of HWP FRL follows the general methodology described in Schou et al. (2015). In addition to earlier reports and projections, domestically harvested and exported wood products have now been included, and in estimating the inflow to the HWP pool alternative methods have been tested. The current reporting is based on separate accounts for broadleaved and coniferous species. In the estimation of inflow to the HWP pool both a separation of species and a joint inflow are estimated.

The projected inflow to the HWP pool in the period 2018 - 2030 is based on the ratio of the annual projected harvest for the period to the historic harvest in 2009 – here illustrated for an approach with separation of species groups, comparable to the accounting methodology:

$$HWP_{pro,i} = HWP_{2009} * \left(\frac{H_{C,pro,i}}{H_{C,2000-09}} * \frac{EFH_{C,2009}}{EFH_{C,2000-09}} + \frac{H_{NC,pro,i}}{H_{NC,2000-09}} * \frac{EFH_{NC,2009}}{EFH_{NC,2000-09}} \right)$$

where $HWP_{pro,\, i}$ is the projected production of HWP in year i, HWP_{2009} is the historic production of HWP in 2009, $H_{C,\, projected,\, i}$ is the projected harvest of coniferous species in year i, and $H_{C,\, average\ 2000\text{-}09}$ is the average historic harvest of coniferous species for the period 2000 through 2009, $EFH_{C,2009}$ is the fraction of the 2009 harvest of coniferous species used for energy, and $EFH_{C,\, 2000\text{-}09}$ is the average fraction of the 2000-2009 harvest of coniferous species used for energy. The subscript NC refer to broadleaved species (Non Coniferous).

This method is applied based on the assumption that the production of HWP co-varies with the harvest in the forests – and thus that the production of domestic HWP may be forecasted by forecasting the harvest. In Denmark, the share of fuelwood out of the total harvest has been increasing through the reference period 2000-2009. The change in the share of fuelwood out of the total harvest is accounted for in the projections. For accounting purposes it is important to note that the calculated FRL includes emissions from the historic pool of HWP, i.e. emissions from products placed in the pool before the start of the reference period (inherited emissions) – this is to ensure consistency with the annual reporting, which also includes inherited emissions.

Industrial round wood assortment distribution

The assortment distribution of the Danish wood harvest changes over time to meet changes in demand (Figure 29). For both broadleaved and coniferous species, a shift towards energy purposes is seen, but also the distribution between round wood and industrial wood assortments have changed over time. In conifers, a shift from timber to short wood is seen. In 1999 timber made up more than 40 % of the industrial round wood harvest. That fraction has dropped to below 10 % in 2016. In broadleaved species, the changes are less pronounced.

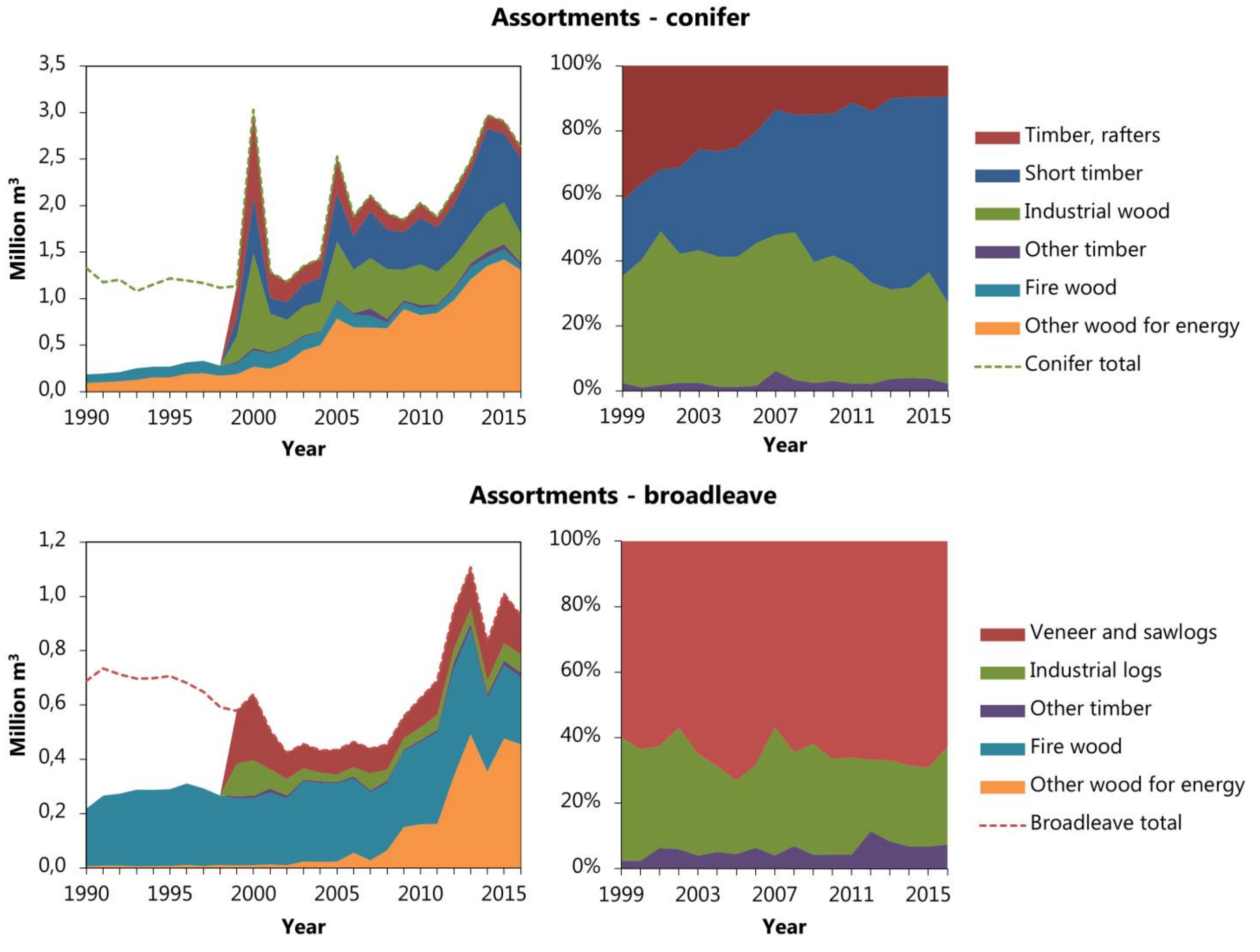

Figure 29. Left panels: Changes in harvested assortments of coniferous and broadleaved species from Danish forest from 1990 to 2016. Before 1999, the statistics did not distinguish between industrial roundwood assortments. Right panels: Relative distribution of industrial roundwood assortments from 1999-2016. Data from Statistics Denmark (SKOV6).

As shown in Figure 30, it is difficult to predict assortment distributions in the period 2010-2016 based on the distribution in the reference period 2000-2009. As such, the assumption that assortment distributions remain constant over time, is not supported by historical data.

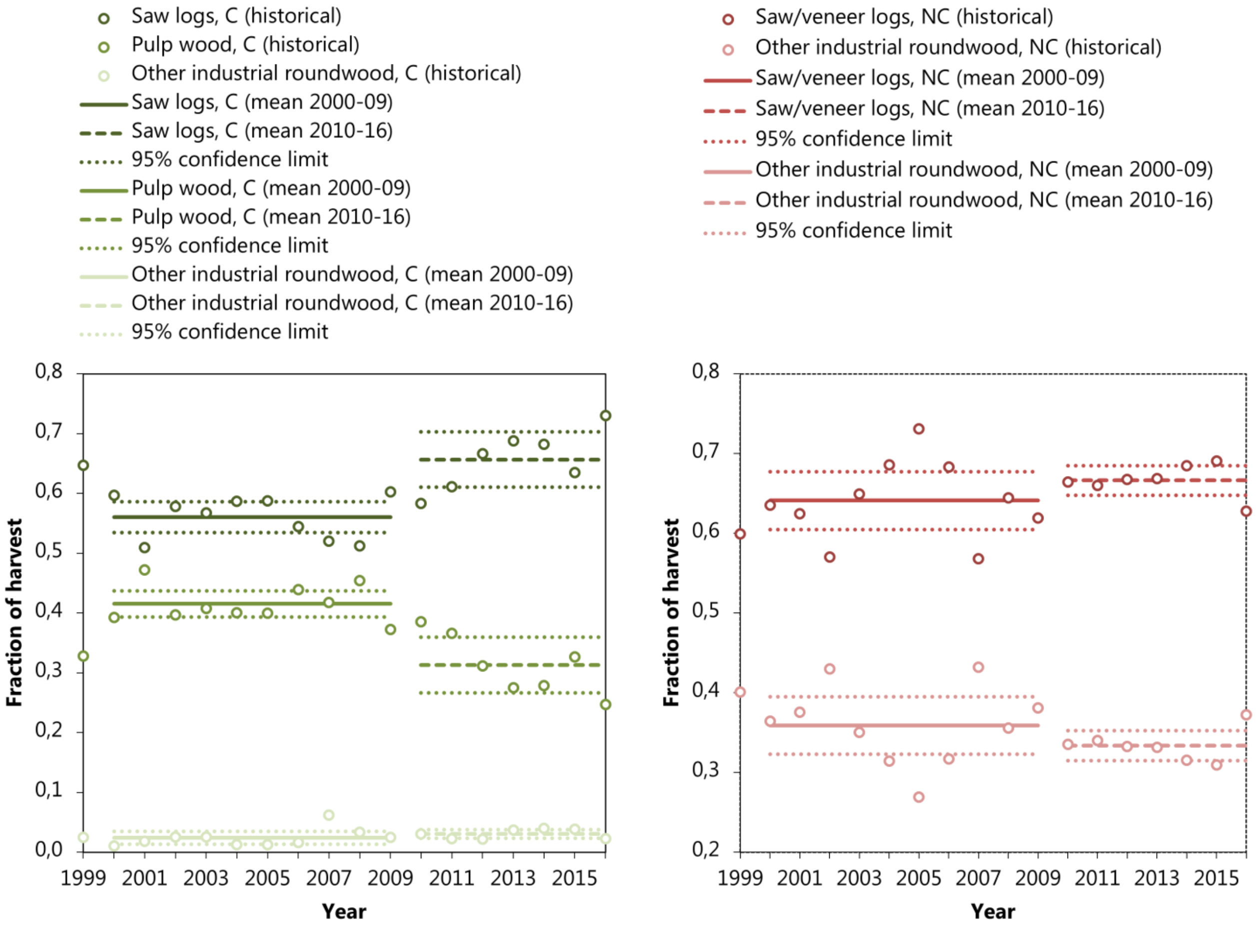

Figure 30. Assortment distribution of industrial round wood of conifers (left panel) and broadleaved species (right panel) for the period 1999 to 2016.

Bioenergy

Harvested wood used for energy is accounted as an instant emission. As shown above, energy purposes have accounted for an increasing part of the harvested wood. Based on data from Statistics Denmark (2018: SKOV6), the fraction of domestic harvest allocated to energy generation can be estimated (Figure 31). As can be seen from the graph, there is a general trend for broadleaves and conifers alike, that the energy fraction has increased over time. Particularly for broadleaves, a main part of the increase from 1990 to 2016 took place in the FRL reference period 2000 - 2009. The same development is also evident for conifers, but not so pronounced. A constant ratio between solid and energy use of forest biomass, as documented in the period from 2000 to 2009, shall be assumed according to the Regulation (EU 2018, Annex IV e).

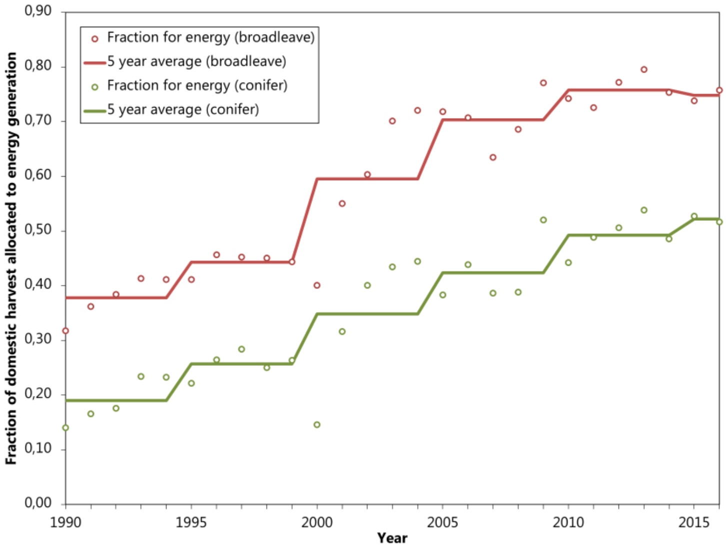

Figure 31. Fraction of domestic harvest allocated to energy generation 1990 - 2016.

Focusing on the reference period 2000 - 2009 there has been a significant (p<0.012) increase in the fraction of the domestic harvest of broadleaved species allocated for energy generation (Figure 32). The same (p<0.027) is seen for coniferous species.

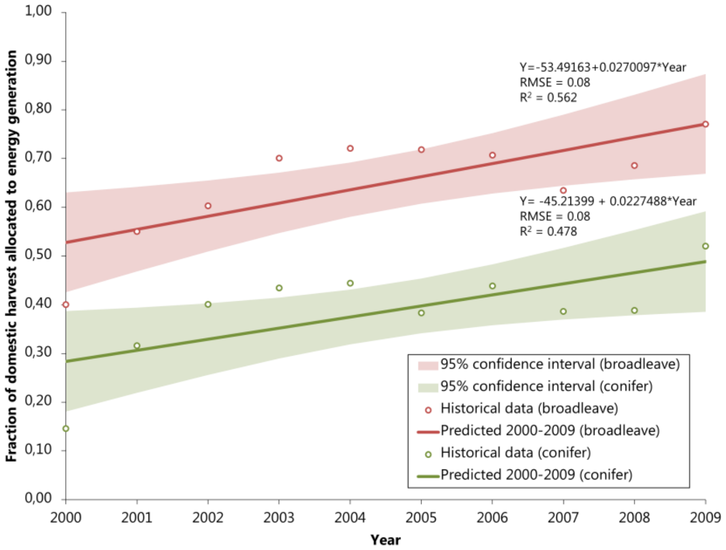

Figure 32 Fraction of domestic harvest allocated for energy generation

Historical data for the period 2010 - 2016 shows that the significant increase in the fraction of the domestic harvest allocated to energy does not continue in the subsequent period (Figure 33). There is no evidence for a significant increase for neither broadleaved (p<0.712) nor coniferous (p<0.099) species.

The mean value for the period 2010 - 2016 is for broadleaved species 0.755 (95 % confidence limits: 0.734-0.777) and for coniferous species 0.501 (95 % confidence limits: 0.471-0.530)

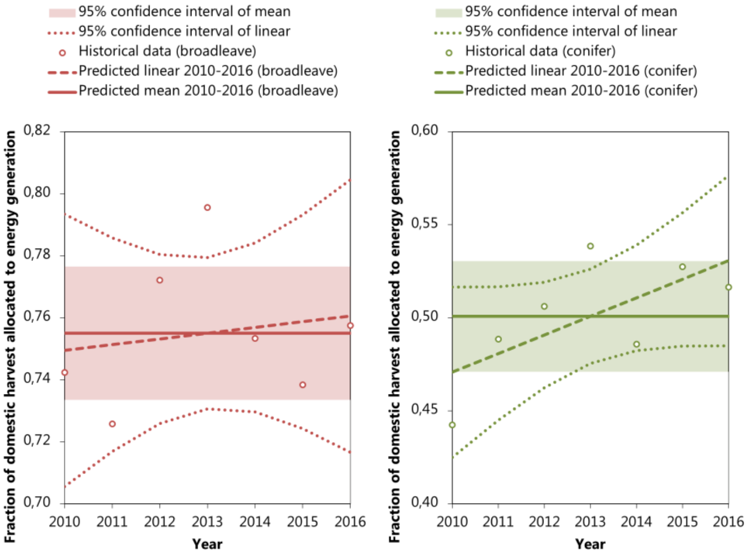

Figure 33. Fraction of domestic harvest allocated to energy generation 2010-2016.

In the period 2000 – 2016, there has been policy actions to increase the use of wood for energy, but as seen above, the fraction of harvest allocated to energy is stable in the most recent years. New policy incentives may increase afforestation and hereby increase the overall harvest. Model based analyses of different incentives were conducted in Graudal et al. (2013), including increasing harvest rates and changed assortments.

Inherited emissions

As a consequence of including domestically harvested and exported wood products, inherited emissions from the period before 2000 must be included through a recalculation of the amount of carbon stored in HWP (HWP stock) (Figure 34). It is assumed that exported wood products undergo same decay as domestically consumed. Changes in the ratio between domestic harvest and exported has no influence on the outflow from the HWP pool and consequently projections are insensitive to future changes export ratios.

