

Danish National Forest Accounting Plan 2021-2030

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and Lars Vesterdal

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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 gives a description of the accounting for greenhouses gasses related to forestry. The perspective on sustainable forest management is described by forest regulation and policies as well as by giving a 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 utilized as baseline (reference level) for the Danish accounting for forests.

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Abbreviations

FRL	Forest Reference Level (EU 2018 Regulation)
FMRL	Forest Management Reference Level (Kyoto Reporting period)
HWP	Harvested Wood Products (include 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 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 greenhouse gas 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 characterized 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 in the Ministerial Conference on the Protection of Forest in Europe (Forest Europe 2015) while achieving the objectives of the Paris Agreement and meeting the greenhouse gas 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.

1.1 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). 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 given in Chapter 8.5.1.

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 CO₂ equivalent per year (CO₂ eq Y⁻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 illustration only.

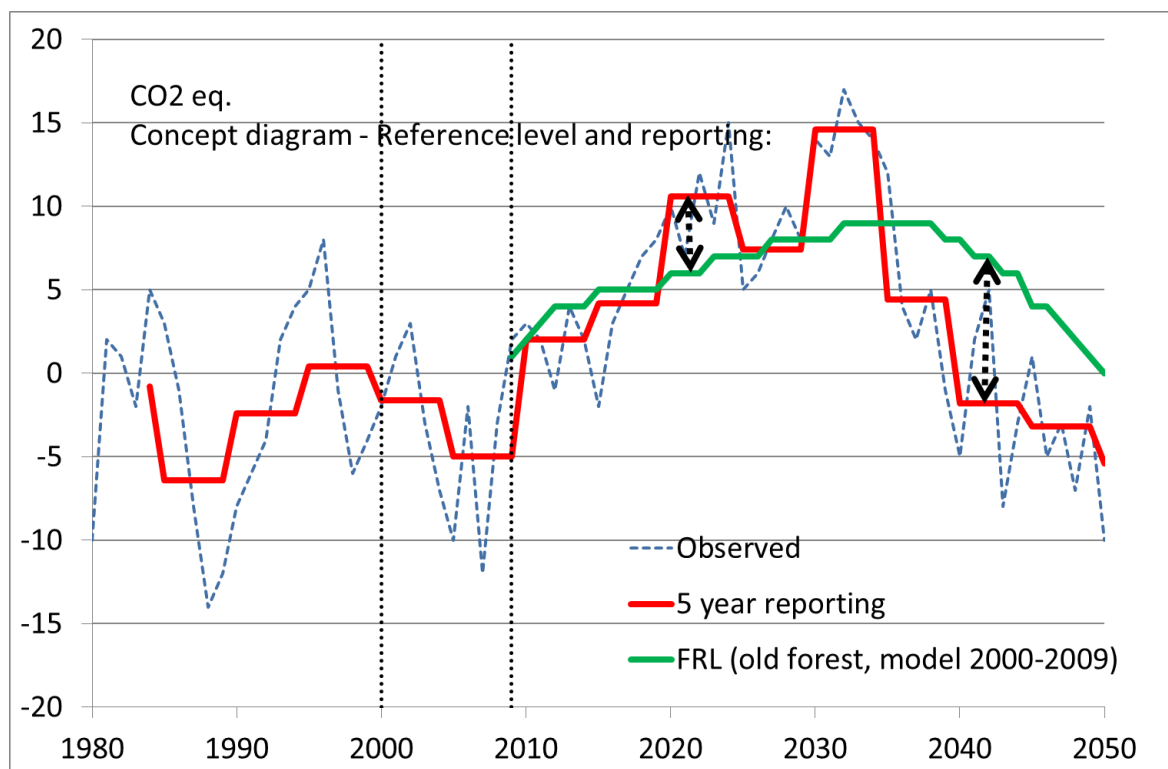


Figure 1 Concept figure on the Forest Reference Level (FRL) and the relation to reporting based on example data for illustration purpose. The blue dotted line indicates observed annual emissions (positive) or uptake (negative). The red full line indicates 5 year reporting values. The green full line indicates the results of a FRL for the old 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).

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 e.g. 30 year in a reporting year will subsequently be included in the FRL and no longer contribute to the afforestation pool.

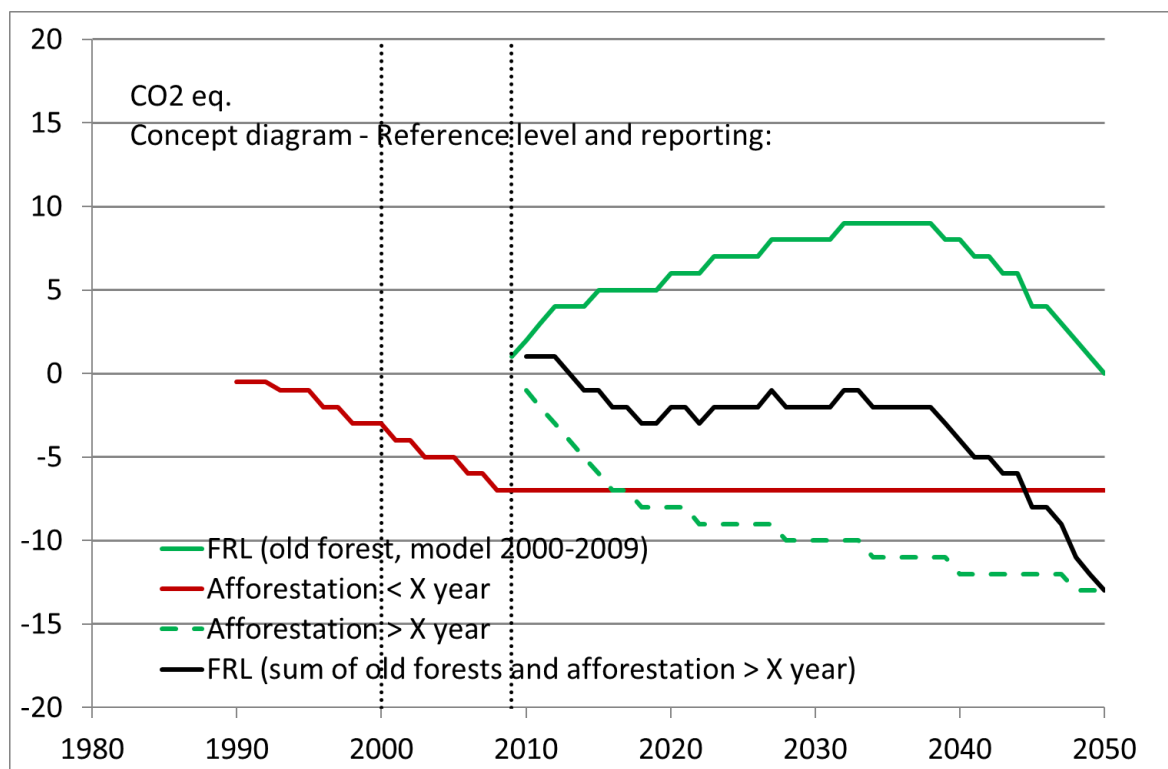


Figure 2 Since the Forest Reference Level (FRL) will include afforestation over a certain age (X - 20 or 30 years) this concept figure indicate the components of this. The green full line indicates the results of a FRL for the old forest, based on the reference period 2000-2009. The dotted green line indicates FRL for the afforestation older than X years. The full black line represents the overall FRL combining old 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, are related to Article 8 and 9 as well as the related Annex IV and V. These can be summarized 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 guidance 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 in the Regulation is addressed in the Danish NFAP is provided in Annex: "Cross reference - EU Regulation & DK-NFAP" on page 69, specifically in Table 7.

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).

1.2 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.

Chapter 2 "Carbon pools and greenhouse gasses", addresses point 1 above.

Chapter 3 "Forest regulation and policies" addresses point 2, whilst Chapter 4 "Danish Sustainable Forest Management" addresses point 3.

Chapter 5 "Forest Reference Level" addresses the remaining points of the list, for each of the categories: Forest land (5.1), Afforested land (5.2), Harvested Wood Products (5.3) and Deforestation (5.4). 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 6 "Conclusion and summary" and the cross reference to full specification in the Regulation are given in Annex 8.1 "Cross reference - EU Regulation & DK-NFAP".

2 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.

2.1 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).

2.1.1 Carbon dioxide (CO₂)

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.

2.1.2 Methane (CH₄)

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 CH₄ 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 5 for values).

2.1.3 Nitrous oxide (N₂O)

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 mole of N₂O.

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 5 for values).

2.2 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.

2.2.1 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 m³ to dry mass and subsequently converting dry mass to carbon amount (Nord-Larsen & Johannsen 2016, pg. 16 ff.).

2.2.2 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.).

2.2.3 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.).

2.2.4 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).

2.2.5 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 Y⁻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 CO₂ 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 ($0.21 \text{ tC ha}^{-1} \text{ Y}^{-1}$ 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.

2.2.6 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 5.3).

2.3 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), see also Annex 8.5.1 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.

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.

2.4 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.

3 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.

3.1 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 §1¹ "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 publically 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

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 8.2.

3.2 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 & Præstholt 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.

3.3 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 5.3 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 estimate 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 5.3).

3.4 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.

4 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 5.

4.1 Forest area, history and owner structure

The current forest area (2016) is estimated to 624,676 ha or 14.5 % of the land area. With a mapping of forest area based on satellites, the forest area has increased with 80,135 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 44,394 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).

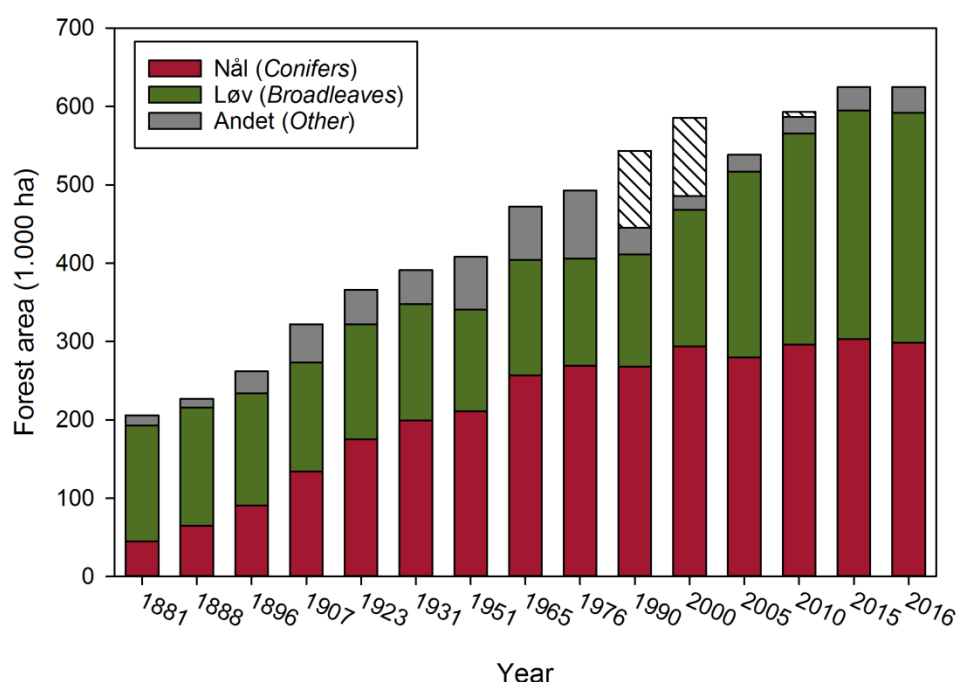


Figure 3 Forest Area development in Denmark 1881-2016. The forest area is distributed to broadleaves, conifers and other. “Other” includes unstocked areas in forests and areas where the species is unknown. Before 2005, the estimates are based on questionnaire surveys. The three hatched areas show the 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).

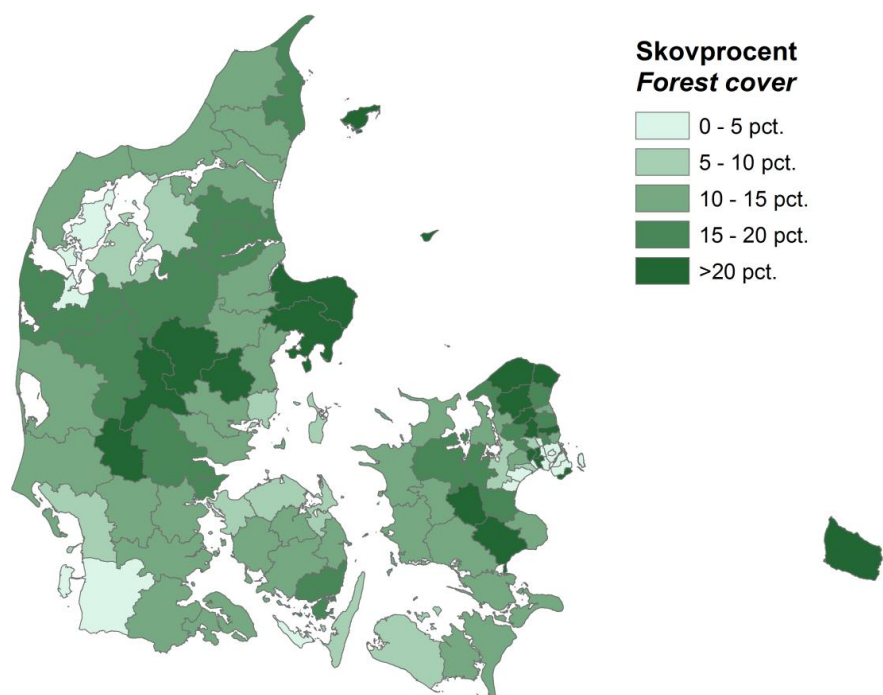


Figure 4 Forest area percentage for individual municipalities.