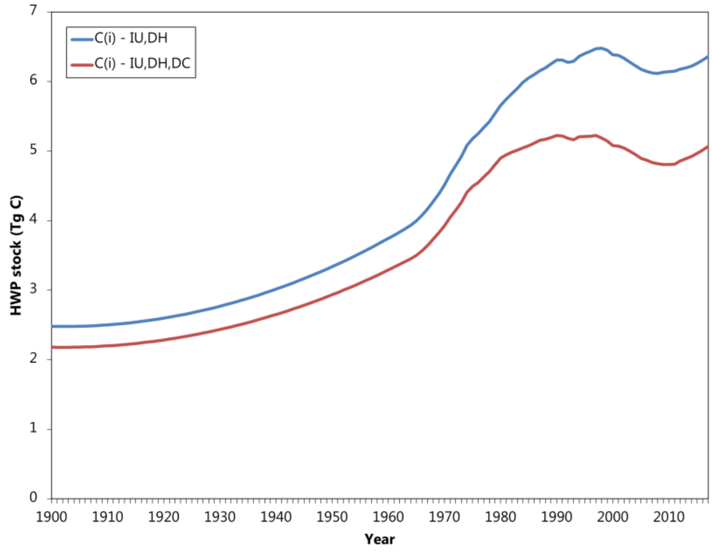

Figure 34. HWP stock of domestically harvested (DH) and domestically harvested and consumed (DH, DC) wood products from 1900 to 2017.

6.3.3 Results and validation

Projection of the fraction of domestic harvest allocated for energy generation

The projection of the future fraction of domestic harvest allocated to energy generation must 1) be based on historical data from the reference period 2000 - 2009, 2) be able to reproduce the subsequent historical development from 2010 to 2016, and 3) be a constant value. As there is no evidence that the development experienced in 2000 - 2009 continued from 2010 and onwards, one option is to assume that the future fraction remains constant at the level of the predicted value in 2009, for both broadleaved (0.77) and conifer (0,49) species (Figure 35). Another solution is to use the mean value from the reference period 2000 - 2009, yielding for broadleaved (0.65) and conifer (0.39) species. To simplify the prediction, a single value for the fraction of total harvest allocated to energy can be applied, either as a mean value, based on the reference period 2000 - 2009 (0.44), or as the endpoint given in 2009 (0.54), as described above. In all cases the estimated fraction remains constant in the predictions.

In principle, the different solutions are in line with the requirements given of a 'constant ration between solid and energy use of forest biomass' in the Regulation (EU 2018, Annex IV e). Basing the projected fraction on the 2009 prediction meets the criteria of being based on the 2000 - 2009 data and it falls within the confidence limits of the subsequent period.

Based on the review process of the first version of the NFAP, the recommendations were to apply a single value for the ratio between solid and energy use of forest biomass as documented in the period from 2000 to 2009 for the total harvest (broadleaved and coniferous combined) and based on the mean for 2000-2009. This has been accepted and is applied in the re-estimation of the HWP component. Basing the projected faction on the mean 2000-2009 is also based on the 2000-2009 data, but do not fall within the confidence limits of the subsequent period.

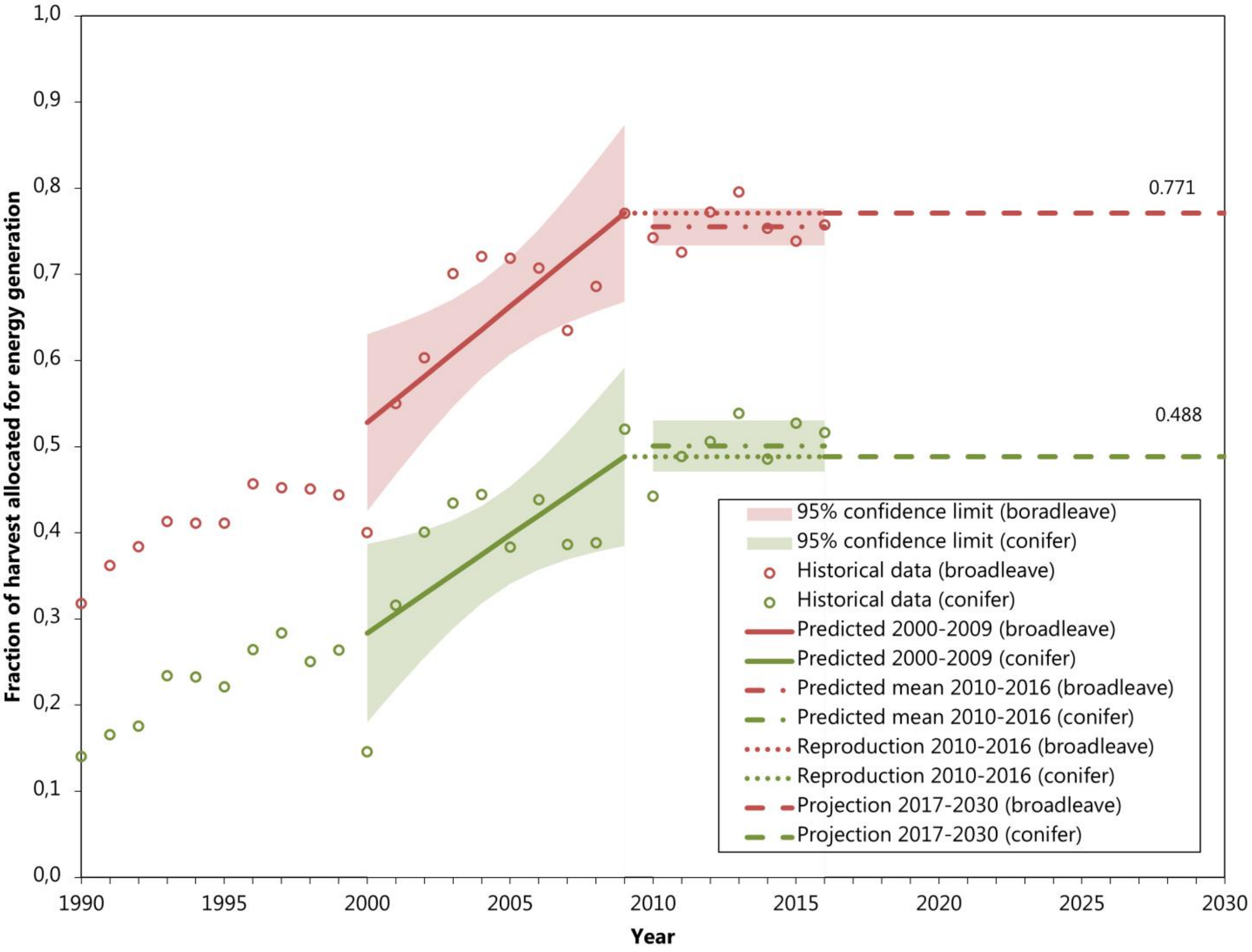

Figure 35. Fraction of domestic harvest allocated for energy generation 1990-2030 – illustration of one of the methods.

Projection of changes in the HWP pool

Future harvests in Danish forests are projected for the period 2010-2050 (see section 6.3.1) to estimate the inflow to the HWP pool as described above. The future harvest is modelled in 5 year intervals (2015, 2020, 2025, 2030, …). The future harvest is based on the projections for stock development described for the forest-land and afforestation (Chapter 6.1 and 6.2 and resulting values given above in 6.3.1).

Default half-life values, are applied to all HWP pools, domestically used and exported HWP. The half-life values given in Annex V of the EU Regulation (EU 2018) is: 2 years for paper, 25 years for wood panels and 35 years for sawn wood.

Table 10 presents the projected changes of the HWP pool by different reference periods (2000 - 2009 or endpoint 2009) and the distinction between total harvest or harvest of coniferous and non-coniferous species.

Table 10 Projected changes of the HWP pool by different reference periods (ref2000-09 or ref2009) and to the distinction between total harvest or harvest divided by coniferous and non-coniferous species.

Year	Total harvest (m3)	Harvest, C (m3)	Harvest, NC (m3)	ΔC(i), ref2000-09, total harvest (kt C yr^{-1})	ΔC(i), ref2009, total harvest (kt C yr^{-1})	ΔC(i), ref2000-09, C/NC divided (kt C yr^{-1})	ΔC(i), ref2009, C/NC divided (kt C yr^{-1})
1990	2.017.800	1.328.800	689.000				
1991	1.913.500	1.178.200	735.300				
1992	1.915.500	1.202.400	713.100				
1993	1.777.800	1.080.300	697.500				
1994	1.852.400	1.153.100	699.300				
1995	1.925.800	1.219.600	706.200				
1996	1.876.300	1.194.900	681.400				
1997	1.817.500	1.168.900	648.600				
1998	1.710.400	1.118.500	591.900				
1999	1.715.400	1.137.600	577.800				
2000	3.671.500	3.031.300	640.200	-7,0	-7,0	-7,0	-7,0
2001	1.792.600	1.286.700	506.000	-41,6	-41,6	-41,6	-41,6
2002	1.606.900	1.182.700	424.100	-56,6	-56,6	-56,6	-56,6
2003	1.807.700	1.351.400	456.500	-48,7	-48,7	-48,7	-48,7
2004	1.866.800	1.433.300	433.500	-51,3	-51,3	-51,3	-51,3
2005	2.962.300	2.528.600	433.900	-30,9	-30,9	-30,9	-30,9
2006	2.349.000	1.884.900	463.900	-21,8	-21,8	-21,8	-21,8
2007	2.549.700	2.109.900	439.900	-7,4	-7,4	-7,4	-7,4
2008	2.371.200	1.917.100	454.100	17,9	17,9	17,9	17,9
2009	2.404.800	1.847.200	557.700	6,0	6,0	6,0	6,0
2010	2.655.400	2.030.500	625.000	6,8	6,8	6,8	6,8
2011	2.565.100	1.875.600	689.500	28,2	28,2	28,2	28,2
2012	3.111.000	2.160.200	950.800	20,3	20,3	20,3	20,3
2013	3.589.900	2.482.700	1.107.200	25,5	25,5	25,5	25,5
2014	3.801.300	2.971.000	830.300	40,0	40,0	40,0	40,0
2015	3.915.200	2.905.200	1.010.000	46,8	46,8	46,8	46,8
2016	3.557.400	2.628.700	928.900	47,5	47,5	47,5	47,5
2017	3.901.800	2.788.800	1.112.900	88,1	88,1	88,1	88,1
2018	3.998.459	2.496.438	1.502.021	66,3	43,0	71,6	32,5
2019	3.998.459	2.496.438	1.502.021	64,5	41,9	69,6	31,5
2020	3.998.459	2.496.438	1.502.021	62,7	40,7	67,6	30,6
2021	3.893.185	2.521.862	1.371.323	55,4	34,6	60,6	26,2
2022	3.893.185	2.521.862	1.371.323	53,8	33,6	58,9	25,4
2023	3.893.185	2.521.862	1.371.323	52,3	32,7	57,2	24,6
2024	3.893.185	2.521.862	1.371.323	50,8	31,8	55,6	23,9
2025	3.893.185	2.521.862	1.371.323	49,4	30,9	54,0	23,1
Average 2021-2025				52,3	32,7	57,3	24,6
kt $CO_{2\ eq}$ yr^{-1}				192	120	210	90
2026	3.816.212	2.484.129	1.332.082	43,9	26,4	48,3	19,1
2027	3.816.212	2.484.129	1.332.082	42,7	25,6	47,0	18,5
2028	3.816.212	2.484.129	1.332.082	41,5	24,9	45,6	17,9
2029	3.816.212	2.484.129	1.332.082	40,3	24,2	44,3	17,3
2030	3.816.212	2.484.129	1.332.082	39,1	23,5	43,0	16,7
Average 2026-2030				41,5	24,9	45,6	17,7
kt $CO_{2\ eq}$ yr^{-1}				152	91	167	66

Figure 36 shows the reported (2000 - 2017) and projected (2018 - 2030) changes is the HWP pool based on the assumptions and methodology described above and recommended by the EU review proces– with the application of a constant fraction based on average 2000 - 2009 and a common total harvest regardless of species. The projections show a consistent sequestration of carbon in the period 2021 - 2030.

For the period, 2021 - 2025 and 2026 - 2030 the average sequestration for the different methods are given in Table 10. For the total harvest approach, with an average 2000 - 2009 fraction allocated to energy generation the HWP contribution to the FRL will be -192 kt $CO_{2\ eq}$ yr^{-1} for 2021-2025 and -152 kt $CO_{2\ eq}$ yr^{-1} for 2026 - 2030 as the HWP pool increases in the period (regardless of method applied). The review team recommends this method, and the recommendation has been applied in the revised NFAP.

For the reporting harvest volumes will be separately accounted for by coniferous and non-coniferous species and species specific accounts for fraction used for energy consumption.

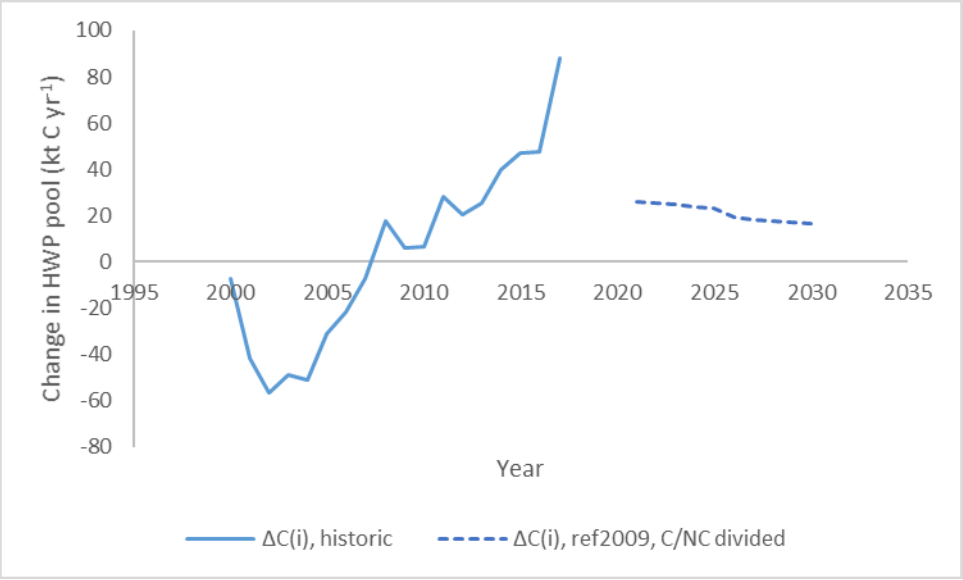

Figure 36. Estimated changes (kt C yr^{-1}) in the HWP pool from 2000 to 2017 and projection to 2030.

The effect of including exported HWP is an increase in the stock, as well as an increase in the inflow to the pool. As the export has been decreasing in recent years, the net effect is that the additional loss from a larger HWP pool (inherited emissions) is higher than the additional inflow from export. The effect of including exported HWP is an increase in the stock, as well as an increase in the inflow to the pool. Also, a large increase in the influx to the HWP pool seen from mid-1960s to mid-1990s now acts as a source of carbon emissions.

6.3.4 Uncertainty

The projected changes in the HWP pool are sensitive to reference period and methodology. Building the projections on the end value of the share of fuelwood out of the total harvest (Figure 35) instead of the average 2000 to 2009 fuelwood share, reduces the amount of carbon in the HWP pool as the inflow to semi-finished wood products.

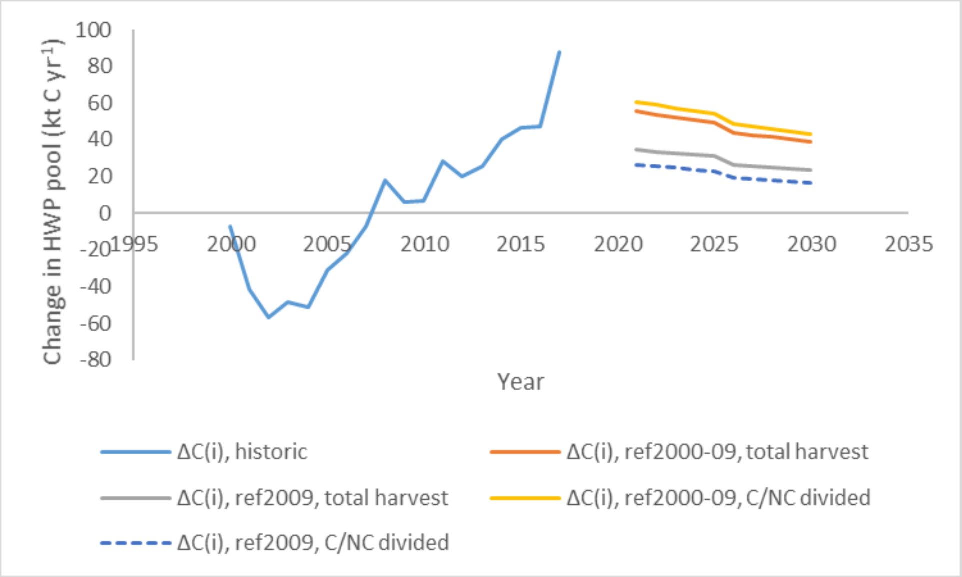

Figure 37. Sensitivity of HWP projections to different reference periods and to the distinction between total harvest or harvest of coniferous and non-coniferous species.

It can be seen in Table 10 and Figure 37, that distinguishing between coniferous and non-coniferous species influence the projected changes to the HWP pool. The share of the harvest allocated to energy is different for coniferous and non-coniferous species, and the development in the fuelwood share through the reference period 2000 to 2009 is different for the two species groups. Between 2000 and 2009 the share of fuelwood out of the total harvest increased faster for non-coniferous species than for coniferous species.

6.4 Deforestation

6.4.1 Data

Deforestation occurs in Denmark mainly due to removal of vegetation in relation to nature restoration and urban development. In the previous reporting periods, deforestation has been limited in Denmark, but for some years, the area has been larger.

Deforestation amounted to an average area of 27 ha yr^{-1} in 1990 - 2005 and 325 ha yr^{-1} in 2005 - 2011. Deforestation increased in 2011 - 2015, with a maximum of 2,251 ha yr^{-1} in 2015. The high rate of deforestation in 2011 - 2015 was caused by a combination of former misclassification of low canopy cover areas as forest in the satellite based forest mapping in 1990 - 2011 and new guidelines for subsidies for management of permanent grasslands, which lead to a reclassification of land from forest to grassland in the Land Parcel Information system. Although no real change was observed in forest canopy cover, this caused some areas to change land use from 'forest area' to 'grasslands' and hence being accounted as deforestation. This effect is expected cease in the period 2021 - 2030.

6.4.2 Method and results

Based on the analysis of forest loss, deforestation is expected to be 116 ha yr^{-1} in the period analysed here. The assessment of the carbon stock transferred to another land use and hence removed from the forest carbon stock is calculated by combining the spatially referenced areas of deforestation with national forest resource maps produced from remote sensing (Nord-Larsen et al 2017). The analyses showed an average carbon stock of 221 t $CO_{2\,eq}$ ha^{-1} on deforested lands, corresponding to a total annual emission from deforestation of 26 kt $CO_{2\,eq}$ yr^{-1}.

Wood harvested from deforestation does not contribute to the HWP pool.

In the estimation of the FRL the deforestation is not included. If it occurs in the period 2021 – 2030, it will be estimated as indicated above, and implemented in the National GHG inventory reporting. A deforestation will be reported as a technical correction to the FRL.

7 Conclusion and summary

In this Danish National Forest Accounting Plan (DK-NFAP), a projection of the development of the carbon pools and corresponding emission of greenhouse gasses for the Danish forest area are given.

The Danish National Forest Accounting Plan has been composed to fulfill the requirements and specification of the EU Regulation (EU 2018), with specific focus on Article 6-8 and Annex IV and V. The cross references between the requirements and the current document are given in Annex 9.1. The dataset used for the FRL and the resulting datasets are listed in Annex 9.3 and 9.4 and will be available as online data.

The overall development in forest carbon pools is visualised in Figure 38 for the carbon pools changing most over the period from 2000 to 2050. The decline after 2010 is caused by the current age distribution in the forest-land from before 1990. After 2030 an increasing total carbon pool and hence a carbon capture of the forests. The contribution from forest-land and afforestation (in age classes <20, 20<T>30 and >30) indicate the effect of Article 5 & 6 of the EU Regulation (EU 2018). It should be noted that the data from 2000 and 2005 are based on less accurate data, since the NFI only started in 2002 with the very first measurements.

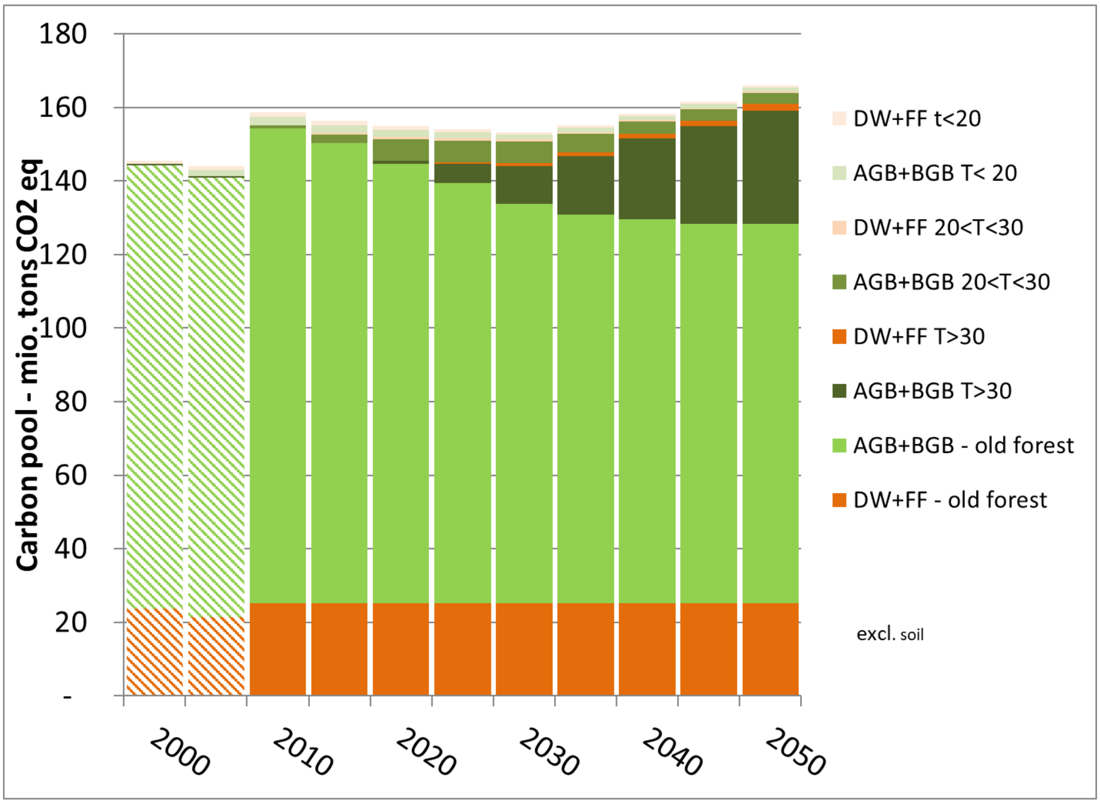

Figure 38 Overall development in the carbon pools in above-ground biomass (AGB), below-ground biomass (BGB), dead wood (DW) and forest floor (FF) pools of the different subdivisions of the total forest area depending on age since afforestation (old - before 1990) or age classes <20, <30 or older than 30, including an afforestation of 1,900 ha yr^{-1}. Data from 2000 and 2005 are based on census data from Statistics Denmark and a mixture of yield tables.

The carbon pool of the Harvested Wood Products (HWP) is accounted for, and the predicted changes for the period will be -192 kt $CO_{2\ eq}$ yr^{-1} for 2021 - 2025 and -152 kt $CO_{2\ eq}$ yr^{-1} for 2026 - 2030. The HWP pool consists of domestically harvested products in use in Denmark or exported.

As can be seen below the FRL, applying a 20-year transition period (Table 11), and a 30-year transition period (Table 12), including HWP (I+II+HWP) or assuming instant oxidation for all harvest (I+II) is provided, where the roman number refer to elements in the table.

Overall, the forest land will have a positive FRL in both periods (2021 - 2025 and 2026 - 2030) indicating emissions from the overall forest land including afforestation over the age of transition. The FRL levels given in the tables above refer to afforestation of 1,900 ha yr^{-1}. In Annex 9.4.3 are given the full tables for afforestation of 3,200 ha yr^{-1}. The FRL values are similar for the forest-land, whereas the differences occur in the afforestation outside the FRL.

The degree of utilization of harvest residues could influence the development of the pools of dead wood, which currently is less than 2 % of pool of living biomass. In areas with higher degree of utilisation for example wood for energy the pools could become smaller, whereas areas increasingly managed for biodiversity purposes could see an increase in the pool of dead wood. The higher degree of utilisation will result in higher traded volume of wood for energy, with the same harvest intensity, as also addressed in Chapter 6.1 and 6.3.

Table 11 Summary of FRL based on 20-year transition age and afforestation of 1,900 ha/yr (see Table 1, p. 37. for details)

	2011-2015	2016-2020	2021-2025	2026-2030	2031-2035	2036-2040	2041-2045	2046-2050
I: FRF - from before 1990								
Stock change + $\sum$ soils and gasses ** (kt $CO_{2\ eq}$ yr^{-1})	**925**	**1,252**	**1,212**	**1,293**	**750**	**422**	**416**	**162**
Afforestation - after 1990								
II: Older than 20								
Stock change +$\sum$ soils and gasses + transfer ** (kt $CO_{2\ eq}$ yr^{-1})	**-47**	**-657**	**-666**	**-784**	**-818**	**-738**	**-719**	**-716**
III: Younger than 20								
Stock change + $\sum$ soils and gasses + transfer (kt $CO_{2\ eq}$ yr^{-1})**	**-183**	**-175**	**-151**	**-114**	**-77**	**-110**	**-110**	**-110**
IV: Deforestation								
Carbon stock (AG+BG+DW+FF) (kt $CO_{2\ eq}$ yr^{-1})**	**499**	**26**	**26**	**26**	**26**	**26**	**26**	**26**
V: Harvested Wood Products								
HWP (kt $CO_{2\ eq}$ yr^{-1})**	**-118**	**-241**	**-192**	**-152**	**-152**	**-152**	**-152**	**-152**
Forest Reference Level 20 year								
I + II ** (kt $CO_{2\ eq}$ yr^{-1})	**889**	**667**	**545**	**510**	**-68**	**-316**	**-303**	**-554**
I + II + V ** (kt $CO_{2\ eq}$ yr^{-1})	**772**	**425**	**354**	**358**	**-220**	**-468**	**-456**	**-706**
Total forest sector								
I+II+III+IV+V** (kt $CO_{2\ eq}$ yr^{-1})	**1,095**	**276**	**228**	**269**	**-271**	**-552**	**-540**	**-791**

* Refer to the state at the end of the period

** Refer to the average for the 5-year period

Table 12 Summary of FRL based on 30 year transition age and afforestation of 1,900 ha/yr (see Table 2, p. 39. for details)

	2011-2015	2016-2020	2021-2025	2026-2030	2031-2035	2036-2040	2041-2045	2046-2050
I: FRF - from before 1990								
Stock change + ∑ soils and gasses ** (kt $CO_{2\ eq}$ yr^{-1})	**925**	**1,252**	**1,212**	**1,293**	**750**	**422**	**416**	**162**
Afforestation - after 1990								
II: Older than 30								
Stock change +∑ soils and gasses + transfer ** (kt $CO_{2\ eq}$ yr^{-1})	**0**	**142**	**-164**	**-276**	**-366**	**-445**	**-537**	**-450**
III: Younger than 30								
Stock change + ∑ soils and gasses + transfer (kt $CO_{2\ eq}$ yr^{-1})**	**-230**	**-975**	**-653**	**-622**	**-529**	**-402**	**-292**	**-376**
IV: Deforestation								
Carbon stock (AG+BG+DW+FF) (kt $CO_{2\ eq}$ yr^{-1})**	**499**	**26**	**26**	**26**	**26**	**26**	**26**	**26**
V: Harvested Wood Products								
HWP (kt $CO_{2\ eq}$ yr^{-1})**	**-118**	**-241**	**-192**	**-152**	**-152**	**-152**	**-152**	**-152**
Forest Reference Level 30 year								
I + II ** (kt $CO_{2\ eq}$ yr^{-1})	**937**	**1,466**	**1,048**	**1,017**	**384**	**-23**	**-121**	**-288**
I + II + V ** (kt $CO_{2\ eq}$ yr^{-1})	**819**	**1,224**	**856**	**865**	**232**	**-176**	**-274**	**-440**
Total forest sector								
I+II+III+IV+V** (kt $CO_{2\ eq}$ yr^{-1})	**1,095**	**276**	**228**	**269**	**-271**	**-552**	**-540**	**-791**

* Refer to the state at the end of the period

** Refer to the average for the 5-year period

In all the periods, the FRL is less than 1 % of the total carbon stock in the forest, and in most cases less than 0.5 % of the total carbon stock, indicating that the changes in the forest, represented by the FRL, are small compared to the total carbon stored in the forests. With the results on uncertainty reported in Johannsen et al (2017), it will be important to focus on the 5 year accounting period and that deviation from the FRL will most likely occur.

It is worth noting, that the total forest sector is the same, regardless of the age at which afforestation is transferred to forest-land. The total forest sector will be a practically stable carbon pools with an increasing tendency after 2030 in carbon stocks. Many factors will influence the actual development, where forest management practices, economic development, need for biomass and protection of biodiversity, as well as climate are among the know factors. The factors will influence the carbon stock development in both positive and negative ways.

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9 Appendices

9.1 Cross reference - EU Regulation & DK-NFAP

Numbering is added for ease of reference in the document. Short description of key elements are given in the last column.

Table 13 Cross reference table - EU Regulation and the Danish National Forest Accounting Plan

No.	Criteria	Text	See pages	How
1	Annex IV A.a	The reference level shall be consistent with the goal of achieving a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century, including enhancing the potential removals by ageing forest stocks that may otherwise show progressively declining sinks;	Regeneration of the forests will stabilise the future carbon capture of the forests. See Figure 24, p.52	The long term development of carbon pools of the Danish forest area have been analysed with the models applied in the FRL. This result in stable carbon pools, while maintaining a harvest level as current.
2	Annex IV A.b	the reference level shall ensure that the mere presence of carbon stocks is excluded from accounting;	See Table 1 and Table 2 for overview and Chapter 6.1.3 for text on forest land and Chapter 6.2.3 for text on afforestation.	Applying the stock change approach directly ensures that the presence or amount of carbon stock itself is not an issue in the accounting. Only the change in stock is included in the estimation of FRL and in the accounting.
3	Annex IV A.c	the reference level should ensure a robust and credible accounting system that ensures that emissions and removals resulting from biomass use are properly accounted for;	See Chapter 3.4, p. 14	The same estimation and calculation procedures and pools are applied in both estimation of FRL and in the accounting.
4	Annex IV A.d	the reference level shall include the carbon pool of harvested wood products, thereby providing a comparison between assuming instantaneous oxidation and applying the first-order decay function and half-life values;	See Chapter 6.3, p. 60	The pool of HWP are addressed and the FRL are given assuming instantaneous oxidation (Table 1 and Table 2 – Row I + II) or applying first order decay function and half-life values (Table 1 and Table 2 – Row I+II+V)