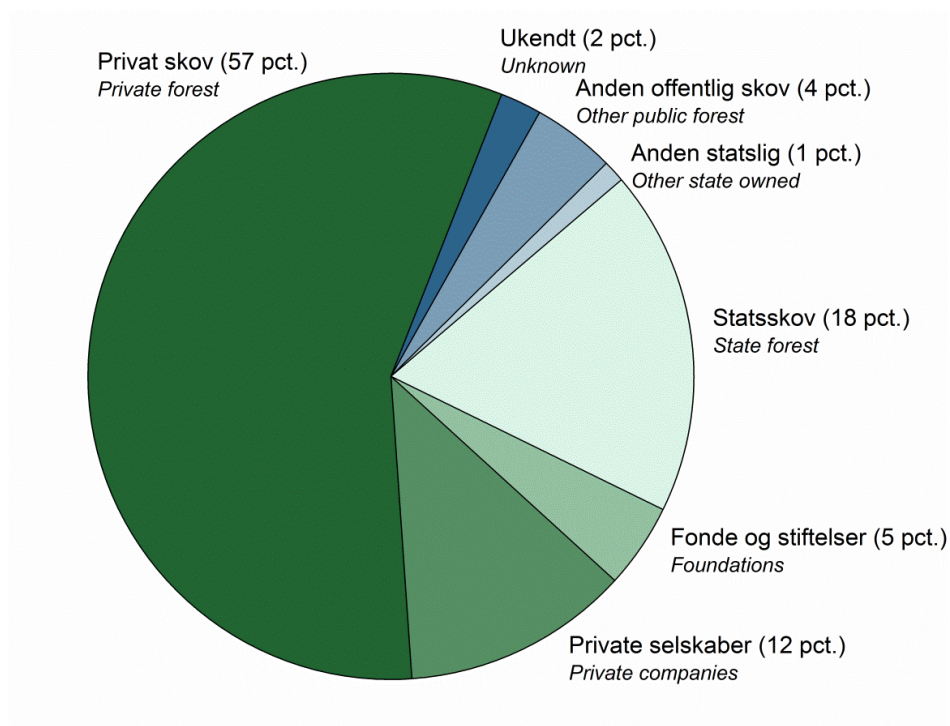


Figure 5 Distribution of forest area by types of ownership.

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 aims for biodiversity 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 2.2 and 5.2 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.

4.2 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).

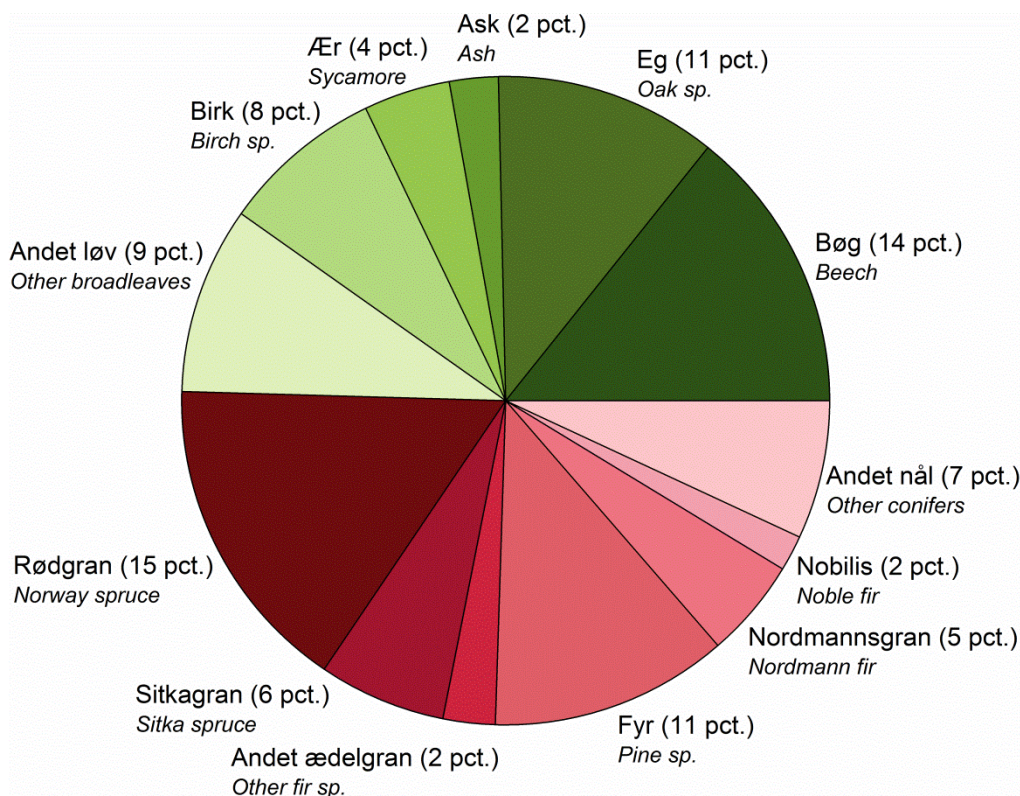


Figure 6 Distribution of the forest area by tree species. Percentages refer to the species share of the total forest area. In addition to this, unstocked areas account for 4.7 % of the area and areas with unknown species account for 0.5 %.

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).

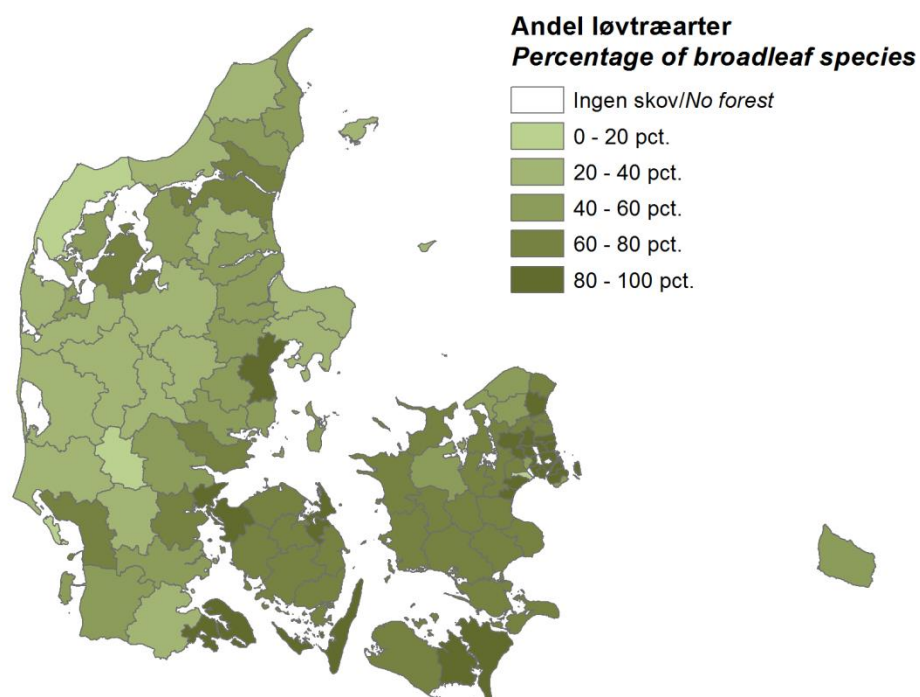


Figure 7 Percentage of broadleaved forest cover for individual municipalities. While broadleaved dominate the forests in the eastern parts of the country, conifers dominate in the western parts.

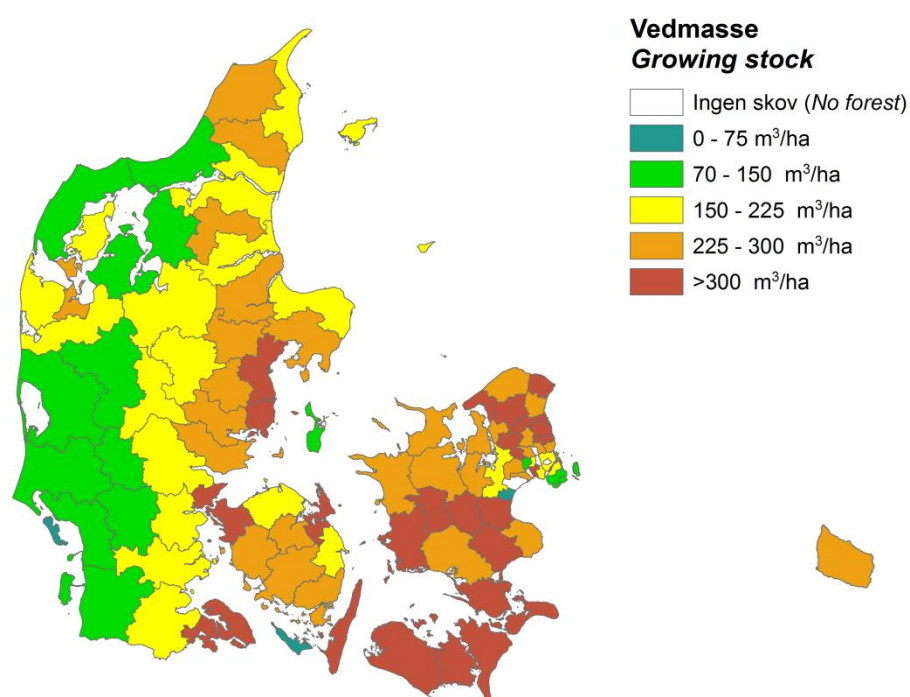


Figure 8 Average growing stock per hectare for different municipalities. Municipalities where no forest was observed within the sample plots are marked as "No forest".

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 are 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.

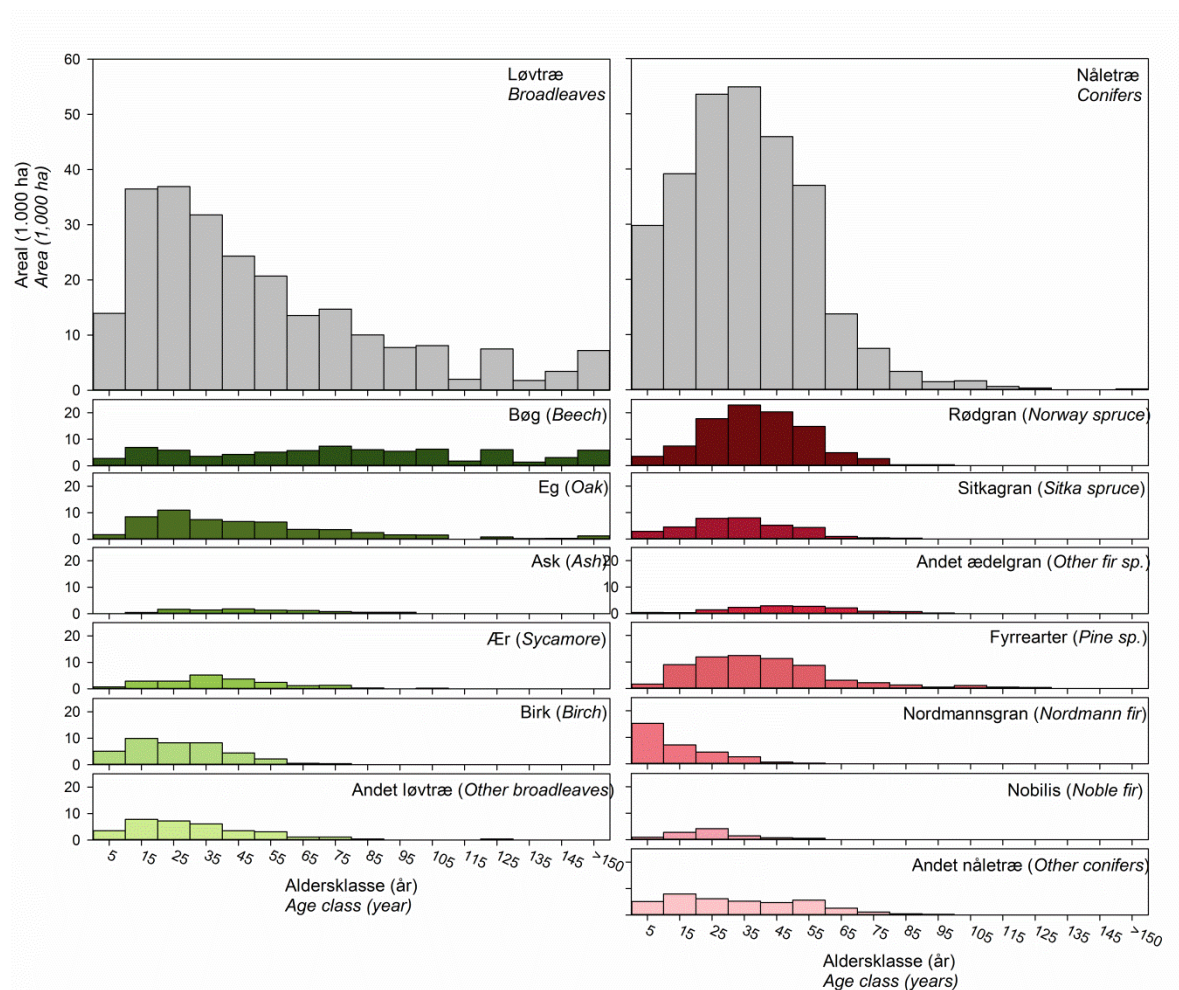


Figure 9 Age class distribution for broadleaves and conifers (in 1,000 ha).

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.

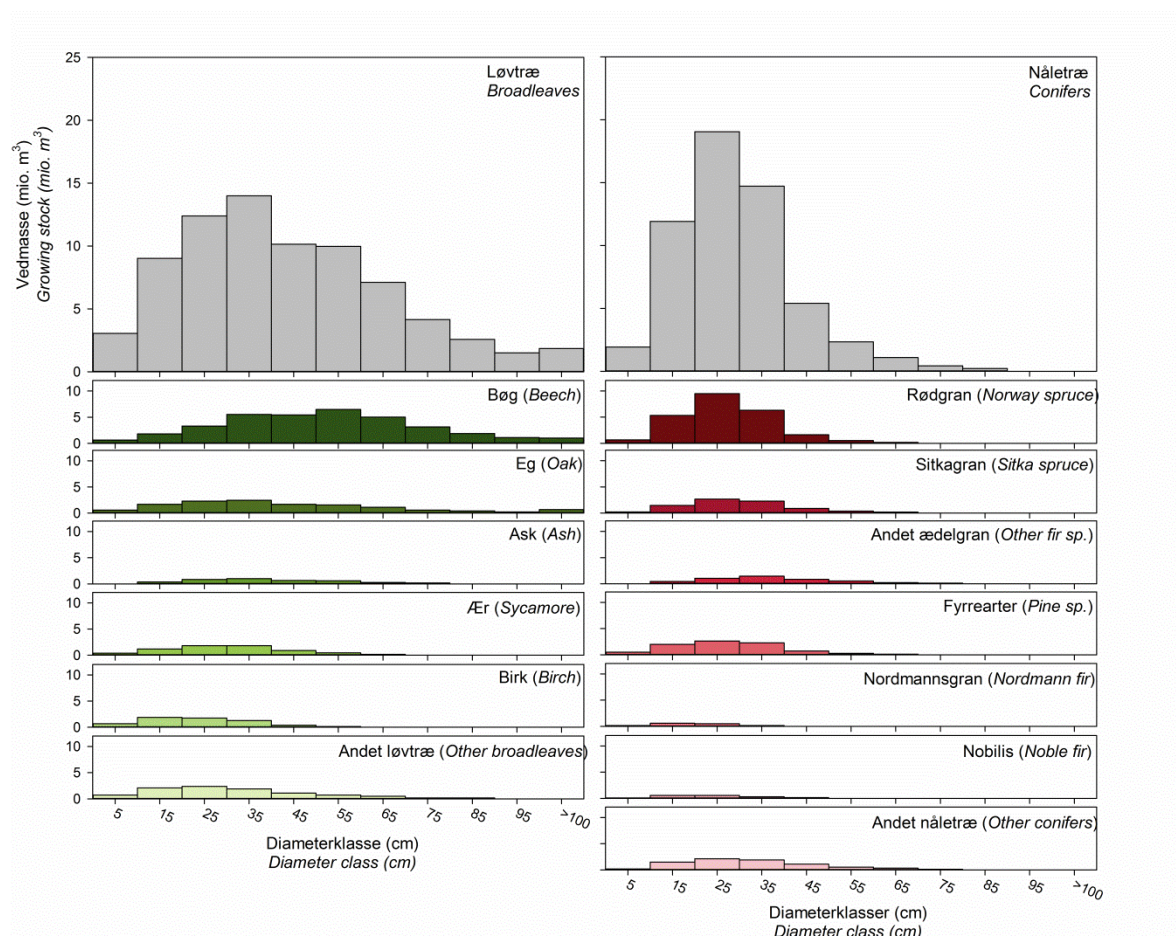


Figure 10 Distribution of growing stock (mio. m³) to diameter classes (cm) according to tree breast height diameter for different tree species and tree species groups.

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).

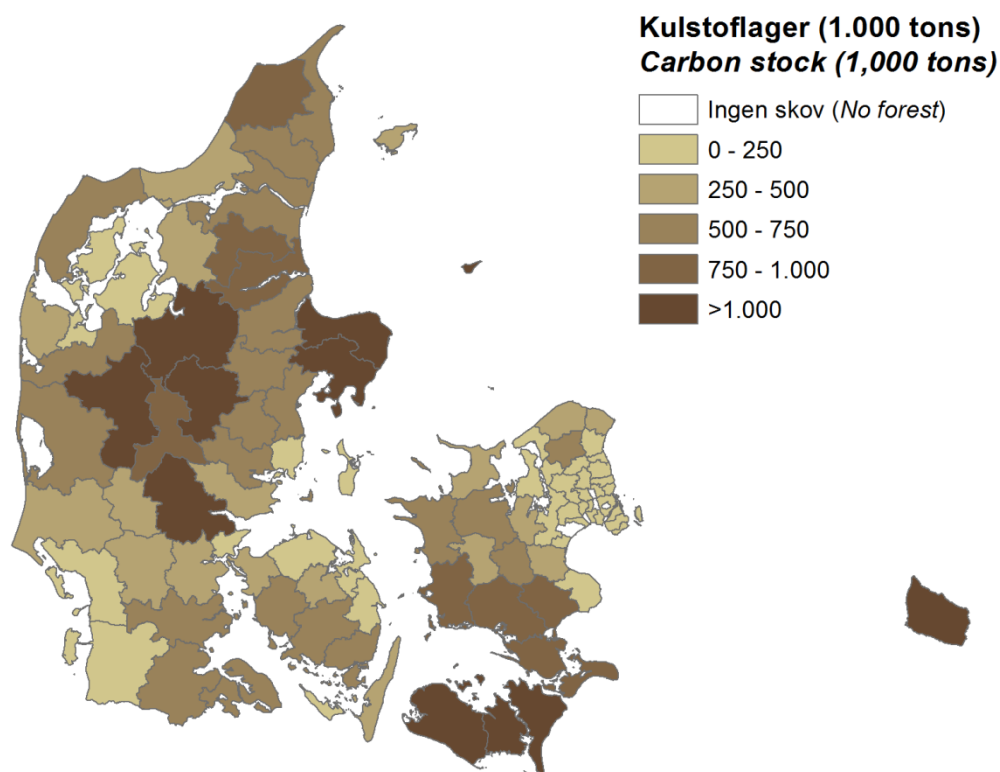


Figure 11 Geographical distribution of carbon stocks in living biomass (in 1,000 t).

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 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 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.

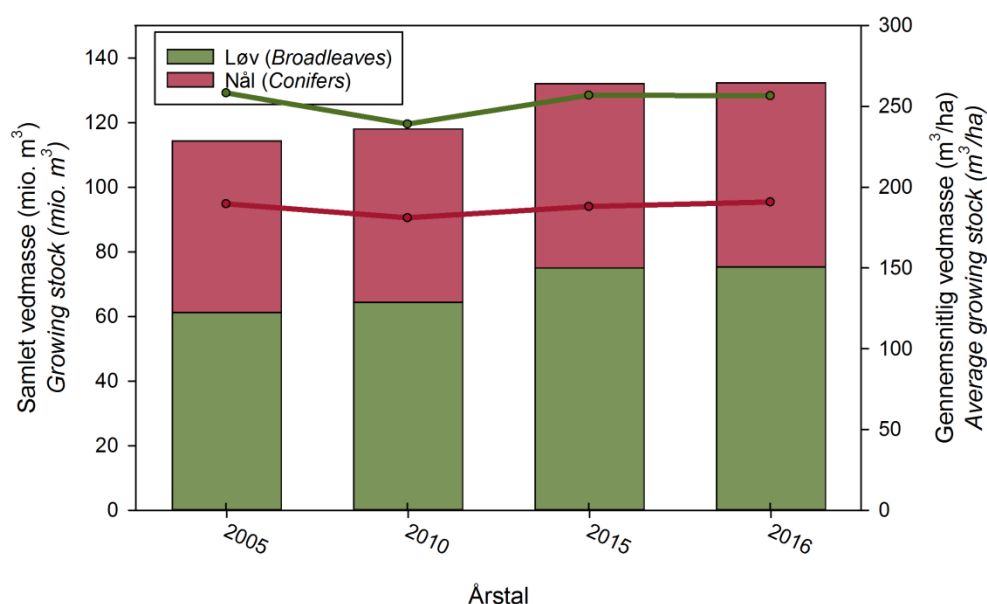


Figure 12 Development in growing stock (bars) and average growing stock per hectare (lines), distributed to broadleaves and conifers.

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.

4.3 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 $9.6 \text{ m}^3 \text{ ha}^{-1} \text{ Y}^{-1}$, with total removals (harvested, wind throw, dead, and missing) of $7.3 \text{ m}^3 \text{ ha}^{-1} \text{ Y}^{-1}$, resulting in a net increment of $2.3 \text{ m}^3 \text{ ha}^{-1} \text{ Y}^{-1}$. The Gross increment varies over the country with a minimum of $8.9 \text{ m}^3 \text{ ha}^{-1} \text{ Y}^{-1}$ in the middle of Jutland and a maximum of $12.5 \text{ m}^3 \text{ ha}^{-1} \text{ Y}^{-1}$ on Zealand. The net increment varies from 0 in the Capital region to $4 \text{ m}^3 \text{ ha}^{-1} \text{ Y}^{-1}$ 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.

4.4 Harvest rates and assortments

The total volume of removals² including harvested, wind thrown, dead, and missing trees, is to $7.3 \text{ m}^3 \text{ ha}^{-1} \text{ Y}^{-1}$. The harvest rates vary among regions, spanning from $5.2\text{-}7.1 \text{ m}^3 \text{ ha}^{-1}$ with the maximum in the Capital region and the lowest value in the northern part of Jutland. On average, the harvest rates are $5.8 \text{ m}^3 \text{ ha}^{-1}$ (Indicator 3.1 Forest Europe).

In total, the NFI estimates the total harvest to be $3.5 \text{ mill. m}^3 \text{ Y}^{-1}$ and the missing volume to be $0.4 \text{ mill. m}^3 \text{ Y}^{-1}$. Assuming that the missing volume has been harvested, this amounts to $3.9 \text{ mill. m}^3 \text{ Y}^{-1}$, which is comparable to the harvest assessment performed by Statistics Denmark, reporting an annual total harvest of $3.9 \text{ mill. m}^3 \text{ Y}^{-1}$ 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 an underestimation of the actual harvest in the Danish forests.

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.

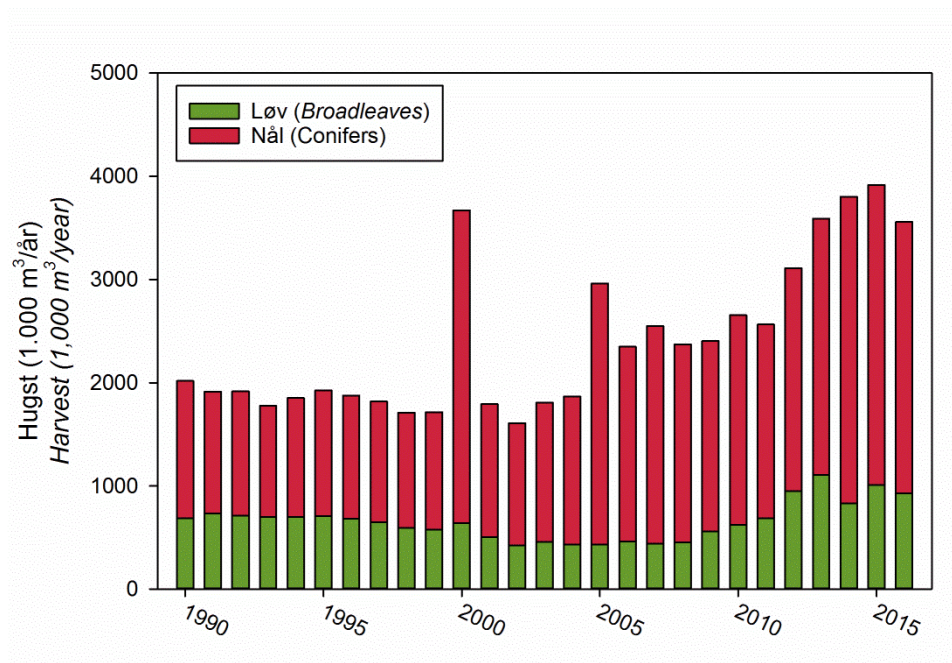


Figure 13 Total harvested volume of broadleaves and conifers reported as sold from the forests (Statistics Denmark: Statistikbanken.dk/SKOV6). Note that the development both reflects a change completeness in the survey (increasing number of respondents from 2000 on onwards) and a change in method from 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 3.3), 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.

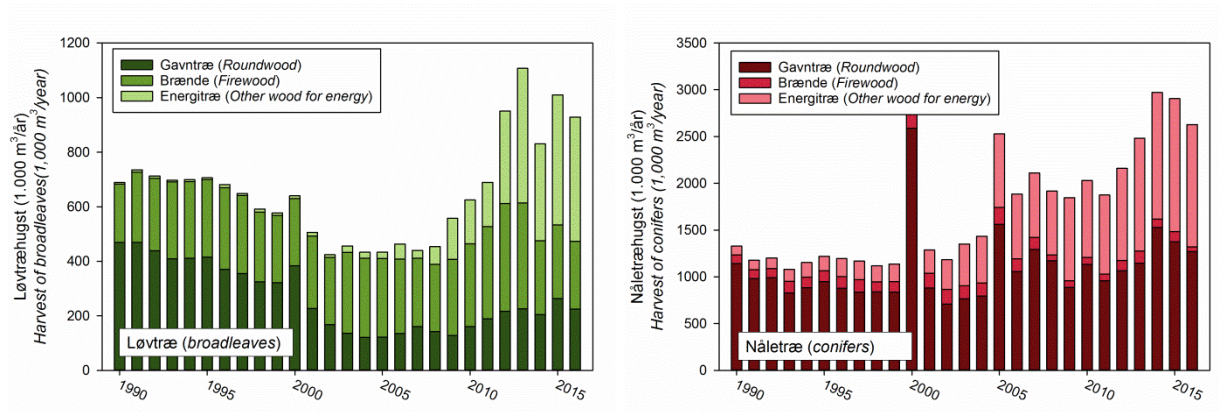


Figure 14 Total harvested volume of broadleaves (green) and conifers (red) distributed to different assortments (Statistikbanken.dk/SKOV6). Note also here the changes in population and method mentioned earlier applies, as well as the basis for the graphs being traded products from the forests.