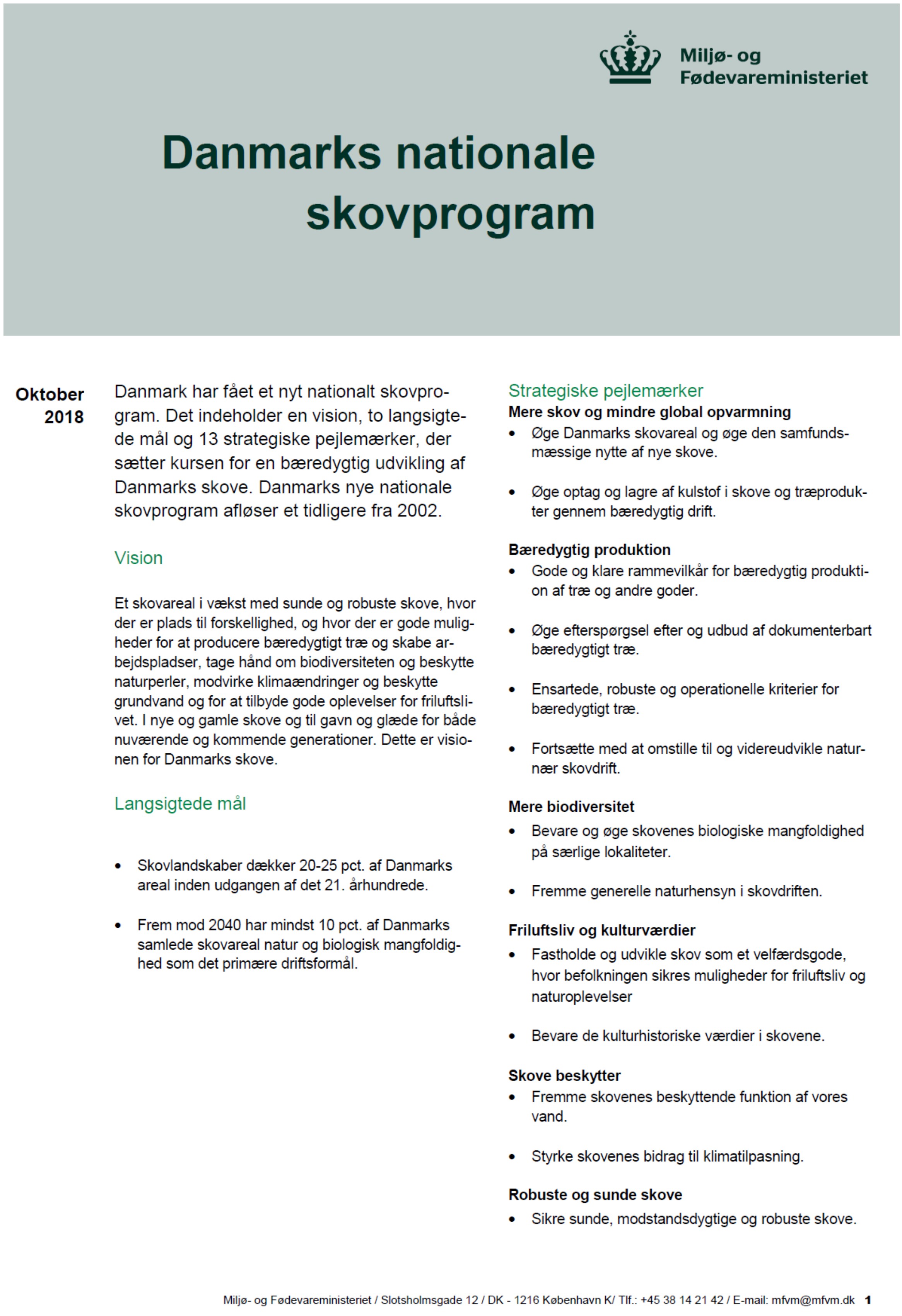
No.	Criteria	Text	See pages	How
5	Annex IV A.e	a constant ratio between solid and energy use of forest biomass as documented in the period from 2000 to 2009 shall be assumed;	See paragraph on Bioenergy, p. 63	The constant ratio are given based on the average value for the period 2000-2009. Chapter 6.3.3.
6	Annex IV A.f	the reference level should be consistent with the objective of contributing to the conservation of biodiversity and the sustainable use of natural resources, as set out in the EU forest strategy, Member States' national forest policies, and the EU biodiversity strategy;	See Chapter 5.5, p. 32 The FRL documents a stable long term development of the forest resources and an increase in forest area. (see also Figure 24, p. 52).	The reference level is based on the management conducted in 2000-2009, given the legislation and regulation in the period. The National Forest Program (1992 and 2005 versions) aim for sustainable forest management. After the reference period, further focus has been given to biodiversity as well as to use of renewable resources from forests. These are expected to be within sustainable forest management.
7	Annex IV A.g	the reference level shall be consistent with the national projections of anthropogenic greenhouse gas emissions by sources and removals by sinks reported under Regulation (EU) No 525/2013;	For each of the major components a validation compares the FRL projections with the reported values (see Chapter 6.1.4, 6.2.4, 6.3.3) and jointly in annex 9.6.1.	Comparison with core components of National Inventory Reports are given, indicating how the reference level are consistent with the reported values. The limitations of data, the reference period and the baseline data influence the results (see also Annex 9.6.2).
8	Annex IV A.h	the reference level shall be consistent with greenhouse gas inventories and relevant historical data and shall be based on transparent, complete, consistent, comparable and accurate information. In particular, the model used to construct the reference level shall be able to reproduce historical data from the National Greenhouse Gas Inventory.	The estimation of the FRL follows the same methods and guidelines as the accounting. The full datasets area listed in annex 9.3 and 9.4. The reproduction of the historical data is tested, but the short reference period 2000 - 2009 poses challenges, as it cannot capture changes caused by later events. See the detailed description in Chapter 6.1.4 and 6.2.4.	Comparison with core components of National Inventory Reports are given, indicating how the reference level are consistent with the reported values. The limitations of data, the reference period and the baseline data influence the results (see also Annex 9.6.2). A comparsion with previous predictions are included in Annex 9.6.2 Since the Danish NFI started in 2002, there is no option to use a 2000 baseline to compare the reference level model to the development in the 2000-2009 period. This concerns both total forest area as well as stratification of the forest area by region and species types. There are no information on the stock levels by 2000. In Annex 9.6.2 is a comparison with previously reported figures for sink/emissions, with the uncertainties induced by the above mentioned shortcommings.

No.	Criteria	Text	See pages	How
9	Annex IV B.a	a general description of the determination of the forest reference level and a description of how the criteria in this Regulation were taken into account;	See Chapter 2.1, p.7	A general description of this topic is the core of Chapter 6.1.
10	Annex IV B.b	identification of the carbon pools and greenhouse gases which have been included in the forest reference level, reasons for omitting a carbon pool from the forest reference level determination, and demonstration of the consistency between the carbon pools included in the forest reference level;	See Chapter 3, p. 11 and subsequent pages	All greenhouse gasses are included (CO2, CH4, N2O) and all carbon pools (above and below ground living biomass, dead wood, litter layer (forest floor), soil organic carbon as well as harvested wood products. Detailed description in Chapter 3.
11	Annex IV B.c	a description of approaches, methods and models, including quantitative information, used in the determination of the forest reference level, consistent with the most recently submitted national inventory report, and a description of documentary information on sustainable forest management practices and intensity as well as of adopted national policies;	The method for the FRL is described in Chapter 6, p. 36, and is consistent with the methods used for the latest NIR report. The national regulations and policies are described in Chapter 4, p 15 and subsequent pages. Sustainable forest management described in Chapter 5, p. 19 and subsequent pages	The same method is applied for estimation of the FRL as for the calculation for the national inventory report. It is the stock change approach that is utilised. In detail in Chapter 6. The relation to the main criteria for sustainable forest management forms the basis for the information given in Chapter 5. A key criterion is maintaining or increasing forest area and the long-term stability of the carbon uptake in the forest area, while ensuring ecosystem services as described. National regulations and policies adopted after the reference period 2000-2009 and the baseline year 2010, may alter the reported development from the FRL based on the regulation.
12	Annex IV B.d	information on how harvesting rates are expected to develop under different policy scenarios;	See Projection of changes in the HWP pool, p. 67	The harvesting rates for the FRL scenario are given in 6.3.3. In Annex 9.6.3 provide information on how harvest will be influenced by a number of different policy scenarios, including changing of species composition, regeneration practices, genetic breeding of plant material, and harvest practices. The influence is given both on carbon stock as well as on harvest volumes.

No.	Criteria	Text	See pages	How
13	Annex IV B.e	a description of how each of the following elements were considered in the determination of the forest reference level:		
14	Annex IV B.e.i	the area under forest management;	See table 1 & 2, p. 39-41 (for historic development in areas: See Annex 9.3.4)	The full forest area is included in the determination of the FRL. The annual area of afforestation and the time since afforestation determines the transition from afforestation area to the forest area under the FRL determination.
15	Annex IV B.e.ii	emissions and removals from forests and harvested wood products as shown in greenhouse gas inventories and relevant historical data;	For forests see Chapter 6.1.3 and 6.2.3. For HWP see Chapter 6.3.3	The historic data as well as the method applied in the FRL are based on the stock change approach. This is hence an integral part of the estimation of the FRL. The historic removals and development in harvested wood products is a central element in estimation of the current HWP pool, its outflow and hence also the determination of the HWP component of the FRL.
16	Annex IV B.e.iii	forest characteristics, including dynamic age-related forest characteristics, increments, rotation length and other information on forest management activities under 'business as usual';	See Chapter 5, especially p 19-29	The biomass carbon stock in each forest management class is the combined result of influences by regeneration success, the growth of the trees, climate influence, natural mortality, silvicultural methods, and harvest intensity (including fuel wood harvest and their potential effects on remaining stock in the forest stands) occurring in each management class, i.e. the result of the forest management practices. The data reflects the forest management practices as they have been implemented until 2010. This is combined with the transition probabilities ensures rotation length as observed in the reference period.
17	Annex IV B.e.iv	historical and future harvesting rates disaggregated between energy and non-energy uses.	See Bioenergy, p. 63	Both historic and future fraction of domestic harvest allocated to energy are analysed and predicted for both broadleaved and conifer species (Figure 35) and for the full harvest. The influence on the estimated HWP contribution to the FRL is analyzed (6.3.3).

No.	Criteria	Text	See pages	How
18	Annex V.a	If it is not possible to differentiate between harvested wood products in the land accounting categories of afforested land and managed forest land, a Member State may choose to account for harvested wood products assuming that all emissions and removals occurred on managed forest land.	As harvest, utilised as HWP comes from stands older than 30 years, all HWP naturally are accounted for referring to managed forest land.	Harvest with the current options for utilisation of wood assortments (incl. diameter of extracted trees) and the growth rates of the Danish afforestation, will only result in HWP from forests older than 30 years, and hence regardless of transition period from afforestation to forest land, occur under the FRL forest area. This may change with new research and development in the wood industry, but is not currently the case.
19	Annex V.b	Harvested wood products in solid waste disposal sites and harvested wood products that were harvested for energy purposes shall be accounted for on the basis of instantaneous oxidation.	Only HWP in use (IU) and domestically harvested (DH) is included in the accounts.	All wood in waste disposal sites and wood use for energy is accounted for on the basis of instantaneous oxidation.
20	Annex V.c	Imported harvested wood products, irrespective of their origin, shall not be accounted for by the importing Member State (‘production approach’).	Only HWP from domestically harvested (DH) is included in the accounts.	The HWP pool (both inflow and outflow) are based only on wood produced in Denmark.
21	Annex V.d	For exported harvested wood products, country-specific data refer to country-specific half-life values and harvested wood products usage in the importing country.	Default half-life values are applied to all HWP pools. See Projection of changes in the HWP pool, p. 67	In accordance with available data, default half-life values are used for exported HWP. Export is treated as one component, regardless of country of destination.
22	Annex V.e	Country-specific half-life values for harvested wood products placed on the market in the Union should not deviate from those used by the importing Member State.	Default half-life values are applied to all HWP pools. See Projection of changes in the HWP pool, p. 67	In accordance with available data, default half-life values are used for exported HWP. Export is treated as one component, regardless of country of destination.
23	Annex V.f	Member States may, for information purposes only, provide in their submission data on the share of wood used for energy purposes that was imported from outside the Union, and the countries of origin for such wood.	This information has not been included.	The share of wood for energy purposes in Denmark has been increasing, especially after the reference period. However, the project for estimation of the FRL did not include resources for collection of these data, since it does not influence the reference level for the Danish forest area.

9.2 Forest program 2018 fact sheet



Miljø- og
Fødevareministeriet

Danmarks nationale skovprogram

Oktober 2018

Danmark har fået et nyt nationalt skovprogram. Det indeholder en vision, to langsigtede mål og 13 strategiske pejlemærker, der sætter kursen for en bæredygtig udvikling af Danmarks skove. Danmarks nye nationale skovprogram afløser et tidligere fra 2002.

Vision

Et skovareal i vækst med sunde og robuste skove, hvor der er plads til forskellighed, og hvor der er gode muligheder for at producere bæredygtigt træ og skabe arbejdspladser, tage hånd om biodiversiteten og beskytte naturperler, modvirke klimaændringer og beskytte grundvand og for at tilbyde gode oplevelser for friluftslivet. I nye og gamle skove og til gavn og glæde for både nuværende og kommende generationer. Dette er visionen for Danmarks skove.

Langsigtede mål

- Skovlandskaber dækker 20-25 pct. af Danmarks areal inden udgangen af det 21. århundrede.
- Frem mod 2040 har mindst 10 pct. af Danmarks samlede skovareal natur og biologisk mangfoldighed som det primære driftsformål.

Strategiske pejlemærker

Mere skov og mindre global opvarmning

- Øge Danmarks skovareal og øge den samfundsmæssige nytte af nye skove.
- Øge optag og lagre af kulstof i skove og træprodukter gennem bæredygtig drift.

Bæredygtig produktion

- Gode og klare rammevilkår for bæredygtig produktion af træ og andre goder.
- Øge efterspørgsel efter og udbud af dokumenterbart bæredygtigt træ.
- Ensartede, robuste og operationelle kriterier for bæredygtigt træ.
- Fortsætte med at omstille til og videreudvikle naturnær skovdrift.

Mere biodiversitet

- Bevare og øge skovenes biologiske mangfoldighed på særlige lokaliteter.
- Fremme generelle naturhensyn i skovdriften.

Friluftsliv og kulturværdier

- Fastholde og udvikle skov som et velfærdsgode, hvor befolkningen sikres muligheder for friluftsliv og naturoplevelser
- Bevare de kulturhistoriske værdier i skovene.

Skove beskytter

- Fremme skovenes beskyttende funktion af vores vand.
- Styrke skovenes bidrag til klimatilpasning.

Robuste og sunde skove

- Sikre sunde, modstandsdygtige og robuste skove.

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9.3 Datasets used for the FRL

Access to the data available here:

https://www.doi.org/10.17894/ucph.96be1df6-a26e-4d8c-aeb0-7f516d7148dd

9.3.1 Data: Survival modelling

Excel spreadsheet: NFI_survival_input.xlsx

Metadata for NFI survival input data for the Danish FRL	
Colum	explanation
joe07	region - Jutland and Islands
SPEC_TYPE	species type - broadleaved (B), conifers (C), Christmass trees (P)
Acl	age classes (5 year classes, indicating end of age class)
Cut	indication of survival (0) or cut/mortality (1)
Runno	numbering observations

Sample data:

joe07	SPEC_TYPE	acl	cut	runno
Øerne	B	100	0	1
Øerne	B	140	0	2
Øerne	C	30	0	3
Øerne	C		0	4
Øerne	B	90	0	5
Øerne	B	140	0	6
Jylland	C	45	1	7
Jylland	C	25	0	8
Jylland	C	5	0	9
Jylland	B	10	0	10
Jylland	B	10	0	11
More …				

9.3.2 Data: Baseline data for FRL

Excel spreadsheet: NFI_2010_baseline.xlsx

Metadata for NFI 2010 baseline for the Danish FRL	
Colum	explanation
joe07	region - Jutland and Islands
mc_spec	species type - broadleaved (B), conifers (C), Christmass trees (P)
Acl	age classes (5 year classes, indicating end of age class)
area_ha	area of strata in ha
V3_m3	growing stock in volume - m3
Cag3_t_C	Above ground biomass - carbon content - tons C
Cbg3_t_C	Belove ground biomass - carbon content - tons C
Cdw3_t_C	Dead wood - carbon content - tons C
CL3_t_C	Litter layer - carbon content - tons C

Sample data:

joe07	mc_spec	acl	area_ha	V3_m3	Cag3_t_C	Cbg3_t_C	Cdw3_t_C	CL3_t_C
Jylland	B	5	3.243	45.909	10.785	2.617	2.975	47.018
Jylland	B	10	9.389	179.172	42.596	10.318	8.614	136.118
Jylland	B	15	7.846	349.479	89.716	22.408	7.199	113.756
Jylland	B	20	5.194	368.564	94.520	22.954	4.765	75.297
Jylland	B	25	5.705	525.298	133.933	31.695	5.234	82.713
Jylland	B	30	9.078	1.104.566	279.782	65.423	8.328	131.607
Jylland	B	35	8.532	1.050.902	251.278	59.291	7.828	123.695
Jylland	B	40	10.679	1.998.436	493.641	113.871	9.797	154.820
More …								

9.3.3 Data: Growth models for afforestation

Excel spreadsheet: Afforestation_growthmodel.xlsx

Input for Danish FRL - Afforestation growth models

General information

Art	species	pct	density BAG pr m3	Relation full biomass/V3
Bøg	beech	30	0,57	1
Rgr	norway spruce	30	0,38	1,2
Eg	oak	40	0,58	1

bevoksningsprocent	stocking percentage	0,9

Metadata for Afforestation_BAGmodel

T	age from seed
BAG	Biomas above ground - ton drymatter

Sample data:

T	BAG
1	-
2	0
3	1
4	2
5	4
6	6
7	8
8	10
9	11
10	13
11	15
12	16
13	17
14	19
More …	

Metadata for VIDAR growth models

T	[År]	year
HD1	[m]	before harvest - height - m
D1	[cm]	before harvest - diameter - cm
N1	[/ha]	before harvest - stem number - per ha
G1	[m2/ha]	before harvest - basal area - m2 per ha
V1	[m3/ha]	before harvest - volume - m3 per ha
D2	[cm]	harvest - diameter - cm
N2	[/ha]	harvest - stem number - per ha
G2	[m2/ha]	harvest - basal area - m2 per ha
V2	[m3/ha]	harvest - volume - m3 per ha
RTA2	[%]	Relative tree distance in harvest- %
HD3	[m]	after harvest - height - m
D3	[cm]	after harvest - diameter - cm
N3	[/ha]	after harvest - stem number - per ha
G3	[m2/ha]	after harvest - basal area - m2 per ha
V3	[m3/ha]	after harvest - volume - m3 per ha
RTA3	[%]	Relative tree distance after harvest- %
mdHD/dt	[m/år]	Height increment - m per year
mdV/dt	[m3/ha/år]	Volume increment - m3 per ha per year
dVtot	[m3/ha]	Total volume production - m3 per ha
BAG	t/ha	total drymass per ha of remaining stock (v3) - tons per ha.

Sample data:

BØG CMM bon 2 - Beech site class 2									
T	HD1	D1	N1	G1	V1	D2	N2	G2	More …
[År]	[m]	[cm]	[/ha]	[m2/ha]	[m3/ha]	[cm]	[/ha]	[m2/ha]	
20	7,7	5,3	5907	13,14	64,3	4,8	0	0	
22	8,8	6,1	5823	17,06	93,4	5,5	0	0	
24	9,9	6,8	5717	21,04	128,3	6,2	0	0	
27	11,8	7,9	5501	26,79	189,5	7,2	442	1,79	
30	13,7	8,9	4808	30,21	242,9	8,2	986	5,21	
33	15,6	10,2	3631	29,55	264,1	9,4	658	4,55	
37	17,7	11,8	2775	30,32	302,7	10,9	565	5,32	
41	19,6	13,5	2075	29,66	323,3	12,6	373	4,66	
45	21,2	15,2	1608	29,16	341,5	14,3	259	4,16	
50	22,9	17,3	1265	29,7	374,3	16,4	222	4,7	
56	24,6	19,8	975	30,09	407,6	19	179	5,09	
More…									

9.3.4 Data: Areas of Forest remaining Forest Land and Afforestation areas by year

For afforestation see: Excel spreadsheet: Afforestation_area_year.xlsx

Metadata for Danish FRL - Afforestation area by year	
year	Calendar year in which the afforestation occurs
AF total	Total afforested area since 31.12.1989 - ha
Annual AF	Annual afforested area - ha

Data: The full forest area is provided to Annex IV Section B, criterie e)I of the Regulation (EU 2018). Note – the last three columns of the table below are only added in this report, while the first thee columns are in the excel spreadsheet.

year	AF total	Annual AF	FRF - Unstocked	FRF - stocked	Total Forest
1989	-	-	22.462	506.623	529.085
1990	3.678	3.678	22.462	506.623	532.763
1991	7.356	3.678	22.462	506.623	536.441
1992	11.034	3.678	22.462	506.623	540.119
1993	14.712	3.678	22.462	506.623	543.797
1994	18.390	3.678	22.462	506.623	547.475
1995	22.068	3.678	22.462	506.623	551.153
1996	25.746	3.678	22.462	506.623	554.831
1997	29.424	3.678	22.462	506.623	558.509
1998	33.102	3.678	22.462	506.623	562.187
1999	36.780	3.678	22.462	506.623	565.865
2000	40.458	3.678	22.462	506.623	569.543
2001	44.136	3.678	22.462	506.623	573.221
2002	47.814	3.678	22.462	506.623	576.899
2003	51.492	3.678	22.462	506.623	580.577
2004	55.170	3.678	22.462	506.623	584.255
2005	58.907	3.737	22.462	506.623	587.992
2006	62.644	3.737	22.462	506.623	591.729
2007	66.382	3.737	22.462	506.623	595.467
2008	70.119	3.737	22.462	506.623	599.204
2009	73.857	3.737	22.462	506.623	602.942
2010	77.594	3.737	22.462	506.623	606.679
2011	81.332	3.737	22.462	506.623	610.417
2012	81.334	2	22.462	506.623	610.419
2013	86.338	5.004	22.462	506.623	615.423
2014	86.896	558	22.462	506.623	615.981
2015	88.761	1.865	22.462	506.623	617.846

9.4 Resulting datasets for the FRL

Access to the data available here:

https://www.doi.org/10.17894/ucph.96be1df6-a26e-4d8c-aeb0-7f516d7148dd

9.4.1 Survival curves

Excel spreadsheet: NFI_survival_curve.xlsx

Metadata for NFI survival curves the Danish FRL	
column	explanation
joe07	region - Jutland and Islands
SPEC_TYPE	species type - broadleaved (B), conifers (C), Christmass trees (P)
acl	age classes (5 year classes, indicating end of age class)
Survival	survival percentage - %

Sample data:

NFI survival curves the Danish FRL			
joe07	SPEC_TYPE	acl	Survival
Jylland	B	0	1
Jylland	B	0	0,999333
Jylland	B	5	0,9953
Jylland	B	10	0,990422
Jylland	B	15	0,988154
Jylland	B	20	0,983309
Jylland	B	25	0,973812
Jylland	B	30	0,969152
Jylland	B	35	0,956027
Jylland	B	40	0,947051
Jylland	B	45	0,940615
Jylland	B	50	0,927537
Jylland	B	55	0,92408
More …			

9.4.2 Result: DK_FRL_forest_land_detail

Excel spreadsheet: DK_FRL_forest_land_detail.xlsx

Metadata for NFI based prognosis of forest land as part of DK FRL	
column	explanation
ite	Iteration - 0=2010, no=number of 5 year time steps
joe07	region - Jutland and Islands
mc_spec	species type - broadleaved (B), conifers (C), Christmass trees (P)
acl	age classes (5 year classes, indicating end of age class)
area	Area of strata
Hareal	regenerated area of strata
V3	growing stock in volume - m3
Cag3	Above ground biomass - carbon content - tons C
Cbg3	Belove ground biomass - carbon content - tons C
Cdw3	Dead wood - carbon content - tons C
CL3	Litter layer - carbon content - tons C
V2	total harvested in volume - m3 over 5 years
Cag2	total harvested Above ground biomass - carbon content - tons C over 5 years
Cbg2	total harvested Belove ground biomass - carbon content - tons C over 5 years

Sample data:

ite	joe07	mc_spec	acl	area	Hareal	V3	Cag3	More …
0	Jylland	B	5	3.243		45.909	10.785	
0	Jylland	B	10	9.389		179.172	42.596	
0	Jylland	B	15	7.846		349.479	89.716	
0	Jylland	B	20	5.194		368.564	94.520	
0	Jylland	B	25	5.705		525.298	133.933	
0	Jylland	B	30	9.078		1.104.566	279.782	
0	Jylland	B	35	8.532		1.050.902	251.278	
0	Jylland	B	40	10.679		1.998.436	493.641	
0	Jylland	B	45	10.980		2.208.682	545.602	
0	Jylland	B	50	8.683		1.918.897	476.028	
More …								

9.4.3 Result: FRL 2010-2050 - with 3,200 ha annual afforestation

Table 14 Summary of Forest Reference Level - FRL - annual average values for each period, base year 2010, transfer at 20 years, afforestation 3,200 ha/yr. Positive changes indicate emissions, while negative changes indicate uptake.

	2011-2015	**2016-2020**	**2021-2025**	**2026-2030**	**2031-2035**	**2036-2040**	**2041-2045**	**2046-2050**
I: FRF - from before 1990								
Area* (ha)	529,085	529,085	529,085	529,085	529,085	529,085	529,085	529,085
Carbon stock* (AG+BG+DW+FF) (kt $CO_{2\ eq}$)	150,382	144,602	139,382	133,754	130,842	129,571	128,330	128,359
Stock change** (AG+BG+DW+FF) (kt $CO_{2\ eq}$ Y^{-1})	769	1.156	1,044	1,126	582	254	248	-6
CO2 from drained soils (kt $CO_{2\ eq}$ Y^{-1})	123	123	123	123	123	123	123	123
N2O drained organic soils (kt $CO_{2\ eq}$ Y^{-1})	17	17	17	17	17	17	17	17
CH4 drained and rewetted organic soils (kt $CO_{2\ eq}$ Y^{-1})	28	28	28	28	28	28	28	28
∑ soils emissions (kt $CO_{2\ eq}$ Y^{-1})	168	168	168	168	168	168	168	168
Stock change + ∑ soils emissions ** (kt $CO_{2\ eq}$ Y^{-1})	**937**	**1,324**	**1,212**	**1,293**	**750**	**422**	**416**	**162**
Afforestation - after 1990								
II: Older than 20								
Area* (ha)	22,068	40,458	58,907	77,594	88,761	104,761	120,761	136,761
Carbon stock* (AG+BG+DW+FF) (kt $CO_{2\ eq}$)	2,622	7,339	12,138	17,564	22,475	27,927	33,729	39,809
Stock change** (AG+BG+DW+FF) (kt $CO_{2\ eq}$ Y^{-1})	-328	-943	-960	-1,085	-982	-1,090	-1,161	-1,216
Carbon stock transfer**$^{\#}$ (AG+BG+DW+FF) (kt $CO_{2\ eq}$ Y^{-1})	278	278	280	283	161	242	242	242
Carbon accumulation - soil (kt $CO_{2\ eq}$ Y^{-1})	-11	-19	-28	-37	-43	-50	-58	-66
CO2 from drained soils (kt $CO_{2\ eq}$ Y^{-1})	11	26	40	54	64	73	81	89
N2O drained organic soils (kt $CO_{2\ eq}$ Y^{-1})	2	4	5	7	9	10	11	12
CH4 drained and rewetted organic soils (kt $CO_{2\ eq}$ Y^{-1})	0	1	1	1	1	2	2	2
∑ soils emissions (kt $CO_{2\ eq}$ Y^{-1})	3	10	18	25	32	34	36	38
Stock change +∑ soils emissions + transfer (kt $CO_{2\ eq}$ Y^{-1})**	**-47**	**-655**	**-662**	**-777**	**-790**	**-814**	**-883**	**-936**

	2011-2015	2016-2020	2021-2025	2026-2030	2031-2035	2036-2040	2041-2045	2046-2050
III: Younger than 20								
Area* (ha)	66,694	64,304	61,854	59,167	64,000	64,000	64,000	64,000
Carbon stock* (AG+BG+DW+FF) (kt $CO_{2\ eq}$)	3,320	3,166	2,963	2,645	2,998	2,998	2,998	2,998
Stock change** (kt $CO_{2\ eq}$ Y^{-1})	45	31	41	64	-71	0	0	0
Carbon stock transfer** # (AG+BG+DW+FF) (kt $CO_{2\ eq}$ Y^{-1})	-278	-278	-280	-283	-161	-242	-242	-242
Carbon loss from conversion (kt $CO_{2\ eq}$ Y^{-1}) ##	49	70	70	70	70	70	70	70
Carbon accumulation - soil (kt $CO_{2\ eq}$ Y^{-1})	-32	-31	-30	-28	-31	-31	-31	-31
CO2 from drained soils (kt $CO_{2\ eq}$ Y^{-1})	35	29	23	17	15	15	15	15
N2O drained organic soils (kt $CO_{2\ eq}$ Y^{-1})	5	4	3	2	2	2	2	2
CH4 drained and rewetted organic soils (kt $CO_{2\ eq}$ Y^{-1})	1	1	0	0	0	0	0	0
$\sum$ soils emissions (kt $CO_{2\ eq}$ Y^{-1})	50	44	39	33	28	28	28	28
Stock change + $\sum$ soils emissions + transfer(kt $CO_{2\ eq}$ Y^{-1})**	**-183**	**-203**	**-201**	**-186**	**-203**	**-214**	**-214**	**-214**
IV: Deforestation								
Area**(ha)	2,251	116	116	116	116	116	116	116
Carbon stock (AG+BG+DW+FF) (kt $CO_{2\ eq}$ Y^{-1})**	**499**	**26**	**26**	**26**	**26**	**26**	**26**	**26**
V: Harvested Wood Products								
HWP (kt $CO_{2\ eq}$ Y^{-1})**	**-118**	**-241**	**-192**	**-152**	**-152**	**-152**	**-152**	**-152**
Forest Reference Level 20 year								
I + II (kt $CO_{2\ eq}$ Y^{-1})**	**889**	**669**	**550**	**516**	**-40**	**-393**	**-467**	**-774**
I+II +V ** (kt $CO_{2\ eq}$ Y^{-1})	**772**	**427**	**358**	**364**	**-192**	**-545**	**-619**	**-927**
Total forest sector								
I+II+III+IV+V** (kt $CO_{2\ eq}$ Y^{-1})	**1,095**	**279**	**211**	**232**	**-341**	**-704**	**-779**	**-1,086**

* Refer to the state at the end of the period

** Refer to the average for the 5-year period

The full effect of growth/harvest/mortality for the age class 20 is assigned to the afforestation before transferring the area to the forest land. Therefore, the stock of age class 20 remains in the afforestation until the end of the year (December 31) and transferred at the beginning of the next year (January 1).

Emissions from removal of crop biomass before afforestation. For change from cropland to forest this is estimated to be 22 t CO_2 eq ha^{-1} equaling a loss of 12 t of biomass per ha.

Table 15 Summary of Forest Reference Level - FRL - annual average values for each period, base year 2010, transfer at 30 years, afforestation 3,200 ha/yr. Positive changes indicate emissions, while negative changes indicate uptake.

	2011-2015	**2016-2020**	**2021-2025**	**2026-2030**	**2031-2035**	**2036-2040**	**2041-2045**	**2046-2050**
I: FRF - from before 1990								
Area* (ha)	529,085	529,085	529,085	529,085	529,085	529,085	529,085	529,085
Carbon stock* (AG+BG+DW+FF) (kt $CO_{2\,eq}$)	150,382	144,602	139,382	133,754	130,842	129,571	128,330	128,359
Stock change ** (AG+BG+DW+FF) (kt $CO_{2\,eq}$ yr^{-1})	769	1.156	1,044	1,126	582	254	248	-6
CO2 from drained soils (kt $CO_{2\,eq}$ yr^{-1})	123	123	123	123	123	123	123	123
N2O drained organic soils (kt $CO_{2\,eq}$ yr^{-1})	17	17	17	17	17	17	17	17
CH4 drained and rewetted organic soils (kt $CO_{2\,eq}$ yr^{-1})	28	28	28	28	28	28	28	28
$\sum$ soils emissions (kt $CO_{2\,eq}$ yr^{-1})	168	168	168	168	168	168	168	168
Stock change + $\sum$ soils emissions ** (kt $CO_{2\,eq}$ yr^{-1})	**937**	**1,324**	**1,212**	**1,293**	**750**	**422**	**416**	**162**
Afforestation - after 1990								
II: Older than 30								
Area* (ha)	0	3,678	22,068	40,458	58,907	77,594	88,761	104,761
Carbon stock* (AG+BG+DW+FF) (kt $CO_{2\,eq}$)	0	878	5,671	11,049	16,930	23,282	28,108	34,188
Stock change ** (AG+BG+DW+FF) (kt $CO_{2\,eq}$ yr^{-1})	0	-176	-958	-1,076	-1,176	-1,270	-965	-1,216
Carbon stock transfer ** # (AG+BG+DW+FF) (kt $CO_{2\,eq}$ yr^{-1})	0	314	786	786	791	798	454	683
Carbon accumulation - soil (kt $CO_{2\,eq}$ yr^{-1})	0	-2	-11	-19	-28	-37	-43	-50
CO2 from drained soils (kt $CO_{2\,eq}$ yr^{-1})	0	6	21	35	49	66	73	82
N2O drained organic soils (kt $CO_{2\,eq}$ yr^{-1})	0	1	3	5	7	9	10	11
CH4 drained and rewetted organic soils (kt $CO_{2\,eq}$ yr^{-1})	0	0	0	1	1	1	2	2
$\sum$ soils emissions (kt $CO_{2\,eq}$ yr^{-1})	0	6	13	21	28	39	42	44
Stock change +$\sum$ soils emissions + transfer ** (kt $CO_{2\,eq}$ yr^{-1})	**0**	**144**	**-160**	**-270**	**-357**	**-433**	**-469**	**-488**

	2011-2015	**2016-2020**	**2021-2025**	**2026-2030**	**2031-2035**	**2036-2040**	**2041-2045**	**2046-2050**
III: Younger than 30								
Area* (ha)	88,761	101,083	98,694	96,304	93,854	91,167	96,000	96,000
Carbon stock* (AG+BG+DW+FF) (kt CO$_{2\ eq}$)	5,943	9,627	9,430	9,159	8,543	7,643	8,620	8,620
Stock change** (kt CO$_{2\ eq}$ yr^{-1})	-283	-737	39	54	123	180	-195	0
Carbon stock transfer** # (AG+BG+DW+FF) (kt CO$_{2\ eq}$ yr^{-1})	0	-314	-786	-786	-791	-798	-454	-683
Carbon loss from conversion (kt CO$_{2\ eq}$ yr^{-1})##	49	70	70	70	70	70	70	70
Carbon accumulation - soil (kt CO$_{2\ eq}$ yr^{-1})	-43	-49	-47	-46	-45	-44	-46	-46
CO2 from drained soils (kt CO$_{2\ eq}$ yr^{-1})	46	48	42	36	30	21	22	22
N2O drained organic soils (kt CO$_{2\ eq}$ yr^{-1})	6	7	6	5	4	3	3	3
CH4 drained and rewetted organic soils (kt CO$_{2\ eq}$ yr^{-1})	1	1	1	1	1	0	0	0
$\sum$ soils emissions (kt CO$_{2\ eq}$ yr^{-1})	52	49	43	37	32	23	22	22
Stock change + $\sum$ soils emissions + transfer (kt CO$_{2\ eq}$ yr^{-1})**	**-230**	**-1,002**	**-703**	**-694**	**-636**	**-595**	**-628**	**-662**
IV: Deforestation								
Area** (ha)	2,251	116	116	116	116	116	116	116
Carbon stock (AG+BG+DW+FF) (kt CO$_{2\ eq}$ yr^{-1})**	**499**	**26**	**26**	**26**	**26**	**26**	**26**	**26**
V: Harvested Wood Products								
HWP (kt CO$_{2\ eq}$ yr^{-1})**	**-118**	**-241**	**-192**	**-152**	**-152**	**-152**	**-152**	**-152**
Forest Reference Level 30 year								
I + II ** (kt CO$_{2\ eq}$ yr^{-1})	**937**	**1,468**	**1.052**	**1,024**	**393**	**-11**	**-53**	**-326**
I + II + V ** (kt CO$_{2\ eq}$ yr^{-1})	**819**	**1,227**	**860**	**872**	**241**	**-163**	**-205**	**-479**
Total forest sector								
I+II+III+IV+V** (kt CO$_{2\ eq}$ yr^{-1})	**1,095**	**279**	**211**	**232**	**-341**	**-704**	**-779**	**-1,086**

* Refer to the state at the end of the period

** Refer to the average for the 5-year period

The full effect of growth/harvest/mortality for the age class 30 is assigned to the afforestation before transferring the area to the forest land. Therefore, the stock of age class 30 remains in the afforestation until the end of the year (December 31) and transferred by the beginning of the next year (January 1).