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 (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 3.1) 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 3.4), 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 entering cessation of 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.

4.5 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 4.2).

The history of the Danish forest area, with continued afforestation (see chapter 4.1), 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.

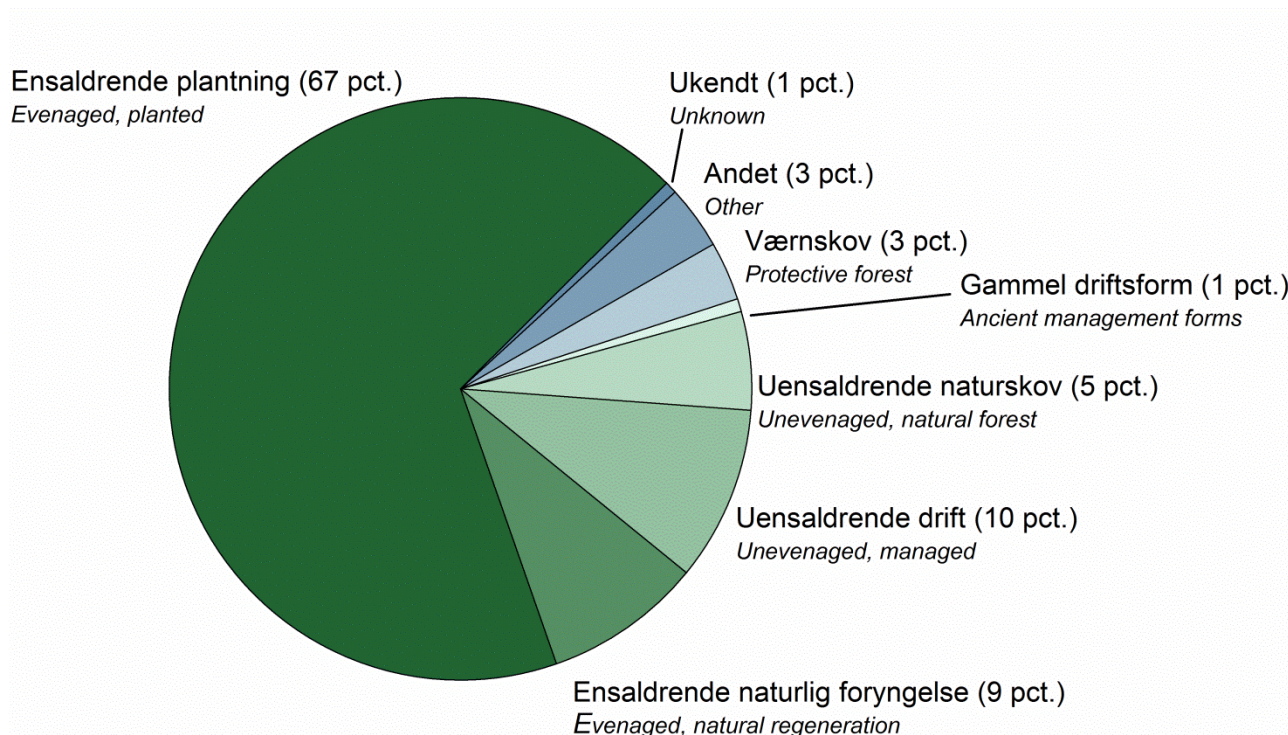


Figure 15 Distribution of the forest area to management types. The percentages are of the total forest area, excluding the 2 % auxiliary areas. Temporarily unstocked areas are part of the even-aged, planted area.

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 are 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 Fødevarerministeriet 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 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.

4.6 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).

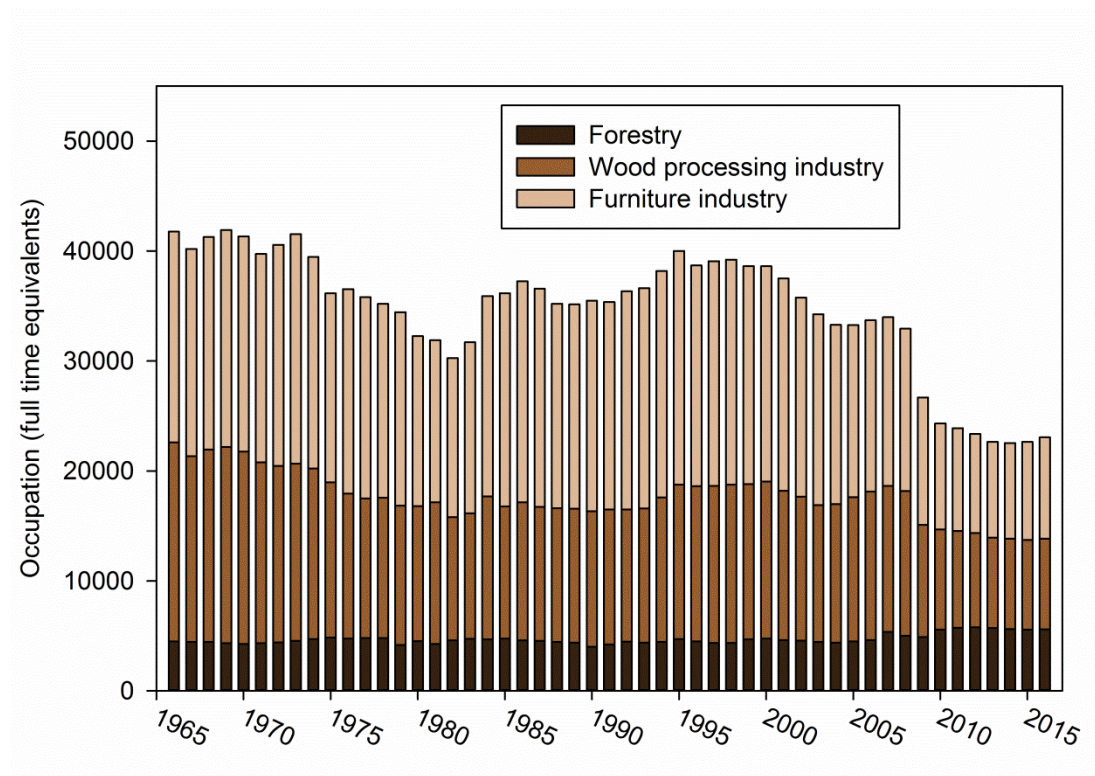


Figure 16 Occupation in the forestry sector and associated industry 1966-2016 (Statistikbanken.dk/NABB117).

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.

5 Forest Reference Level

To increase the transparency and documentation of all elements of the FRL, the construction is divided into 4 main parts. Each part addresses crucial issues for FRL estimation:

- Forest land - the area that has been forest before 1990. This area was identified in the land-use mapping and is stable on terms of forest management. This area formed the basis for the FMRL in the Kyoto commitment period. This area constitutes more than 85 % of the total forest area, based on the assessment in 2010 in combination with satellite based forest mapping of the forest area in 1990.
- Afforested land - the area that was afforested since 1990. The area is characterized by a large variation in tree species, soil, and forest management practices combined with differences in ownership and subsidy schemes selected. It takes time for the new forest to reach a stable condition in terms of carbon balance. An age of 30 years is applied here, as duly justified based on the IPCC guidelines. Only the share of the afforestation older than the age set for the stable conditions, will be included in the estimation of the FRL. The youngest part of the afforestation will be outside the FRL.
- Harvested Wood Products - the wood pool outside of the forest land that is 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.
- Deforestation - occurring in the period 1990 - 2016. Will influence the forest land and afforested area. Wood harvested from deforestation does not contribute to the HWP pool according to the IPCC Guidelines (IPCC 2014). Deforestation is included in the estimation of the FRL. If the reported deforestation deviates from the deforestation included in the FRL estimate, a technical correction will be submitted, 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 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. These analyses are not included in this report, but are briefly mentioned.

The tables below give a summary of the FRL and the components. The data, stratification, methods, sub results and validation are described in the subsequent sections. Table 1 gives the main results, with a 30 year transition period. The annual rate of afforestation in the period 2021-2030 affects the estimated accounts separate from the reference level. In the tables below an annual afforestation rate of 1.900 ha/year is expected. In Annex 8.4.3 similar tables are presented applying an annual afforestation rate of 3.200 ha/year.

Table 1 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)	150.024	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)	757	1.084	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)	16,92	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
Σ soils emissions (kt CO ₂ eq Y ⁻¹)	168	168	168	168	168	168	168	168
Stock change + Σ soils emissions ** (kt CO₂ eq Y⁻¹)	925	1.252	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 Y ⁻¹)	0	-176	-958	-1,076	-1,176	-1,270	-965	-886
Carbon stock transfer ** # (AG+BG+DW+FF) (kt CO ₂ eq Y ⁻¹)	0	314	786	786	791	798	399	406
Carbon accumulation - soil (kt CO ₂ eq Y ⁻¹)	0	-2	-11	-19	-28	-37	-43	-47
CO2 from drained soils (kt CO ₂ eq Y ⁻¹)	0	5	17	29	41	56	62	67
N2O drained organic soils (kt CO ₂ eq Y ⁻¹)	0	1	2	4	6	8	9	9
CH4 drained and rewetted organic soils (kt CO ₂ eq Y ⁻¹)	0	0	0	1	1	1	1	1
Σ soils emissions (kt CO ₂ eq Y ⁻¹)	0	4	9	14	20	27	29	31
Stock change + Σ soils emissions + transfer ** (kt CO₂ eq Y⁻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 Y ⁻¹)	-283	-710	87	122	225	365	77	0
Carbon stock transfer** # (AG+BG+DW+FF) (kt CO ₂ eq Y ⁻¹)	0	-314	-786	-786	-791	-798	-399	-406
Carbon loss from conversion (kt CO ₂ eq Y ⁻¹)###	49	42	42	42	42	42	42	42
Carbon accumulation - soil (kt CO ₂ eq Y ⁻¹)	-43	-45	-41	-37	-33	-28	-27	-27
CO ₂ from drained soils (kt CO ₂ eq Y ⁻¹)	46	46	39	32	24	15	13	13
N ₂ O drained organic soils (kt CO ₂ eq Y ⁻¹)	6	6	5	4	3	2	2	2
CH ₄ drained and rewetted organic soils (kt CO ₂ eq Y ⁻¹)	1	1	1	1	1	0	0	0
Σ soils emissions (kt CO ₂ eq Y ⁻¹)	52	50	46	42	37	31	30	30
Stock change + Σ soils emissions s + transfer** (kt CO₂ eq Y⁻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 CO₂ eq Y⁻¹)	499	26	26	26	26	26	26	26
V: Harvested Wood Products								
HWP (kt CO₂ eq Y⁻¹)**	-95	-95	-180	-117	-100	-100	-100	-100
Forest Reference Level 30 year								
I + II ** (kt CO₂ eq Y⁻¹)	925	1.394	1.048	1.017	384	-23	-121	-288
I + II + V ** (kt CO₂ eq Y⁻¹)	830	1.299	868	901	284	-123	-221	-388
Total forest sector								
I+II+III+IV+V** (kt CO₂ eq Y⁻¹)	1.106	350	241	305	-219	-500	-488	-738

* 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 (31. December) and is transferred by the beginning of the next year (1. January).

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.

5.1 Forest land

Forest land comprises 85 % of the forest area and was established before 1990. This area includes afforestation from the period 1805 - 1990 and in relation to the FRL, considered one entity. The age structure and species composition (as described in chapter 4) is quite varied. Below, the FRL components for this area are described.

Initial analyses indicated that a robust and transparent method is needed, focusing on stock change, utilizing available data in the reference period (2000-2009) and utilizing the data in the period 2010-2017 to produce robust estimation of age related dynamics for survival of stands, but ensuring full consistency with the development observed in the reference period. The initial analyses included:

- Single tree growth, mortality and harvest models,
- Models of increment, survival, mortality and harvest by management classes,
- Markov models based on age, diameter and volume classes as well as site and owner classifications.

Overall, most of the analyses documented that 1) forests have a long living ages (30-200 years) which is difficult to document with only sparse data from a 10-year period (2000-2009); 2) with limited data on the diversity of history, owners, species, silviculture and forest management practices models had to focus on key drivers to produce a robust and transparent estimation (elements of this described in Knudsen 2018).

The GHG emissions from soils are based on area estimates and annual emission factors (Nielsen et al. 2018; Nord-Larsen & Johannsen 2016) and share of area with organic soils, and soils influenced by changes in drainage status. The majority of the forest area is assumed to be no source of emissions from the soil.

5.1.1 Data

The NFI provides data for estimation of the FRL for the Forest land. The basic design of the NFI and the calculation methods are shortly described in Chapter 2 and 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 5 years, and hence the Danish NFI only now (in 2017) is on its 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 main 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.