Emissions from removal of crop biomass before afforestation. For change from crop land to forest this is estimated to be 22 t CO$_2$ eq ha^{-1} equaling a loss of 12 t of biomass per ha.

9.5 Methodological considerations regarding IPCC guidelines

9.5.1 Time to stable carbon pools - 20 or 30 years?

Due to the fact that the Regulation opens for either a 20 year or a 30 year transition period, the IPCC (2006) guidelines for this issue have been reviewed. Volume 4, chapter 4.3 (IPCC 2006) states

"Land Converted to Forest Land is covered in this section of the national greenhouse gas inventory until the time the soil carbon in new forests reach a stable level. A default period of 20 years is suggested."

A note for this sentence further gives the information

"It is clear that most forest ecosystems will take longer than 100 years to return to the level of biomass, soil and litter pools in undisturbed state; however human-induced activities can enhance the rate of return to stable state of carbon stocks. With this in mind and as a practical matter, the default 20-year time interval is suggested to capture the establishment of the forest ecosystems. Countries also have the option to extend the length of the transition period, though a consistent transition period will be required for the land-use matrix system of land area representation to work properly."

In the Danish reporting (Nielsen et al 2018, p. 430) a transition period of 100 years is applied for the soil carbon pool in afforestation, for a change of 21 t C ha^{-1} when converting cropland to forest (from 121 t C ha^{-1} in cropland to 142 t C ha^{-1} in forest land). At the same time, Denmark has applied a 20-year period for the remaining carbon pools, before transferring the land area from the afforestation reporting to the land remaining forest land, in the IPCC reporting. Under the Kyoto reporting, all afforestation since 1990 remained afforestation. With the set up in the Regulation (EU 2018), applying the IPCC reporting as base and revisiting the IPCC (2006) guidelines, the option of using a 30-year period before transferring afforestation to the land remaining forest land should be seen in relation to the IPCC guidelines, as time until stable levels of both soil carbon, as well as carbon in living biomass under Danish growth conditions, takes considerably longer than 20 years to reach a stable level.

The suggested 20-year transition period may in some climatic zones be sufficient to reach a state of more than 80 % of steady state pools, but under temperate forest zones, a period of closer to 100 years would be correct, based on available yield tables and long term field experiments (VIDAR 2018), as can be seen from Figure 39. It shows the development of CO_2 accumulation in forest under Danish conditions with beech, oak and Norway spruce, both total accumulation and standing stock in the forest, given the standard forest management regime with intermediate thinnings. Even in forest stands with no active thinnings, mortality will cause the standing stock to be lower than the total accumulated carbon capture (documented in long-term experiments with degree of thinning). The main point in this context is the period until some degree of steady state, which, for Norway spruce, is the earliest at 50-60 years after germination of the seed. There is no doubt that the Danish forests have a longer transition period than the default 20-years given in the IPCCC guidelines (V4_04_ch4.3) and the state can be duly justified by growth models, long term-field experiments and inventory data for Denmark (see e.g. Schou et al 2014, Nord-Larsen et al 2017, VIDAR 2018).

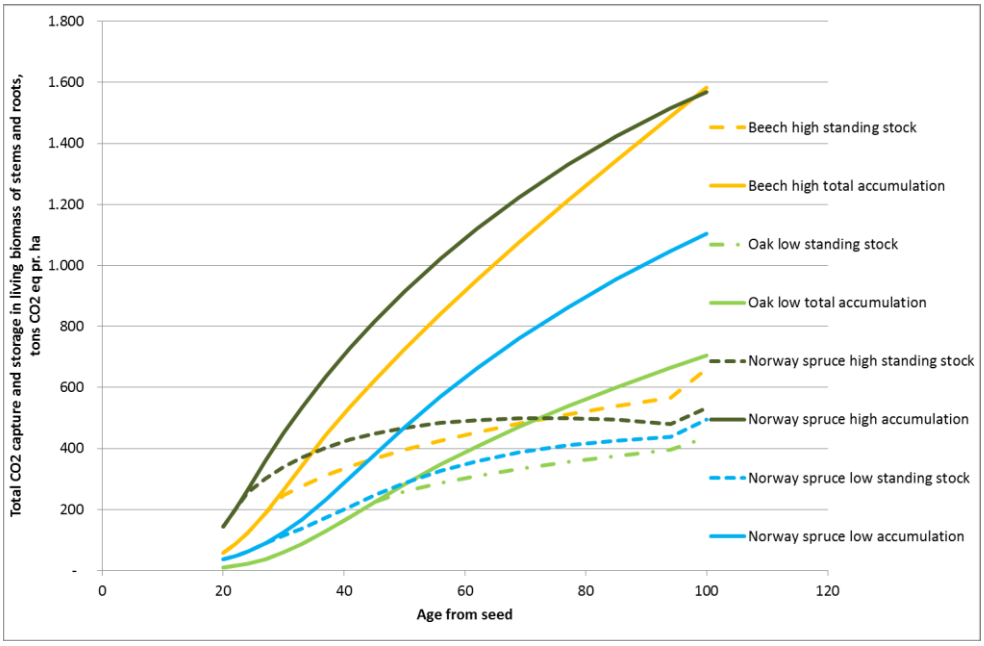

Figure 39 Development of CO_2 accumulation in forest under Danish conditions with beech, oak and Norway spruce, both total accumulation and standing stock in the forest, given the standard forest management regime with intermediate thinnings (Vidar).

The EU Regulation allows for a 30-year transition period if duly justified, which would be more in line with the growth of forests than 20-years under the Danish conditions, but still far from a situation of steady state.

A consistent adherence to the IPCC guidelines will require a common transition period for the full afforested land of the same length, either 100, 30, or 20 years, to ensure stable levels of biomass, soil and litter pools.

The overall conclusion based on the above review of models and reports on Danish afforestation, supports the choice of a 30-year transition period for afforestation in the Danish FRL.

9.5.2 Biomass loss in conversion to forest land

Another issue of investigation in the IPCC (2006) guidelines is the issue of change in biomass stocks in connection with land-use conversion, in this case with afforestation on former cropland and grassland. Until now, the reporting from Denmark has included a loss of biomass from cropland of 6 t C ha^{-1} (Nielsen et al. 2018, table 6.8) equaling a loss of 12 t of biomass per ha. In Volume 4, chapter 2.3.1.2 (IPCC 2006) the Tier 1 approach states "Tier 1 employs a default assumption that there is no change in initial biomass carbon stocks due to conversion." and "default assumption that there is no change in initial carbon stocks in biomass ". *However, since the Danish land-use mapping provides knowledge on the previous land-use on a converted area then the Tier 2 method can be used. In Tier 2 (and 3) methods, the conversion includes both gains and losses of biomass (equation 2.15 and 2.16 of the IPCC 2006). In the specifications are referred to biomass "immediately after the conversion" and the examples of removals include "annual decrease in biomass carbon stocks due to losses from harvesting, fuel wood gathering and disturbances on land converted to other land-use category, in tons C yr^{-1}". Similar descriptions are given in Volume 4, Chapter 4.3.1.2 (IPCC 2006), under "Change in biomass stocks on land before and after conversion, ΔCCONVERSION" where Tier 1 askes for no calculation and Tier 2 and 3 asks for estimates of stock consistent with those used in calculations of carbon stock changes in e.g. grass land and crop land. The examples generally are aimed at removal of woody vegetation (i.e. perennial vegetation carbon stocks removed when previously unmanaged forest are replaced by plantation), whereas a crop of wheat (harvested long before the new trees are planted or sown) do not meet the description in the guidelines. Furthermore, the guidelines do not indicate at what time of the year, the stock is estimate, but the land-use matrix applies a date of December 31 as delimiter, where the stock of the e.g. cropland will be lower than the maximum value used in the reporting (Nielsen et al 2018).

In addition to the above mentioned issues, is the issue of parity in handling of different land use changes. In the current set up the forest land use accounts for the full effect by deforestation, that is the counterpart of afforestation. However, in both cases the forest accounting has the debits for the loss of biomass.

The IPCC guidelines are not clear on this issue, especially given that Tier 1 allows for no estimate conversion loss. As the IPCC guidelines are set as the framework for the EU accounting (according to the Regulation, EU 2018). It will be raised in the review process, to find the balanced interpretation of the IPCC guidelines, that best meets the goal of the EU Regulation (EU 2018).

9.5.3 The stock change method with changing forest area

The stock change method is based on actual assessment of carbon stock at two given points in time and provides estimates of change over time as given by the difference between the two consecutive inventories of carbon stocks.

A special issue arises when the area changes over time because afforestation area of a certain age is transferred to the forest-land category (Article 5 & 6 – EU 2018). In these situations, there needs to be a special focus on the area and associated carbon stock that is transferred from the afforestation category to the forest land category. This is required in order to assign the actual change to the afforestation including the growth/harvest/mortality of the last year, before transferring the carbon stock of the age class to the forest land carbon stock. Therefore, the stock of the age class to be transferred remains in the afforestation until the end of the year (December 31) and is transferred by the beginning of the next year (January 1). This is done on an annual basis. This is applied in both estimation of the FRL and in the accounting.

The principle is illustrated by the following example for time T1 and T2, one year apart. Age X indicates the age of transition from afforestation to forest land, i.e. either 20 or 30 years.

Area (ha) by 1.1 of:	T1	T2	Stock density t CO2 eq/ha
Forest land	**100**	**100**	75
Afforestation of age X-2	7	2	10
Afforestation of age X-1	10	7	11
Afforestation of age X	**14**	**10**	12
Afforestation of age X+1	**8**	**14**	13
Afforestation of age X+2		**8**	14
Total area in FRL	**122**	**132**	

The area development and stock density leads to the following development in stocks (note equilibrium stock is assumed on the remaining forest land area).

Stock (t CO2 eq) by 1.1	T1	T2
Forest land	**7.500**	**7.500**
Afforestation of age X-2	70	20
Afforestation of age X-1	110	77
Afforestation of age X	**168**	**120**
Afforestation of age X+1	**104**	**182**
Afforestation of age X+2	**0**	**112**
Stock in FRL (bold figures)	**7.772**	**7.914**
Stock in the full area	**7.952**	**8.011**

A raw estimate of stock change T1-T2 would be 7914-7722=142, but the transfer of carbon stock from afforestation of age X =120 needs to be deducted, as this has only just been included in the FRL pool and the growth occurred before the transfer. This results in a real stock change on the area already in the FRL pool of 142-120=22. This equals the change in carbon stock of the forest-land (=0), and the afforestation of age X+1 and X+2 (182+122-168-104) =22.

For the afforestation area the raw estimate of stock change T1-T2 would be (20+77-70-110) =-83. Again the stock of the afforestation of age X = 120 needs to be taken into account, this time added, as the growth occurred before the transfer to the FRL pool. This results in a real stock change for the afforestation of -83+120= 37.

The overall change of the stock T1-T2 in the full forest area is 59, which is the sum of changes in the pool under FRL and under afforestation and hence ensuring consistency.

This principle has been discussed and agreed upon by experts from DG Clima and JRC during the JRC LULUCF Workshop, Stresa 26.4.-27.4.2017.

This principle is applied in the estimation of the Danish FRL to address the significant influence of the afforestation since 1990 on the overall stock change in the Danish forest area and is referred to in the tables as “Carbon stock transfer” addressing average annual values in the 5-year estimation intervals.

9.6 Supplementary information on FRL estimation

Following the review process, some supplementary information is provided here on the methodologies and sensitivity of the FRL to the models and the baseline data.

9.6.1 Principles and sensitivity analysis of survival modelling

Transition probabilities are estimated based on data collected by the National Forest Inventory in 2002-2017. The data includes plot specific information on whether the forest stand is regenerated or survives the subsequent 5-year period. The data available for the estimation is composed of a full total, of 4,440 plots with repeated measurements and age information by initial observation. Of these, regeneration activities occur on less than 400 plots, i.e. less than 10 % of the plots.

The frequency of NFI plots with coniferous forest peaks at age-class 20-29 years and hereafter declines rapidly with only few plots exceeding 80 years (Figure 40). The frequency of NFI plots with broadleaves is more slowly declining, with no distinct peaks. The frequency of NFI plots with final harvesting of broadleaves is surprisingly high for stand ages <40 years, which may be due to assignment of stand age to the new generation of naturally regenerated trees rather than the older generation of seed trees.

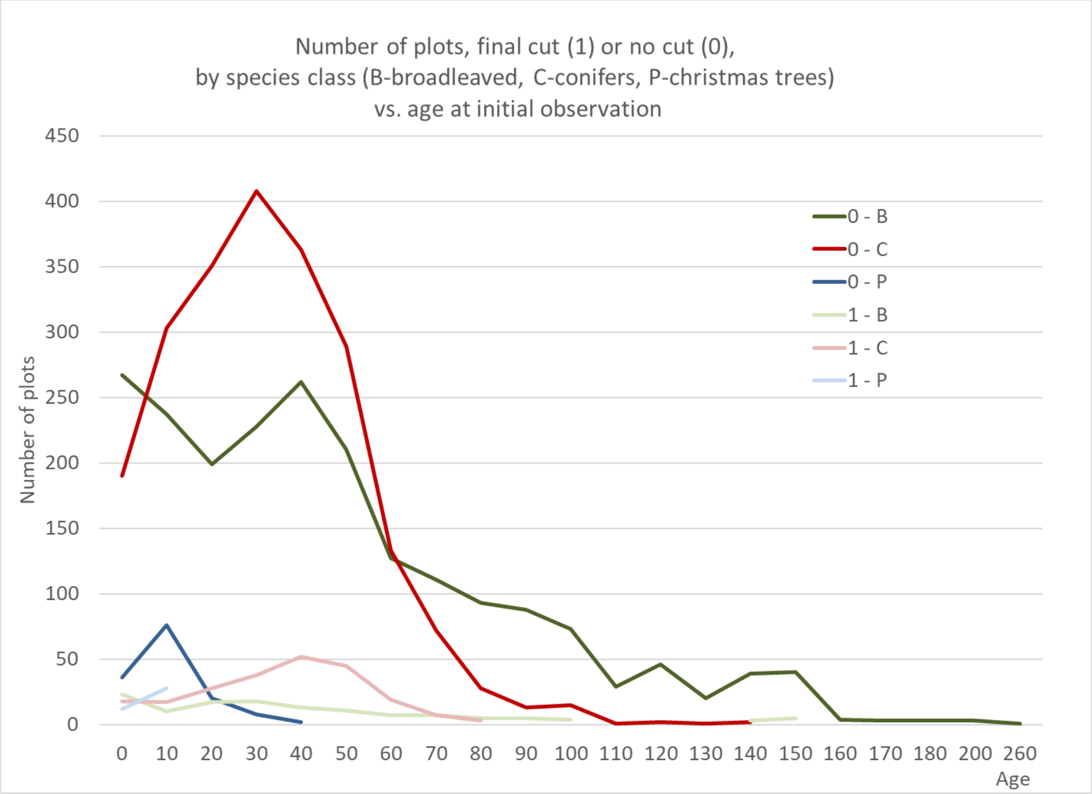

Figure 40 Number of plots from the NFI by species class (B-broeadleaved, C-conifers, P-Christmas trees) by age at initial observation and distributed by no cut (0) or final cut (1).

The frequency of observations increases from the first year of the Danish NFI in 2002, but is stabilising from 2005 (Figure 41). Measurements during the first years of the NFI were incomplete due to problems with training, logistics, and data capture infrastructure. Measurements have consistently been complete since 2008.

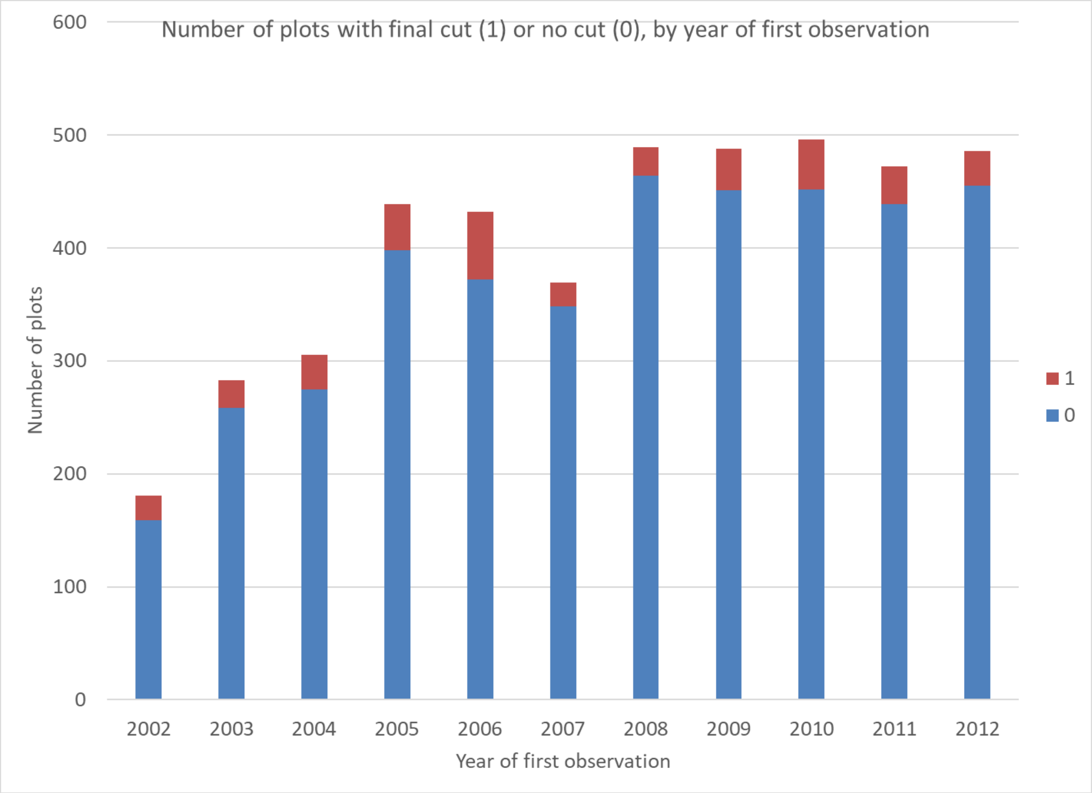

Figure 41 Number of plots from the NFI by first observation and distributed by no cut (0) or final cut (1).

The survival models were estimated from the permanent plots, using the PROC PHREG[4] of the SAS Institute (Cox 1972, 1975). The model is estimated based on the Cox model, by maximising the partial likelihood and computes the baseline survivor function, by using the Breslow (1972) estimates. The estimation allows for censored data, i.e. the fact that the dataset only contains a small subset (5-15 years of observations) of the entire lifespan of forest stands (60-200+ years). The results give the predicted survival for all forest strata, as given in Table 5. The resulting curves and uncertainties are given in Figure 21 and Figure 22.

Initial analyses included other factors for classification of the forest area such as e.g. owner, soil types, and more detailed site classifications. However, these additional factors did not contribute to the overall accuracy in predicting the survival models and were not included in the final model.

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[4] The PROC PHREG procedure performs regression analysis of survival data based on the Cox proportional hazards model. Cox's semiparametric model is widely used in the analysis of survival data to explain the effect of explanatory variables on hazard rates. The partial likelihood of Cox also allows time-dependent explanatory variables, like age.

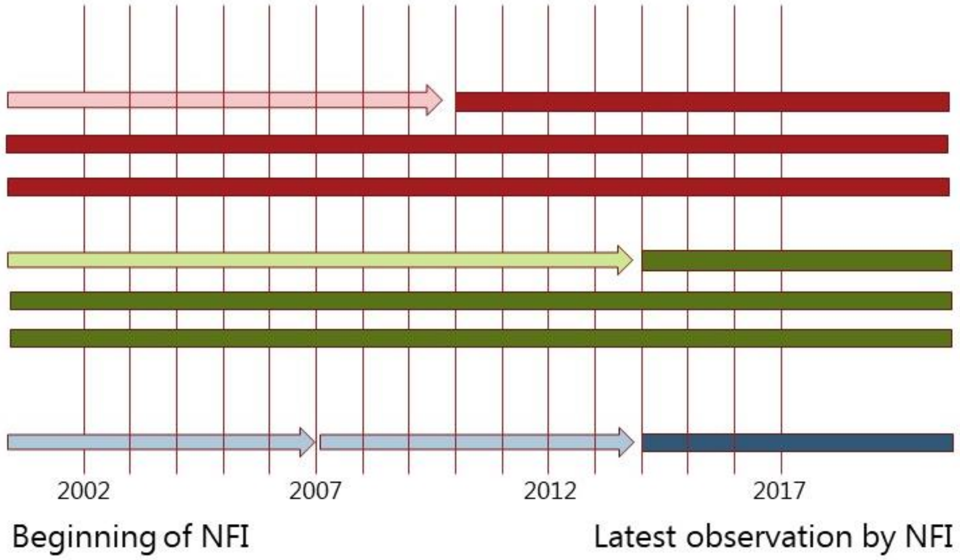

Figure 42 Principal illustration of the event history of NFI plot data. An arrow indicates a cut followed by a regeneration with the same species type. The open-ended bars indicate that there is no formal record of later actions, but the age of stands indicate the time of regeneration prior to the NFI plot data (inspired by Herringa et al 2010, p. 306).

The estimated models can be tested in terms of their prediction of the development of the forest area over age for the different growing regions and species types. Resulting simulations can be seen in Figure 43. The overall impression from the simulations matches well with the observed forest management practices observed by the National Forest Inventory data, as this is reflected in age classes for the forest area. The longer rotation ages of broadleaved on the more fertile soils of 'Islands' reflects the higher frequency of forest areas including areas set aside for longer rotations or in some cases biodiversity forests.

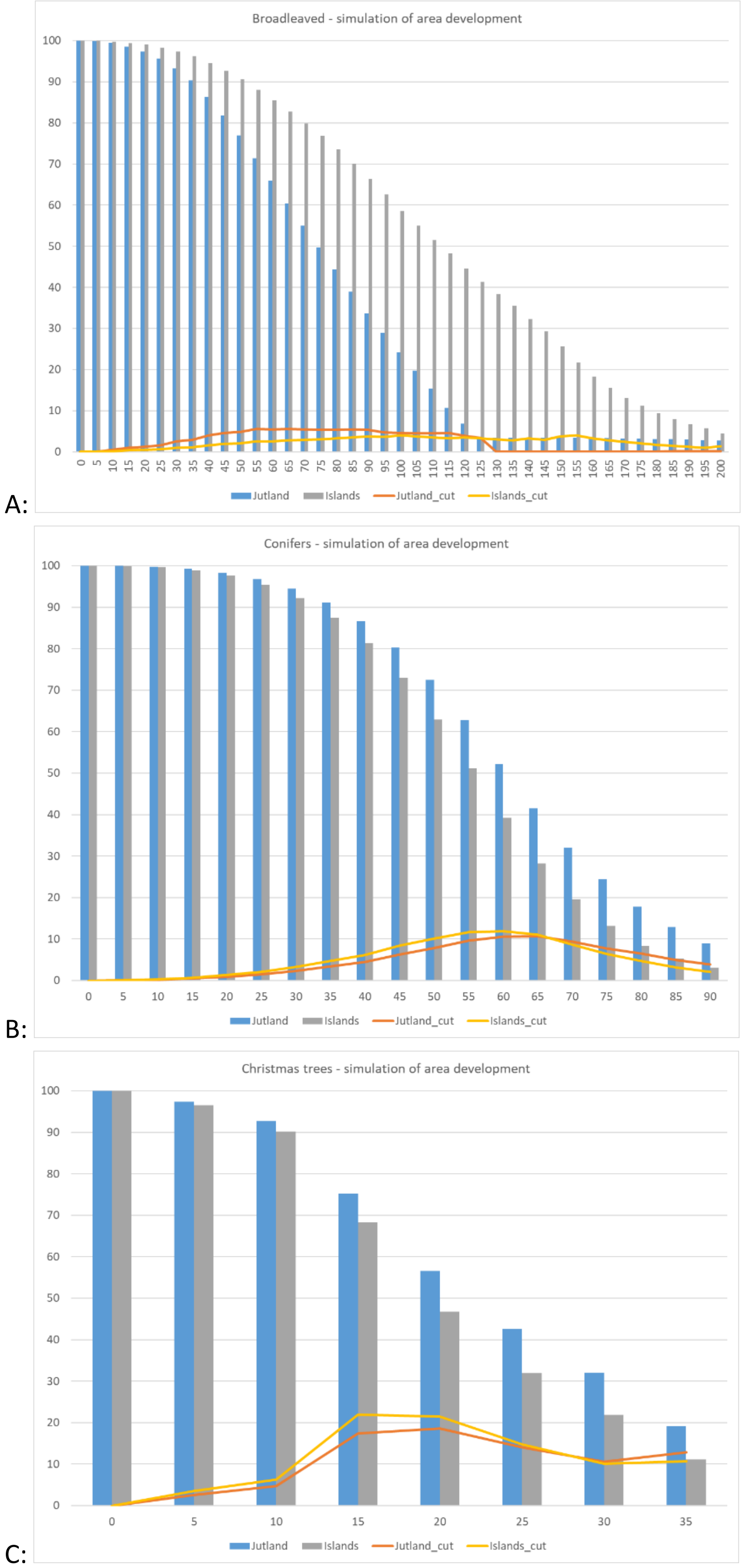

Figure 43 Simulation of area development of broadleaved (A), conifers (B) and Christmas trees (C) based on the estimated survival models. Note the different scale of the x-axis indicating the age classes.

To test the influence of the estimate of the survival models on the estimated reference level, the predicted development was run for the upper (Table 16) and the lower (Table 17) 95 % confidence interval for the estimated survival rates. Given as supplement to Table 6.

Table 16 Upper value of survival rates - Predicted development in stocks of the forest land (kt CO2 eq) for the year 2010 - 2050 in 5-year intervals.

YEAR	Above ground Biomass - Reference	Annual change - reference	Above ground biomass – upper value survival rates	Above ground biomass - Deviation from reference	Annual change – upper value survival rates	Annual change – deviation from reference
	kt $CO_{2\ eq}$	kt $CO_{2\ eq}$	kt $CO_{2\ eq}$	%	kt $CO_{2\ eq}$	%
2010	105.703		105.703	0%		
2015	102.577	-3.126	104.420	2%	-1.283	-59%
2020	97.815	-4.762	101.170	3%	-3.250	-32%
2025	93.520	-4.295	98.018	5%	-3.153	-27%
2030	88.902	-4.618	93.881	6%	-4.137	-10%
2035	86.514	-2.388	91.723	6%	-2.157	-10%
2040	85.471	-1.043	90.718	6%	-1.006	-4%
2045	84.451	-1.020	89.552	6%	-1.166	14%
2050	84.470	19	89.312	6%	-240	-1397%

Table 17 Lower value of survival rates - Predicted development in stocks of the forest land (kt CO2 eq) for the year 2010 - 2050 in 5-year intervals.

YEAR	Above ground Biomass - Reference	Annual change - reference	Above ground biomass – lower value survival rates	Above ground biomass - Deviation from reference	Annual change – lower value survival rates	Annual change – deviation from reference
	kt $CO_{2\ eq}$	kt $CO_{2\ eq}$	kt $CO_{2\ eq}$	%	kt $CO_{2\ eq}$	%
2010	105.703		105.703	0%		
2015	102.577	-3.126	100.770	-2%	-4.932	58%
2020	97.815	-4.762	94.643	-3%	-6.127	29%
2025	93.520	-4.295	89.402	-4%	-5.241	22%
2030	88.902	-4.618	84.509	-5%	-4.894	6%
2035	86.514	-2.388	82.091	-5%	-2.418	1%
2040	85.471	-1.043	81.158	-5%	-933	-11%
2045	84.451	-1.020	80.403	-5%	-755	-26%
2050	84.470	19	80.741	-4%	338	1727%

The result of the sensitivity analysis indicates an uncertainty of the full stock within +/- 6 % compared to the reference values. For the annual change in stock, the uncertainty is higher, ranging from 0 to +/- 60% of the annual change of the reference numbers. The uncertainty of the annual change is in all cases less than 5 % of the full carbon stock in the above ground biomass. This reflects that even with a reference value within a 95 % interval (based on the survival curves) the uncertainty of the annual changes may be high. The same pattern was also reported based on analysis of reporting data based on the NFI data (Johannsen et al 2017). Note that these analyses have focused on the above ground biomass, as this primarily is influenced by survival rates. Below ground biomass is closely related to the above ground biomass, whereas pools of dead wood, litter and soil carbon is not linked to survival curves.

9.6.2 Sensitivity to baseline year

The regulation is not strict in the indication of a suitable baseline year. In the estimation the baseline year 2010 (representing data collected in the period 2006-2010) forms the baseline for the estimation of the FRL for the forest area from before 1990. In order to test the sensitivity to this choice, two alternative baseline years are tested, i.e. 2015 and 2017. The results can influence both live biomass as well as the other pool. In the Table 18 below shows a comparison of the development with the two different baseline years, as well as the resulting annual change when focusing on these pools influenced by the survival models.

The varying baseline year results in varying levels of stocks, mainly in the above ground biomass, illustrated in Figure 44. For information the reported data (from the NIR for forest area including Christmass trees) are included in the graph.

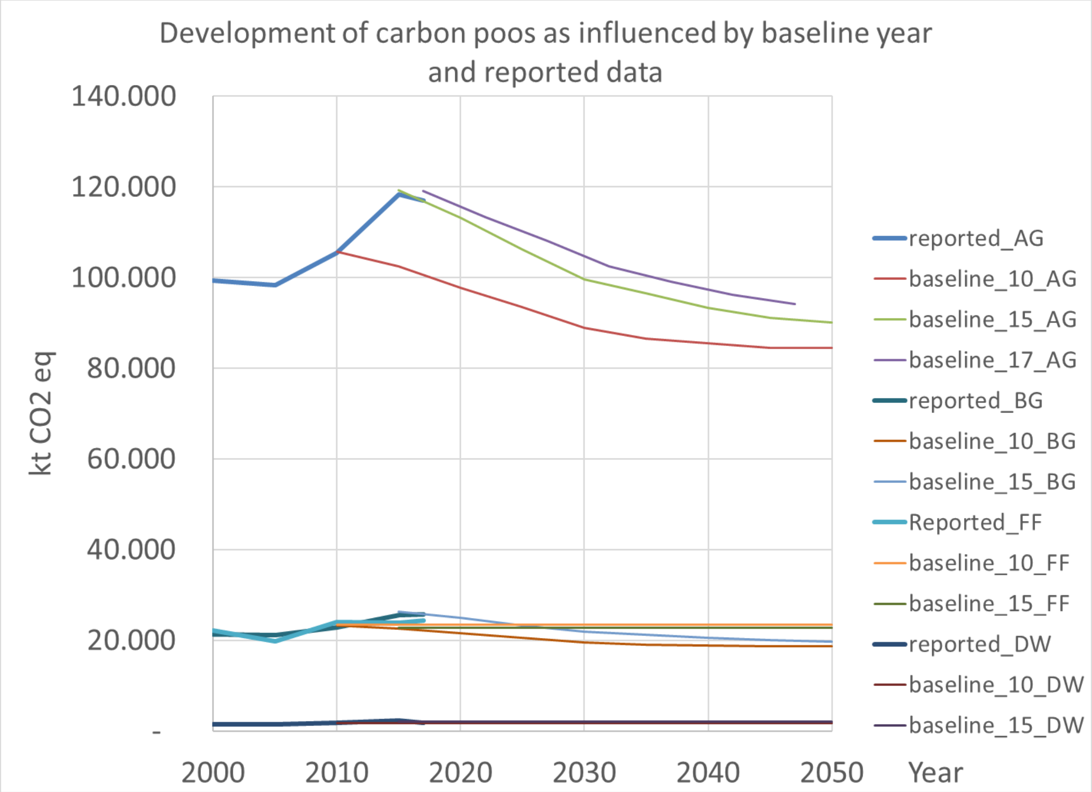

Figure 44 Development of carbon pools (AG – above ground, BG – below ground, DW – dead wood, FF – forest floor) in kt CO_2 eq. The labels indicate the baseline year – 2010, 2015 or 2017. Reported data are included for the period 2000-2017.

Table 18 Alternative baseline years (2010, 2015 and 2017) with resulting prediction of development in stocks of the forest land (kt CO2 eq) for the year 2010 - 2050 in 5-year intervals.