For the permanent plots of the NFI, the successive measurements data for the plots 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 plots (as described in Chapter 2). 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 8.3.1 contains the input data and in Figure 17 below is given 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.

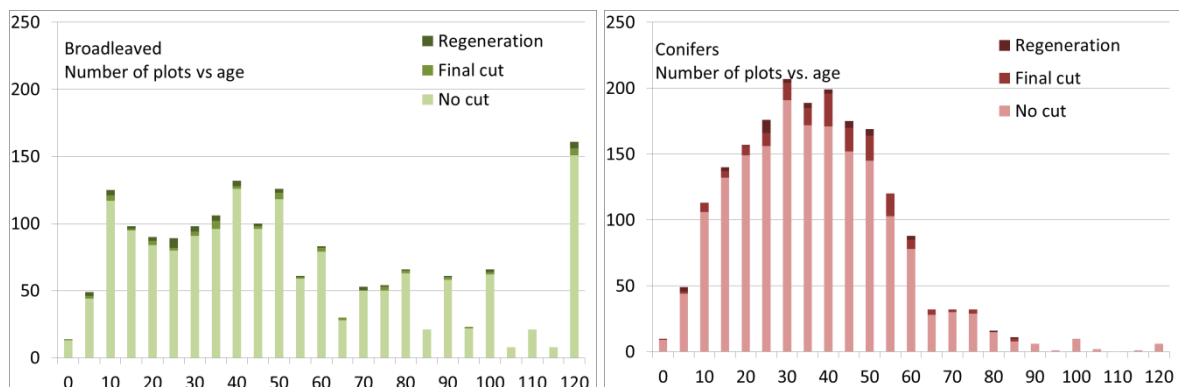


Figure 17 Data available for estimation of the survival model. NFI data for the period 2002 - 2017, 1941 observation for the conifers and 1743 for the broadleaved. The age class 120 of the broadleaved include stands of 120-200 years of age.

The state of the forest area by 2010 is used as the baseline for the expected development, in order to be in line with the reference period of the Regulation (EU 2018), i.e. 2000-2009. The baseline is given by forest area distribution to growth region, species group and 5-year age classes (in summary called management classes for stratification - see Table 2). The dataset 8.3.2 contains the baseline data and the age class distribution by 2010 is given in Figure 18 . The management classes are the same as used to model the survival times, based on data from the permanent plots, giving 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. The key parameter resulting from the forest management practices are the growing stock of each management class.

Table 2 gives the stratification classes of the forest area, to handle the forest management practices in the modelling of the forest reference level. This stratification gives a picture of the forest area of common growth and management regimes and secures a minimum number of sample plots for use as basis for the initialization for the FRL estimation. The stratification has been tested for different resolutions e.g. in age classes (1, 5 or 10 year age classes, span of 35 - 200 year) and species type (broadleaved/conifers/Christmas trees or more detailed). The choice of age class width of 5 years reflects a combination of need for iterating in 5 year time steps and the availability of data. In old age classes with low number of observations, the estimations of area and carbon pools are based on averages of 10 year age classes (e.g. values for age classes of 130 and 135 of broadleaved are based on the averages for the combined age class). The stratification finally selected resulted in the models with the lowest uncertainty, with the requirements of the reference period and the baseline for predictions being 2010.

Table 2 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
Age classes	5 year classes - 0 - 200	40

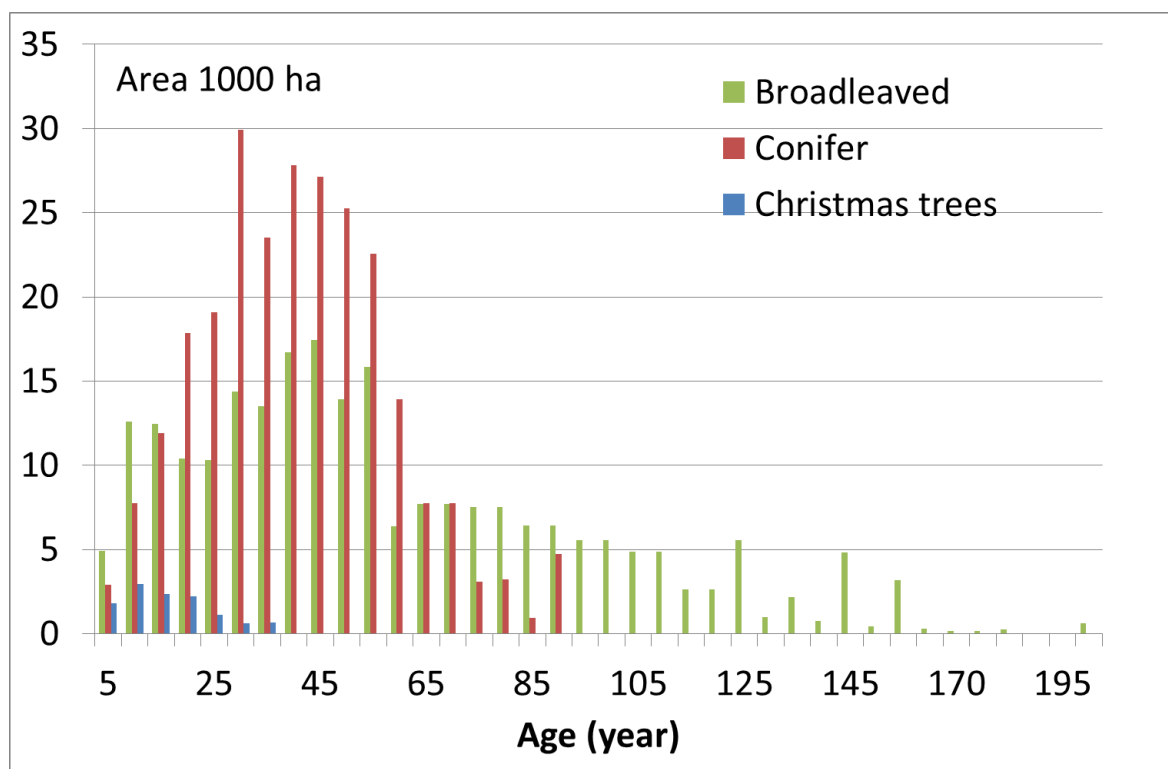


Figure 18 Age class distribution of the forest land area by 2010, by broadleaved, conifers and Christmas trees.

The 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. This reflects the forest management practices as they have been implemented until 2009. 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 8.3.2) and visualized in Figure 19. 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 $\text{m}^3 \text{ha}^{-1}$ in old age classes.

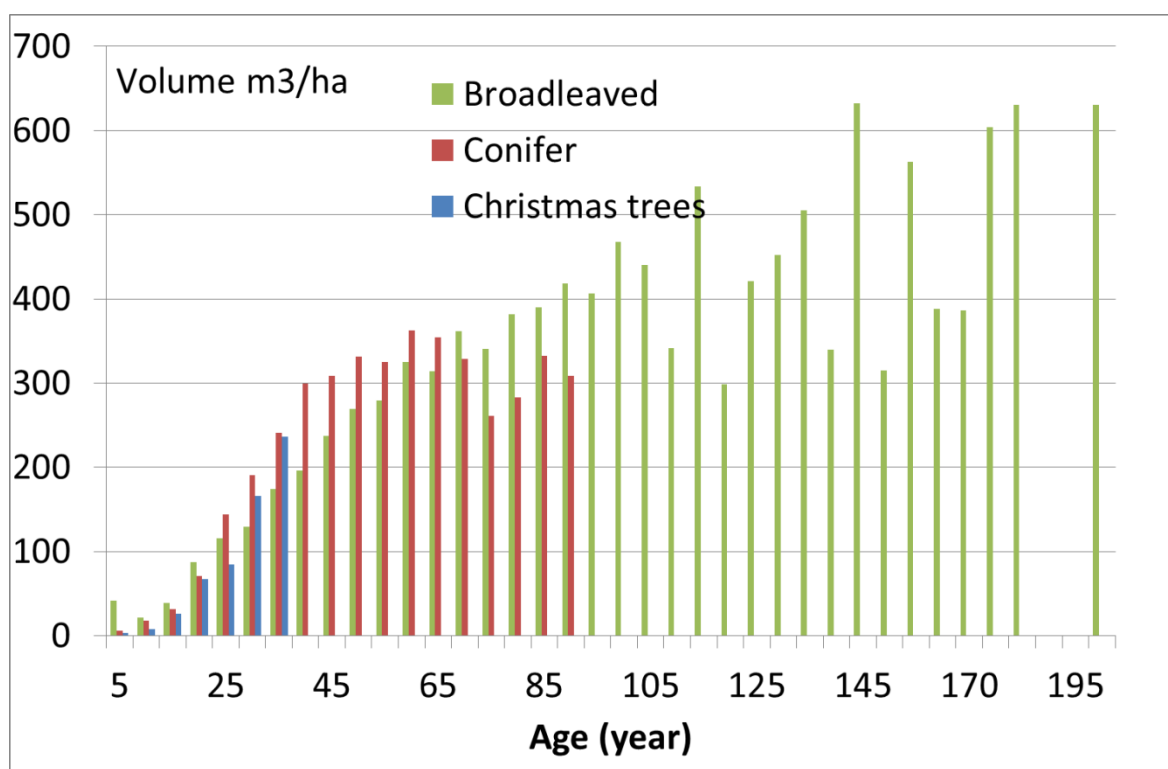


Figure 19 Growing stock (above ground biomass $\text{m}^3 \text{ha}^{-1}$) by age class distribution by 2010, for broadleaved, conifers and Christmas trees.

5.1.2 Methods

The principal method chosen for the FRL of the Forest land is 'stock change'. 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. In this approach it is essential to ensure that stocks are measured consistently for consecutive intervals. Challenges are related to certainty of total carbon stock estimates and hence the effect on change estimates. This approach is utilized for accounting of the living and dead carbon pools in the Danish forests (Nielsen et al 2018, Nord-Larsen & Johannsen 2016). The uncertainties related to stock change methods are analyzed 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.

Projections of carbon stocks and stock changes are based on estimated carbon stocks and their distribution to management classes - by growth region, species and age classes. The increment and the harvest are not modelled when using the stock change method. The estimation of the baseline for 2010 as the starting year for the FRL is based on the NFI data collected in the period 2006-2010, resulting in a dataset for all the pools included in the FRL and in the accounting of the management classes. All carbon pools are estimated according to the standard methods, as described in Chapter 2 and Nord-Larsen & Johannsen (2016) (see dataset 8.3.2).

The area distribution by management classes in 2010-2050 is projected in 5-year time steps, 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 to be 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 permanent plots, using the PROC PHREG³ of the SAS Institute (Cox 1972, 1975). Survival analysis results in models reflecting the factors included in the stratification that influence the probability of survival for further 5 years, equaling the time of a NFI cycle. The data available for the estimation is composed of a full total, of 4,512 plots. Of these, regeneration activities occur on less than 400 plots, i.e. less than 10 % of the plots. Since the Danish NFI started in 2002, the data represent plots from period 2002-2012 (the first two cycles) as year of state including the information whether the plot is cut or survives the subsequent 5 year period. 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 survival model is estimated based on the Cox model, by maximizing the partial likelihood and computes the baseline survivor function, by using the Breslow (1972) estimates. The results give the predicted survival for all forest strata, as given in Table 2.

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.

Projections for emissions from forest soil

The temporal change in shares of drained and rewetted soils was assessed based on current trends in forest management. A change in these soil categories were 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).

CO₂: The expected emission of carbon dioxide from the forest soils is estimated to 123 kt CO_{2 eq} Y⁻¹. This is expected to be constant for the entire period 2013-2040. The estimate is based on 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 2.6 ton CO₂-C ha⁻¹ Y⁻¹. (IPCC 2014: Wetland supplement, Chapter 2, Table 2.1).

N₂O: 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 N₂O Y⁻¹ - corresponding to 4.4 kg N₂O ha⁻¹ Y⁻¹. With the GWP of 298 this equals an annual emission of 17 kt CO_{2 eq} Y⁻¹ (IPCC 2014: Wetland supplement Chapter 2, Table 2.5 negligible if water table shallower than 20 cm).

CH₄: Based on the changes in drainage status of the organic soils in the forests, the emissions of methane are estimated. For the organic drained soils the emission is 2.5 kg CH₄ ha⁻¹ Y⁻¹ and for the ditches (2.5 % of the area) on organic drained soils the emission is 217 kg CH₄ ha⁻¹ Y⁻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 CH₄ ha⁻¹ Y⁻¹ for poor and 288.0 kg CH₄ ha⁻¹ Y⁻¹ for rich soils. The total annual emission amounts to 1.13 kt

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.

CH₄ Y⁻¹ with a GWP of 25 equivalent to an annual emission of 28 kt CO₂ eq Y⁻¹ (IPCC 2014: Wetland supplement, Table 2, 2.3-2.5 and 3.3).

5.1.3 Results

The FRL component for forest land is estimated through multiple steps. The first step is the estimation of the survival models, which result in the survival curves given in Figure 20, by growth region, species group and age classes (see resulting model estimates in 8.4.1).