	Above Ground Biomass	Below Ground Biomass	Dead Wood	Forest Floor	TOTAL	Annual change
2010 baseline	kt $CO_{2\,eq}$	kt $CO_{2\,eq}$	kt $CO_{2\,eq}$	kt $CO_{2\,eq}$	kt $CO_{2\,eq}$	kt $CO_{2\,eq}$ /yr
2010	105.703	23.300	1.797	23.429	154.228	
2015	102.577	22.580	1.797	23.429	150.382	769
2020	97.815	21.562	1.797	23.429	144.602	1.156
2025	93.520	20.637	1.797	23.429	139.382	1.044
2030	88.902	19.627	1.797	23.429	133.754	1.126
2035	86.514	19.103	1.797	23.429	130.842	582
2040	85.471	18.874	1.797	23.429	129.571	254
2045	84.451	18.654	1.797	23.429	128.330	248
2050	84.470	18.664	1.797	23.429	128.359	-6
2015 baseline	kt $CO_{2\,eq}$	kt $CO_{2\,eq}$	kt $CO_{2\,eq}$	kt $CO_{2\,eq}$	kt $CO_{2\,eq}$	kt $CO_{2\,eq}$ /yr
2010	-	-	-	-	-	
2015	119.287	26.319	2.161	22.834	170.601	
2020	113.211	24.924	2.161	22.834	163.130	1.494
2025	106.270	23.314	2.161	22.834	154.580	1.710
2030	99.584	21.868	2.161	22.834	146.447	1.627
2035	96.596	21.287	2.161	22.834	142.878	714
2040	93.267	20.562	2.161	22.834	138.825	811
2045	91.081	20.047	2.161	22.834	136.123	540
2050	90.131	19.807	2.161	22.834	134.933	238
2017 baseline	kt $CO_{2\,eq}$	kt $CO_{2\,eq}$	kt $CO_{2\,eq}$	kt $CO_{2\,eq}$	kt $CO_{2\,eq}$	kt $CO_{2\,eq}$ /yr
2010	-	-	-	-	-	
2015	-	-	-	-	-	
2017	119.184	26.257	1.729	22.140	169.309	
2022	113.272	24.898	1.729	22.140	162.039	1.454
2027	108.162	23.757	1.729	22.140	155.787	1.250
2032	102.470	22.562	1.729	22.140	148.900	1.378
2037	99.055	21.897	1.729	22.140	144.820	816
2042	96.210	21.243	1.729	22.140	141.322	700
2047	94.195	20.750	1.729	22.140	138.814	502

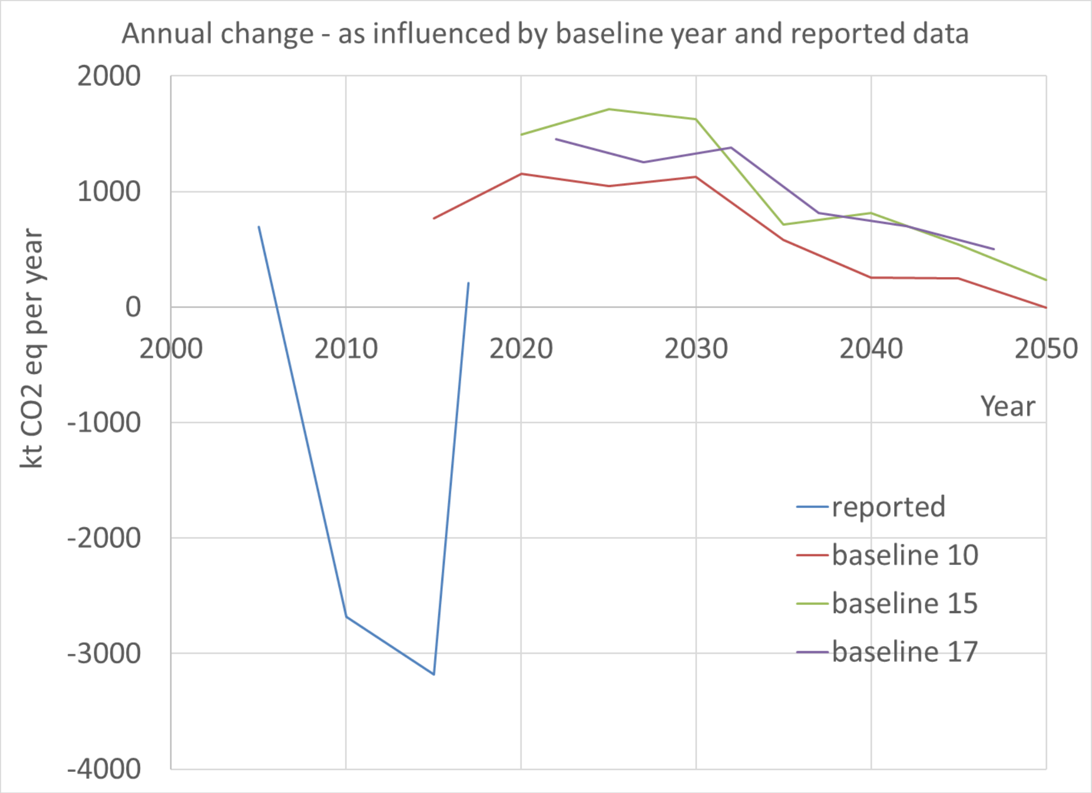

Figure 45 Development of annual change in sum of carbon pools (above ground, below ground, dead wood and forest floor) in kt CO_2 eq per year. The labels indicate the baseline year – 2010, 2015 or 2017. Reported data for 2005-2017 are included for the same pools.

The sensitivity to baseline year have been tested, applying baseline data from 2015 and 2017 as alternative starting points for the estimation of FRL. Even though there are differences in the numbers, the overall pattern in annual changes are similar regardless of baseline year (Figure 45). The variation based on baseline year is less than the potential variation caused by variation in survival rates. In comparison with the reported numbers for annual change (5 year mean) in the period 2005 – 2015 a sink have been reported. This is also reflected in the data in Table 7, with the higher total stock in 2015 than predicted with the FRL.

Other national projections

Previously the assessments of future development of the forest sector according to the UN guidelines and it's emissions or sink were conducted without addressing the issue of the changing area, especially caused by afforestation. Some of these have been reported under Regulation (EU) No 525/2013, on anthropogenic greenhouse gas emissions and predictions. A comparison of the national projections under No 525/2013 and the estimation of the FRL in the present National Forest Accounting Plan are provided in the table and figure below. The differences in the originally reported figures and the NFAP projections are caused by differences in handling of the changing area and the transfer of the stock caused by this. In the table and the figures corrected and comparable numbers are given, and providing a consistent set of projections for the forest area including afforestation older than 20 year old. Different growth models were applied for the afforestation younger than 20 year in the previous predictions than expected in the present NFAP.

Table 19 Comparison of national projections under No 525/2013 (NP-FRF+AF>20 – forest remaining forest and afforestation older than 20 year, NP-AF<20 – afforestation younger than 20 year). With FRL from the present report (NFAP-FRF+AF>20 – forest remaining forest and afforestation older than 20 year, NFAP-AF<20 – afforestation younger than 20 year, NFAP-HWP – harvested wood pool). The Corr NP-FRF+AF>20 and Corr-NP-AF<20 handles transfer of afforestation area to the FRF category as in the NFAP and described in Annex 9.5.3.

	2015-2020	2020-2025	2025-2030	2030-2035
NFAP-FRF+AF>20	667	545	510	-68
NFAP-AF<20	-175	-151	-114	-77
NFAP-HWP	-241	-192	-152	-152
NP-FRF+AF>20	-458	-758	-707	-1.316
NP-AF<20	-103	-468	-509	-903
Corr-NP-FRF+AF>20	455	228	199	-667
Corr-NP-AF<20	-1.015	-1.455	-1.415	-1.552

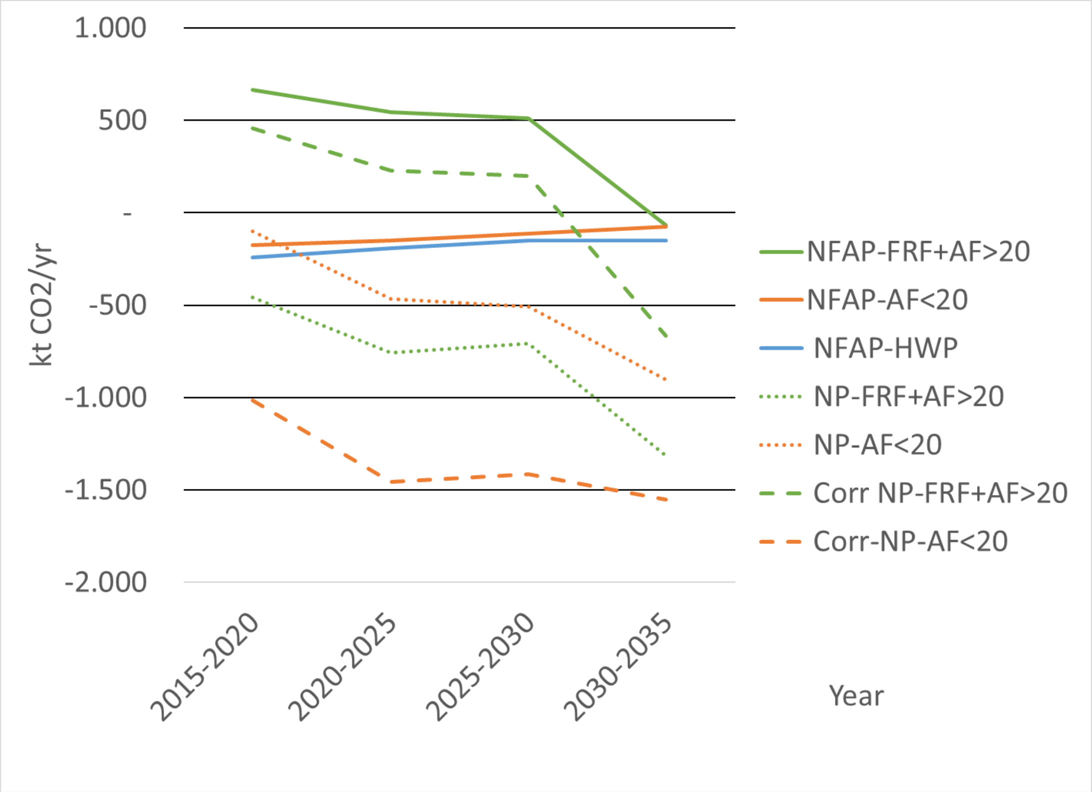

Figure 46 Comparison of national projections under No 525/2013 (NP-FRF+AF>20 – forest remaining forest and afforestation older than 20 year, NP-AF<20 – afforestation younger than 20 year). With FRL from the present report (NFAP-FRF+AF>20 – forest remaining forest and afforestation older than 20 year, NFAP-AF<20 – afforestation younger than 20 year, NFAP-HWP – harvested wood pool). The Corr NP-FRF+AF>20 and Corr-NP-AF<20 handles transfer of afforestation area to the FRF category as in the NFAP and described in Annex 9.5.3.

9.6.3 Sensitivity to silvicultural practices and harvest rates

An extensive analysis of impact of a variety of silvicultural practices and harvest rates, i.e. forest management alternatives, was performed by Graudal et al (2014), including a number of different forest management alternatives. The influence on carbon stock in the forest as well as on total harvest and harvest distribution to use wood and fuel wood were assessed. The basic modelling approach is similar to the estimation in the current report, only the transition probabilities are the same as used in the FMRL estimation for the second Kyoto Commitment period (as reported in Johannsen et al 2011).

The forest management alternatives constituted by a number of silvicultural activities were evaluated. The silvicultural practices evaluated are summarised in Table 20.

Table 20 Silvicultural practices evaluated (based on Graudal et al 2014, table 3.1)

Forest management initiative	Description
BAU – business as usual	Afforestation of 1900 ha yr^{-1}
Afforestation – medium	Afforestation of 2280 ha yr^{-1}
Afforestation – high	Afforestation of 4560 ha yr^{-1}
No afforestation	Afforestation of 0 ha yr^{-1}
Afforestation – broadleaved	Afforestation with only broadleaved
Afforestation – conifers	Afforestation with only conifers
Lower age by regeneration	10 years earliere regeneration
Higher age by regeneration	20 years later regeneration for broadleaved, and 5 years longer for conifers
Regeneration with conifers	In addition to conifer to conifer, the regeneration of broadleaved are 50 % regenerated with conifers
Regeneration with broadlaeved	In addition to broadleaved to broadleaved, the regeneration of conifers are 50 % regenerated with broadleaved
Nurse trees – supplementary plant	By afforestation and regeneration, supplementary plants are planted to assist the long term crop trees. The supplementary trees are harvested by age 20-30 for fuel wood.
Set aside forest area – 5 %	46.100 ha of broadleaved forest area are set aside and not available for wood supply
Set aside forest area – 25 %	50 % of broadleaved forest area are set aside and not available for wood supply
Set aside forest area – 50 %	100 % of broadleaved forest area are set aside and not available for wood supply
Heavy harvest – lower stock	10 % lower stock and 10 % increase of harvest
Lower harvest – higher stock	10 % higher stock and 10 % lower harvest
Assortment for fuel	Harvest with a higher degree of utilisation
Assortment for fuel in conifers	Higher degree of utilization for conifers, lower for broadleaved
Breeding for better plants	Breeding and utilisation of improved plant material for regeneration and afforestation
Intensive breeding for better plants	Intensive breeding efforts and utilisation of improved plant material for regeneration and afforestation

The analysis provided effect of the simulation over a period of 80 years, on the effects on total harvest, and the assortments to fuel and use wood (Table 21) as well as carbon in the above ground biomass and the composition of the forest area by broadleaved and conifers (Table 22). The overall result is that the silvicultural practices can have a major impact on both harvest and carbon stock of the forest, especially in the long run (30-80 years). Rate of afforestation, species choice as well as breeding can have a large effect, especially if combined. In addition, the use of set-aside areas will influence the resulting stock, as well as the amount of harvest volumes.

In relation to the current report and the forest reference level, the analysis by Graudal et al (2014) highlights the potential impact of changes in silvicultural practices in the period of focus here 2021-2030. The time since the reference period (2000-2009) is relatively short in terms of changes in silvicultural practices, which could indicate that only moderate effects of such changes will influence the reporting in the period 2021-2030.

Table 21 Effect of silvicultural practices on total harvest, fuel wood and use wood (based on Graudal et al 2014, table 3.3).

Relative to business as usual	Total harvest			Fuel wood			Use wood		
	2020	2050	2100	2020	2050	2100	2020	2050	2100
BAU – business as usual	100	100	100	100	100	100	100	100	100
Afforestation – medium	100	101	104	100	102	104	100	101	104
Afforestation – high	100	108	127	100	113	131	100	105	125
No afforestation	100	94	80	100	91	78	100	96	82
Afforestation – broadleaved	100	100	98	100	102	102	100	98	96
Afforestation – conifers	100	101	104	100	98	99	100	104	108
Lower age by regeneration	103	98	100	103	100	101	103	97	99
Higher age by regeneration	97	98	98	98	98	100	96	98	96
Regeneration with conifers	100	101	103	100	99	101	100	102	105
Regeneration with broadlaeved	100	101	100	100	108	107	100	95	96
Nurse trees – supplementary plant	100	115	113	100	135	132	100	100	100
Set aside forest area – 5 %	87	96	97	88	91	95	87	100	99
Set aside forest area – 25 %	67	75	82	72	75	80	65	75	84
Set aside forest area – 50 %	49	51	57	43	50	57	52	51	58
Heavy harvest – lower stock	111	112	112	112	112	112	111	111	111
Lower harvest – higher stock	89	88	88	88	88	88	89	89	89
Assortment for fuel	115	118	117	183	188	185	67	66	67
Assortment for fuel in conifers	112	114	113	157	162	159	79	79	80
Breeding for better plants	100	101	113	100	102	115	100	101	112
Intensive breeding for better plants	100	103	119	100	104	121	100	102	118

Table 22 Effect of silvicultural practices on carbon in above ground biomass, area of broadleaved and coniferous forest (based on Graudal et al 2014, table 3.3).

Relative to business as usual	Carbon in above ground biomass			Area of broadleaved			Area of conifers		
	2020	2050	2100	2020	2050	2100	2020	2050	2100
BAU – business as usual	100	100	100	100	100	100	100	100	100
Afforestation – medium	100	101	104	101	103	105	100	102	104
Afforestation – high	101	109	129	105	119	136	103	113	127
No afforestation	100	94	79	97	87	74	98	90	81
Afforestation – broadleaved	100	100	102	103	110	120	98	90	81
Afforestation – conifers	100	100	94	97	87	74	103	112	125
Lower age by regeneration	97	96	97	100	100	100	100	100	100
Higher age by regeneration	100	103	100	100	100	100	100	100	100
Regeneration with conifers	100	100	96	97	88	74	103	112	126
Regeneration with broadleaved	101	104	120	110	136	155	91	66	46
Nurse trees – supplementary plant	101	108	107	100	100	100	100	100	100
Set aside forest area – 5 %	105	111	106	100	100	100	100	100	100
Set aside forest area – 25 %	106	119	115	100	100	100	100	100	100
Set aside forest area – 50 %	106	123	132	100	100	100	100	100	100
Heavy harvest – lower stock	96	90	90	100	100	100	100	100	100
Lower harvest – higher stock	105	110	110	100	100	100	100	100	100
Assortment for fuel	100	100	100	100	100	100	100	100	100
Assortment for fuel in conifers	100	100	100	100	100	100	100	100	100
Breeding for better plants	100	101	110	100	100	100	100	100	100
Intensive breeding for better plants	100	102	114	100	100	100	100	100	100

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