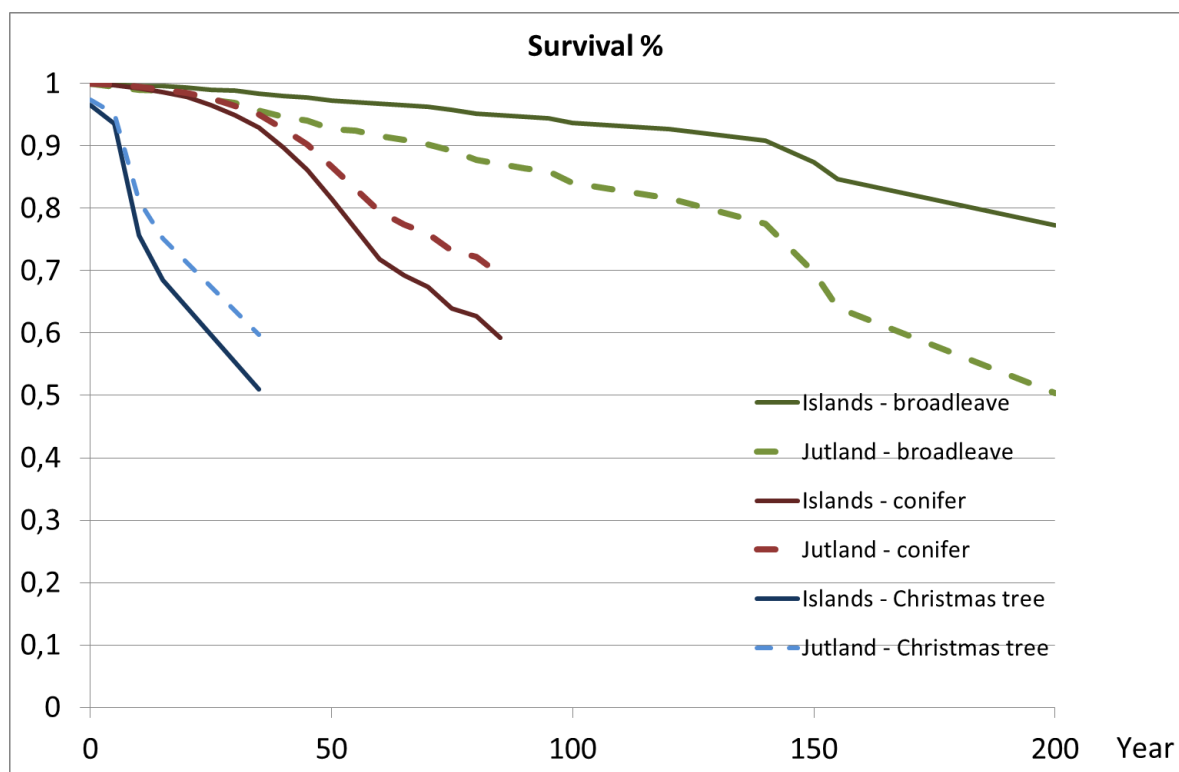


Figure 20 Survival curves for management classes.

The modelling approach reveals the shorter rotation times of conifers reflecting the higher growth rates, while the longer rotation times in Jutland reflecting the poorer soils, compared to soils on the Islands. For broadleaved however, the rotation times in Jutland is shorter than on the Islands, which most likely reflects the higher share of broadleaved forests conserved for longer periods in the Islands. Furthermore, the development through age-classes reflects the expected higher probability for regeneration with age. For the species group of Christmas trees, the very short rotation ages are clearly shown by the resulting models. The estimation of survival times also indicated the maximum age classes with sufficient data to estimate the survival, resulting in the broadleaved having 200 years as upper limit, conifers 90 years and Christmas trees only 35 years. The procedure includes estimation of standard error for the survival probability resulting in a low and high estimate. In Figure 21, the low and high values for broadleaved on the Islands and for conifers in Jutland indicate reasonable certainty in the estimation. The factors are statistically significant.

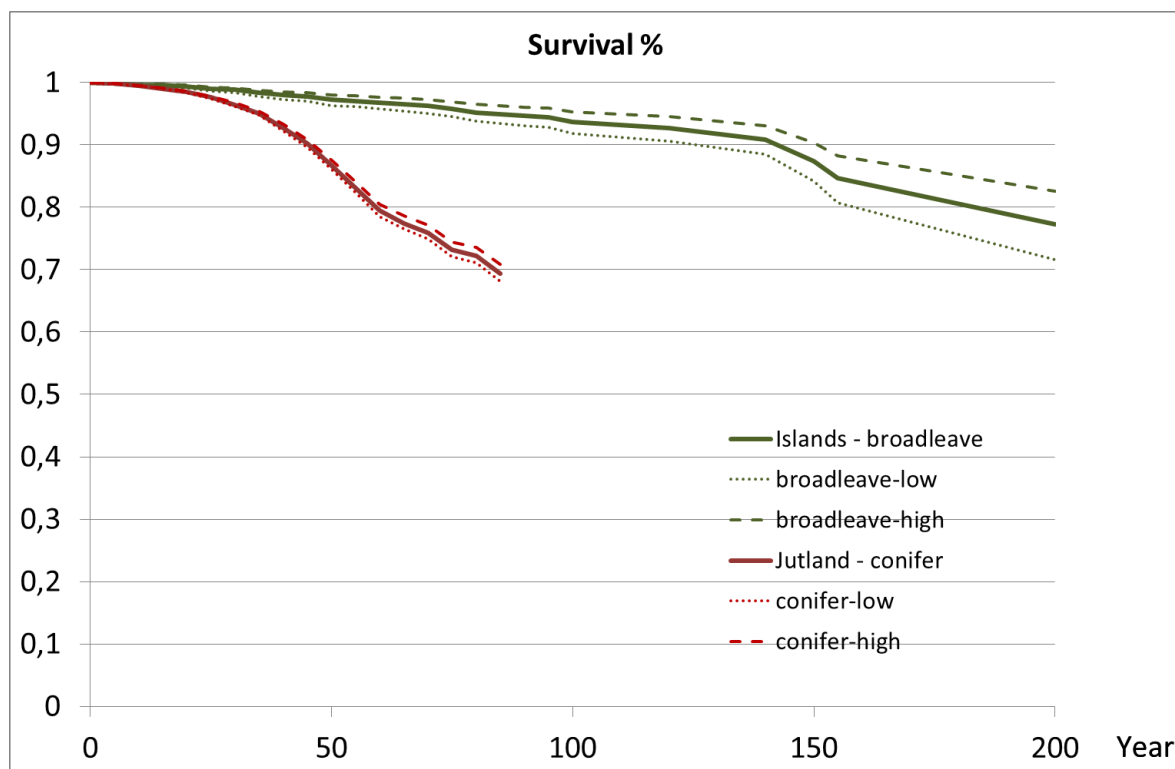


Figure 21 Predicted survival probabilities and their uncertainties as result of growth region, tree species and age classes.

The survival models are related to the biomass, above and below ground. The data for the carbon pools in dead wood, litter and soil indicate no statistic significant changes over time or related to age of the stand. For example dead wood is only recorded on 1/3 of the plots in the NFI and the level is low ($4\text{--}5 \text{ m}^3 \text{ ha}^{-1}$). The changes in litter layer and the carbon pool of the soil are slow and not detectable based on the data from the NFI in the given reference period 2000-2009. The amount of dead wood and litter both reflect the forest management practices conducted in the reference period. Hence, these pools are assumed constant at the level of 2010.

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 summarized in Table 3, and visualized in Figure 22 (see full data in 8.4.2 for 30 year 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 5.3.

Table 3 Predicted development in stocks of the forest land (kt CO₂ eq) for the year 2010 - 2050 in 5-year intervals.

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

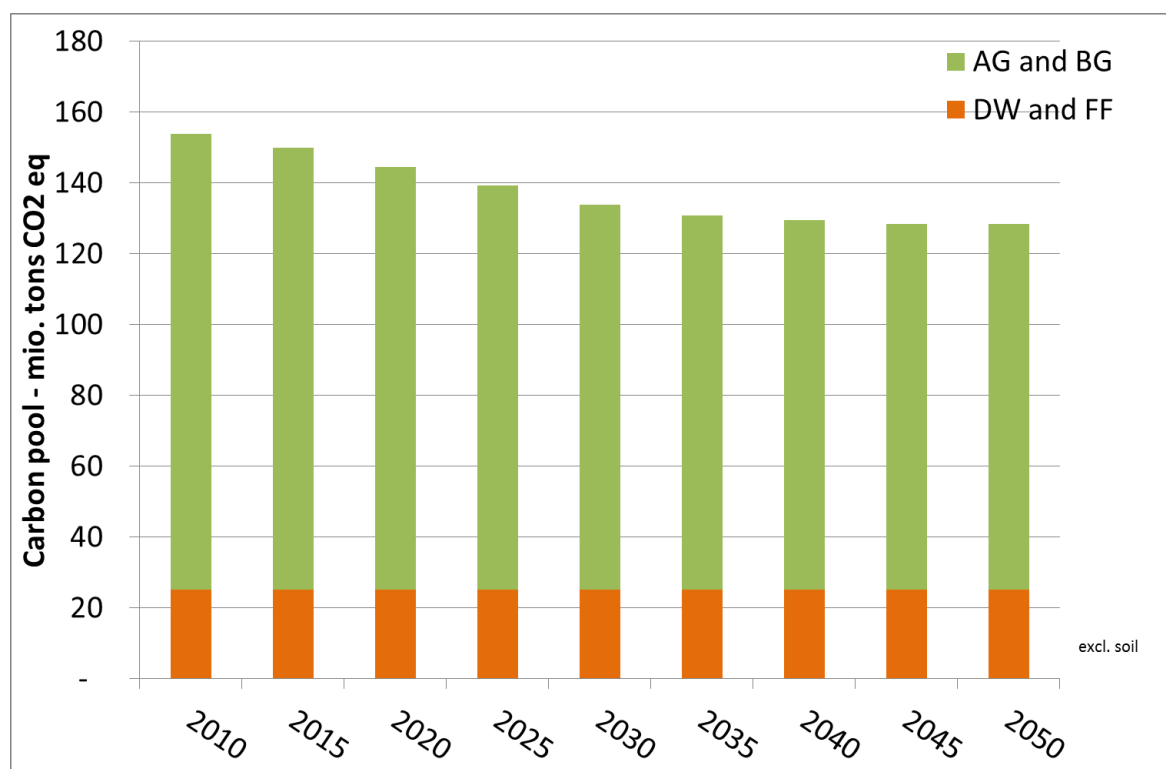


Figure 22 Predicted development in stocks of forest land (kt CO₂ eq) for the year 2010 - 2050 in 5-year intervals - based on Table 3.

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 23), 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.

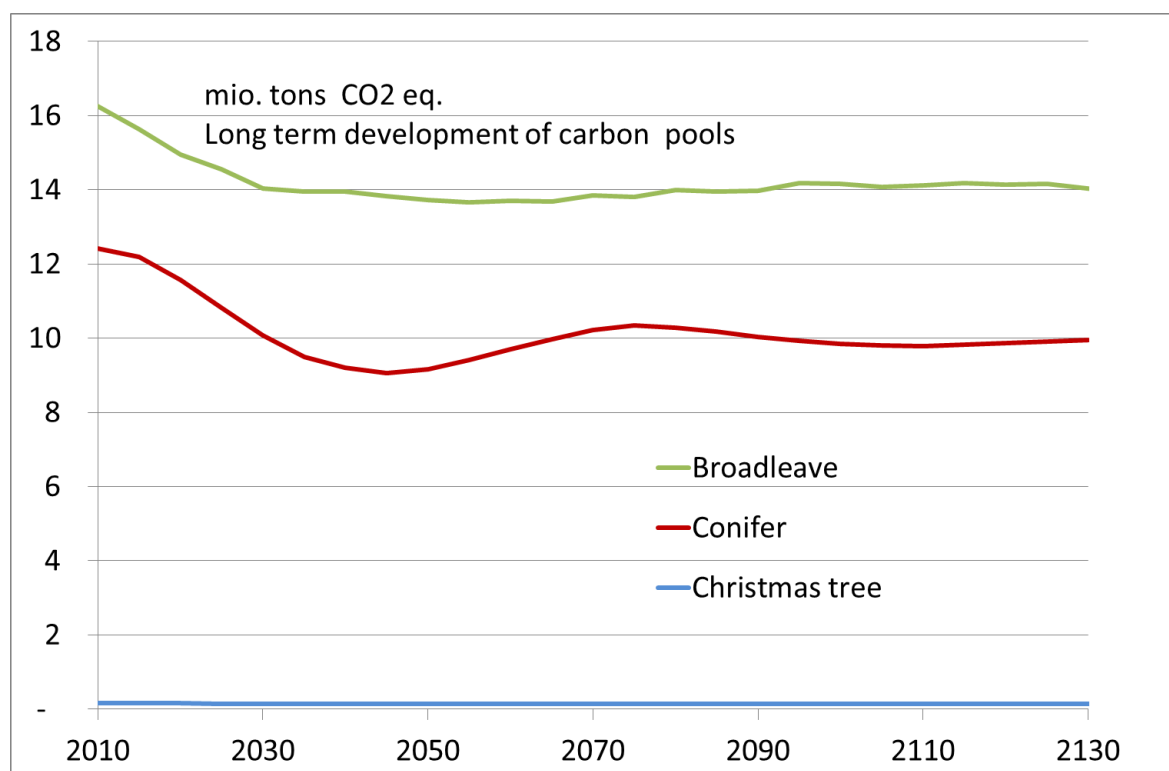


Figure 23 Long term development (2010-2130) of the carbon pool in above ground biomass of existing forest

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" is given in Table 1 (I) and are an emission of 1.252 kt CO₂ eq Y⁻¹ in 2021-2025 and an emission of 1.212 kt CO₂ eq Y⁻¹ in 2026-2030.

5.1.4 Validation

Since the predictions are starting in year 2010, it is possible to compare the prediction for 2015 with the reported data for 2015. In Table 4 gives the estimated FRL and the reported data for the years 2010 (base year) and the subsequent 5 year reporting in 2015.

Table 4 Predicted (FRL) and Reported (NIR) stocks (kt CO₂ eq) for the year 2015

	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	1,275	362	0	0	1,637
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, indicating that the forest in the period from 2010 to 2015 has been reported as a sink, while the estimated FRL indicates a reduction in the same carbon pools. 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. The reasons include:

- 1) Short reference period compared to forest growth,
- 2) Temporary change 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 relatively is 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. 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 4.4) indicate a higher harvest, but is more likely to reflect a change in degree of utilization 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 slight declining trend is noted for the dead wood pool (Nord-Larsen et al 2017). When comparing to the data for harvest to the HWP (Chapter 5.3) it is worth noting, that the amount of input to the Danish industry since 2011 have been based on direct collection of information from the industry, and not on harvest data from the Statistics Denmark. Furthermore, there has been a change in the overall estimation of the harvest by Statistics Denmark (as commented in Chapter 4.4). 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.

It should be noted, that other predictions of the development of the Danish forest GHG accounts have been prepared, but based on other reference periods and other baseline years. This influences the predicted development.

5.1.5 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.

5.2 Afforested land

Focus in this part is on the 15 % of the forest area established after 1990 and the afforestation expected to occur until 2050. In relation to FRL this area is of importance when it is transferred to forest land.

As the afforested land have a varied background the age structure and species composition is also quite varied. This influences the prognosis for the period 2021-2030 and beyond. This is addressed in the Data and Methods paragraphs.

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 given in Annex 8.5.1. In a Danish context a 30-year transition period is in line with the IPCC guidelines (IPCC 2006) and is applied in the estimation of the Danish FRL.

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 have 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 is given in Annex 8.5.2. This issue will therefore be raised during the review process, to clarify which interpretation best follows the guidelines.

5.2.1 Data

The average afforestation rate in the period 1990 - 2005 resulted in 3,678 ha Y⁻¹, and in the period 2005-2011 in 3,737 ha Y⁻¹. 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 Y⁻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 (see 8.3.4 for data on afforestation area 1990-2016). It should be noted that the areas of afforestation include areas initially established with trees for Christmas tree production (most frequent *Abies Nordmaniana*, and Norway spruce), 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 24.

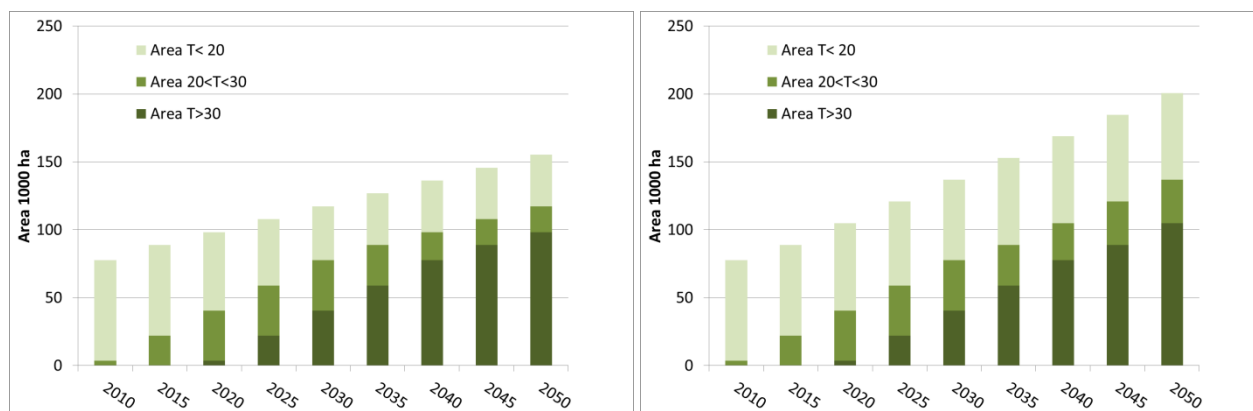


Figure 24 Total afforestation for the period 2010 - 2050 with indication of age classes (<20 yr, <30 yr and older). Afforestation of 1,900 ha Y⁻¹ (left) and 3,200 ha Y⁻¹ (right) from 2016-2050.

5.2.2 Methods

Initial analyses indicate that the available data from afforestation needs to be combined with knowledge from forest experiments and growth models. The new species compositions, and the new types of forest management in the afforestation, during the period 1990-2012, have been 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, and this was attributed to a range of factors, e.g. planting density, species choice. Therefore, for the afforestation in the period 2010-2050, the average annual afforested area of 1,900 ha is added for each year, assuming a species distribution similar to that of the afforestation area during 1990-2015 and resulting in the same level of carbon stocks.

The estimate of carbon stock change attributed to the afforestation is based on a combination of tree growth and yields models based on C.M. Møller (1933) and derived through the VIDAR program for beech (site class 2), oak (site class 4) and Norway spruce (site class 2) (see 8.3.3 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 is used for the projection for the afforestation. The prognosis is 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, 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 the cropland has been included in the accounting in the form of the lost biomass from the previous land-use. For change from crop land to forest conversion 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 Y⁻¹ hence results in an emission of 41.8 kt CO₂ eq Y⁻¹ while an afforestation of 3,200 ha Y⁻¹ will result in an emission of 70,4 kt CO₂ eq Y⁻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 $0.21 \text{ tC ha}^{-1} \text{ Y}^{-1}$ over 100 years. In the approx. 100,000 ha established since 1990 this accumulates to a sink of 13 kt C Y^{-1} or $48 \text{ kt CO}_2 \text{ eq Y}^{-1}$. (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 5.1.2). In the projections, increases in afforestation area are 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 $2.6 \text{ ton CO}_2\text{-C ha}^{-1} \text{ Y}^{-1}$. (IPCC 2014: Wetland supplement, Chapter 2 Table 2.1) results in $47 \text{ kt CO}_2 \text{ eq Y}^{-1}$ (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 $4.4 \text{ kg N}_2\text{O ha}^{-1} \text{ Y}^{-1}$. With a GWP of 298 this equals an annual emission of $6 \text{ kt CO}_2 \text{ eq Y}^{-1}$. (IPCC 2014: Wetland supplement Chapter 2, Table 2.5, negligible if water table shallower than 20 cm and with the afforestation area I 2013).

CH_4 : The methane emissions are based on the changes in drainage status of the organic soils. For the drained organic soils the emissions is $2.5 \text{ kg CH}_4 \text{ ha}^{-1} \text{ Y}^{-1}$ and for the ditches (2.5 % of the area) on organic drained soils the emissions is $217 \text{ kg CH}_4 \text{ ha}^{-1} \text{ Y}^{-1}$. On rewetted organic soils the emission is $235 \text{ kg CH}_4 \text{ ha}^{-1} \text{ Y}^{-1}$. The GWP of methane is 25 (IPCC 2014: Wetland supplement, Table 2, 2.3-2.4 and 3.3).

5.2.3 Results

Development of carbon pools and GHG for afforestation in total, and split according to a transition age of 30, are calculated to give the input for the FRL. Especially the pools for the area with age >30 are important for the FRL as they constitute part hereof (see also Figure 2 page 8). The overall development for the main pools is visualized in Figure 25.

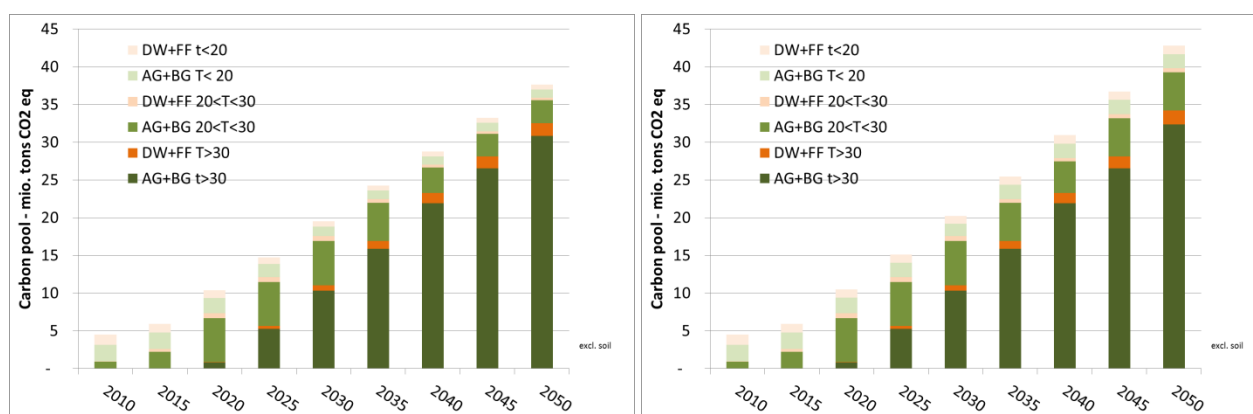


Figure 25 Development in the Above ground biomass (AG), Below ground biomass (BG), Dead Wood (DW) and Forest Floor (FF) pools of the different subdivisions of the afforestation depending on age since establishment <20, <30 or older than 30. (Afforestation rate 1,900 ha Y⁻¹ left and rate 3,200 ha Y⁻¹ right)

It is a special case that the area included in the FRL changes when afforestation areas planted 30 years ago are transferred to the area of "forest land" according to Article 6 (EU 2018). This calls for a special focus on

the age classes 30. The full effect of growth/harvest/mortality for forest area with the last age of the age class (30 years) transferred is assigned to the afforestation before transferring the area to the forest land. Therefore, the stock of the transition age to be transferred remains in the afforestation until the end of the year (31. December) and is transferred by the beginning of the next year (1. January). This is done on an annual basis. This is applied in both estimation of the FRL and in the accounting (see also Figure 1 and Figure 2 on page 8 for the conceptual description and 8.5.3 for technical description).

The contribution of the afforestation to the FRL is based on the share of the afforestation older than the age threshold for transferring the area. For a transition period of 30 years the corresponding results is a sink of -164 kt CO₂ eq Y⁻¹ in 2021-2025 and a sink of -276 kt CO₂ eq Y⁻¹ in 2026-2030 (item II of Table 1).

Beside this contribution to the FRL the afforestation younger than 30 years is estimated to generate a sink of -653 kt CO₂ eq Y⁻¹ in 2021-2025 and a sink of -622 kt CO₂ eq Y⁻¹ in 2026-2030 (see Table 1).

5.2.4 Validation

To test the predictions of the afforestation, the table below gives the number for the different age classes of the afforestation for both the predicted (FRL) and the reported values in 2010 and 2015. 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, and the deviations are high in terms of percentage, but not in absolute values. This reflects the low and rare observations of dead wood, especially in the afforestation area.

Table 5 Predicted (FRL) and Reported (NIR) stocks (kt CO₂ eq) for the year 2015 for afforestation, with a 1.900 ha/yr afforestation since 2011.

	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 CO ₂ eq	1,793	359	33	1,135	3,320
2015 20<T<30 kt CO ₂ eq	2,424	485	11	376	3,296
2015 30<T kt CO ₂ eq	0	0	0	0	0
NIR reporting					
Total	3,962	869	26	1,465	6,322
2015 T<20 kt CO ₂ eq	1,344	315	11	812	2,482
2015 20<T<30 kt CO ₂ eq	2,618	553	15	653	3,840
2015 30<T kt CO ₂ eq	0	0	0	0	0
differences FRL-NIR					
Total	-256	25	-18	-46	-294
2015 T<20 kt CO ₂ eq	-449	-43	-22	-324	-838
2015 20<T<30 kt CO ₂ eq	194	69	4	278	544
2015 30<T kt CO ₂ 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 utilized for afforestation and species composition may cause deviations from the predicted development.

5.2.5 Uncertainty

The uncertainty of the estimation of the FRL contribution from the afforestation are 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 the afforestation may deviate from the management system applied in the growth models.

Another uncertainty will originate in 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 have relative errors of more than 15 % of the mean (see Johannsen et al 2017, Chapter 6.4-6.5).

5.3 Harvested Wood Products

5.3.1 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.

Projection of HWP FRL follows the methodology described in Schou et al. (2015). In addition to earlier reports and projections domestically harvested and exported wood products are included. The estimation of the FRL is based on a projection representing a “business as usual scenario”. 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 average historic harvest in the period 2000-2009:

$$HWP_{projected,i} = HWP_{average\ 2000-09} * \frac{Harvest_{projected,i}}{Harvest_{average\ 2000-09}},$$

where $HWP_{projected,i}$ is the projected production of HWP in year i , $HWP_{average\ 2000-09}$ is the average historic production of HWP for the period 2000-2009, $Harvest_{projected,i}$ is the projected harvest in year i , and $Harvest_{average\ 2000-09}$ is the average historic harvest for the period 2000 through 2009.

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 general this assumption is quite reasonable, however changes in assortment distribution will affect the validity of the assumption - e.g. for Denmark the share of fuelwood in the harvest has been increasing. The validity of assumptions is discussed below.

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 roundwood assortment distribution

The assortment distribution of the Danish wood harvest changes over time to meet changes in demand (Figure 26). For both broadleaved and coniferous species a shift towards energy purposes is seen, but also the distribution between roundwood 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 roundwood harvest. That fraction has dropped to below 10 % in 2016. In broadleaved species the changes are less pronounced.

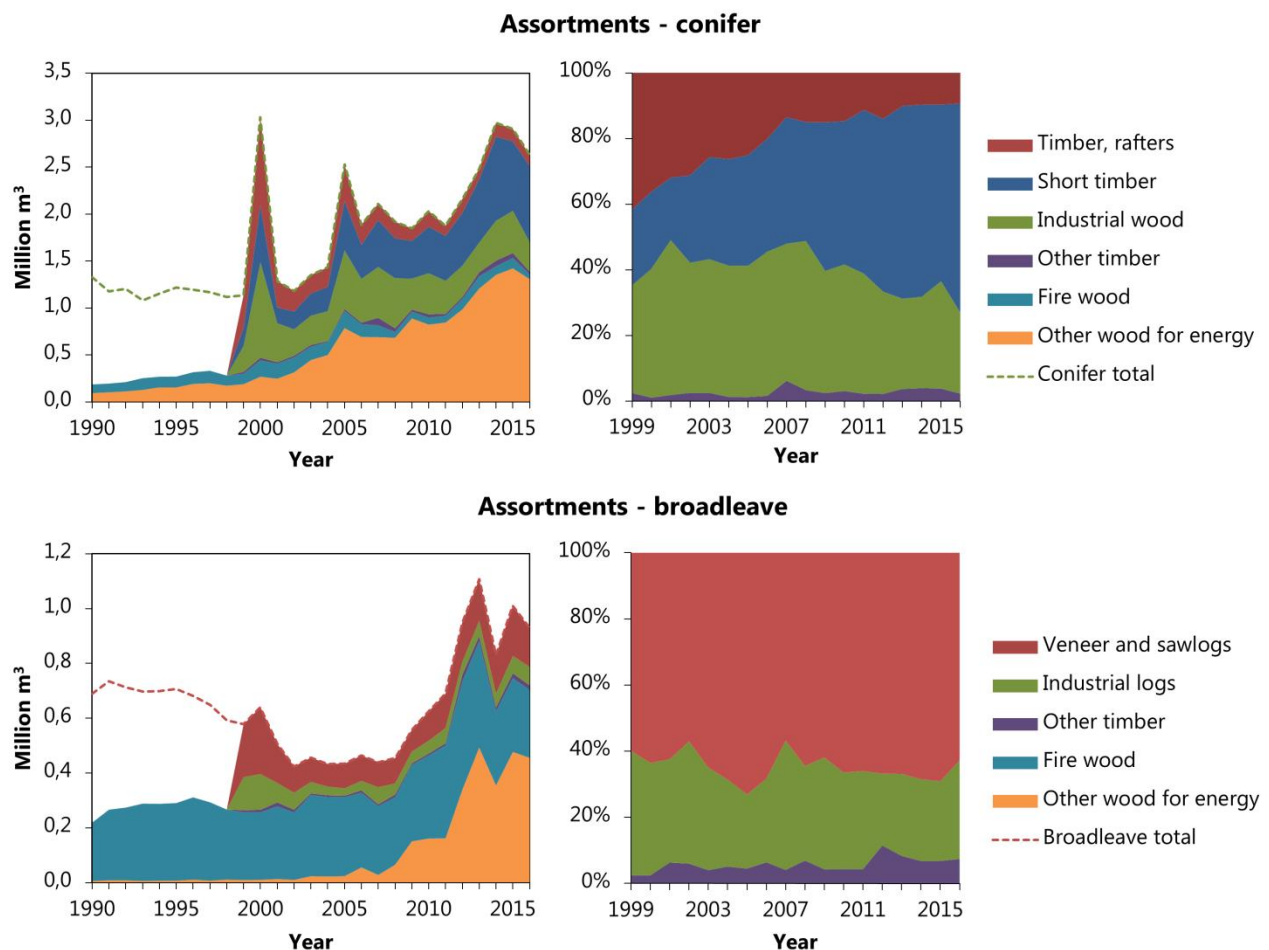


Figure 26. Left panels: Changes in harvested assortments of coniferous and broadleaved species from Danish forest from 1990 to 2016. Before 1999 the statistics did not distinguish between industrial roundwood assortments. Right panels: Relative distribution of industrial Roundwood assortments from 1999-2016. Data from Statistics Denmark (SKOV6).

As shown in Figure 27 it is difficult to predict assortment distributions in the period 2010-16 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.

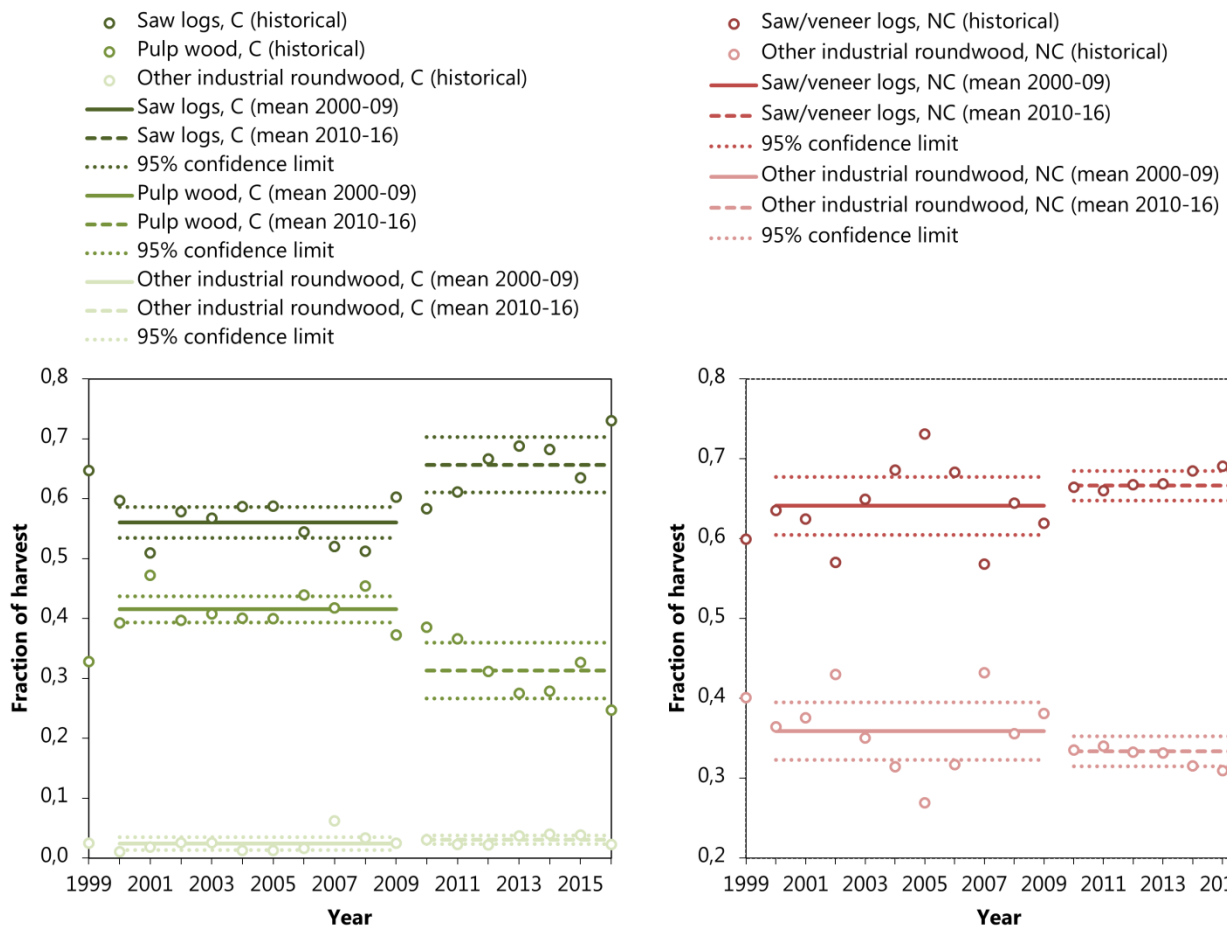


Figure 27. Assortment distribution of industrial roundwood of conifers (left panel) and broadleaved species (right panel) for the period 1999 to 2016.

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 28). 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).

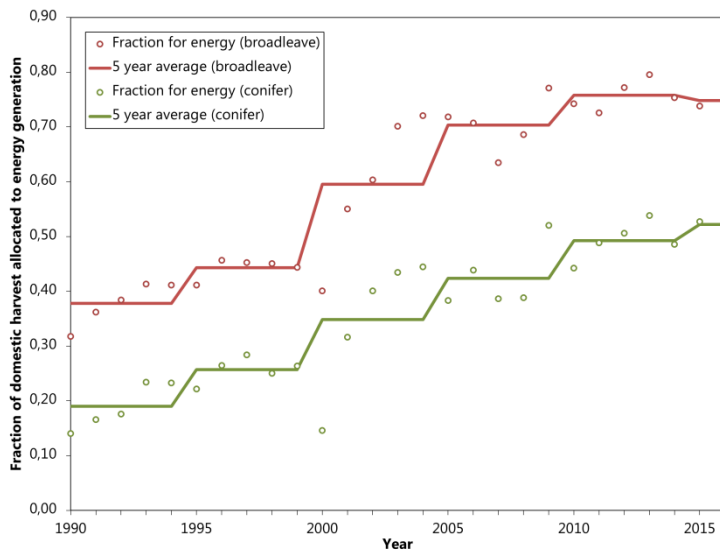


Figure 28. Fraction of domestic harvest allocated to energy generation 1990-2016.

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 29). The same ($p < 0.027$) is seen for coniferous species.

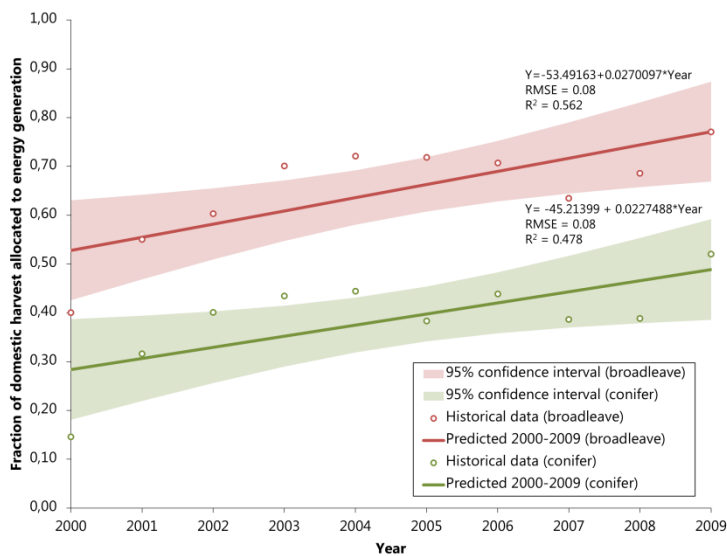


Figure 29 Fraction of domestic harvest allocated for energy generation

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 30). 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 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)

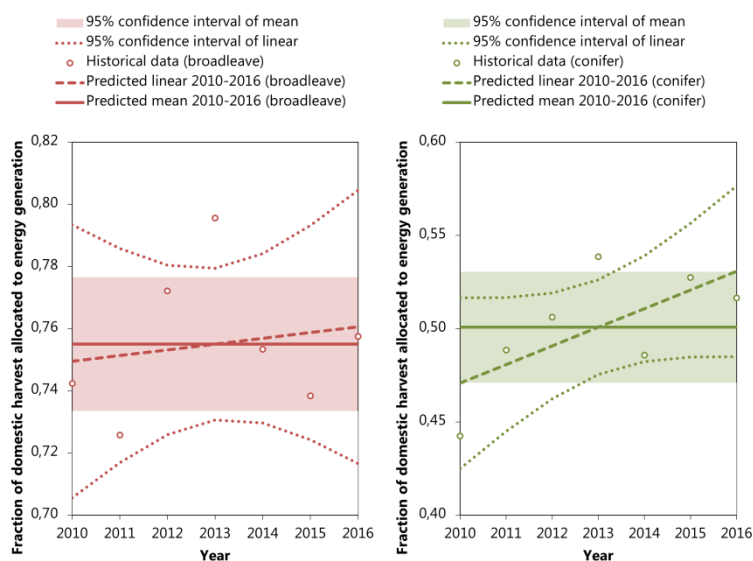


Figure 30. Fraction of domestic harvest allocated to energy generation 2010-2016.

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 31). 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.

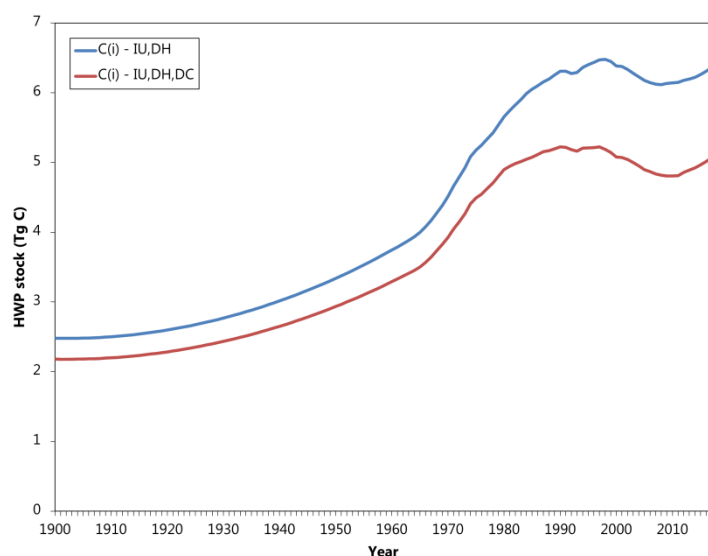


Figure 31. HWP stock of domestically harvested (DH) and domestically harvested and consumed (DH, DC) wood products from 1900 to 2017.

5.3.2 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 we assume that the future fraction remains constant at the level of the predicted value in 2009 for both broadleaved and conifer species (Figure 32). This is also 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)-

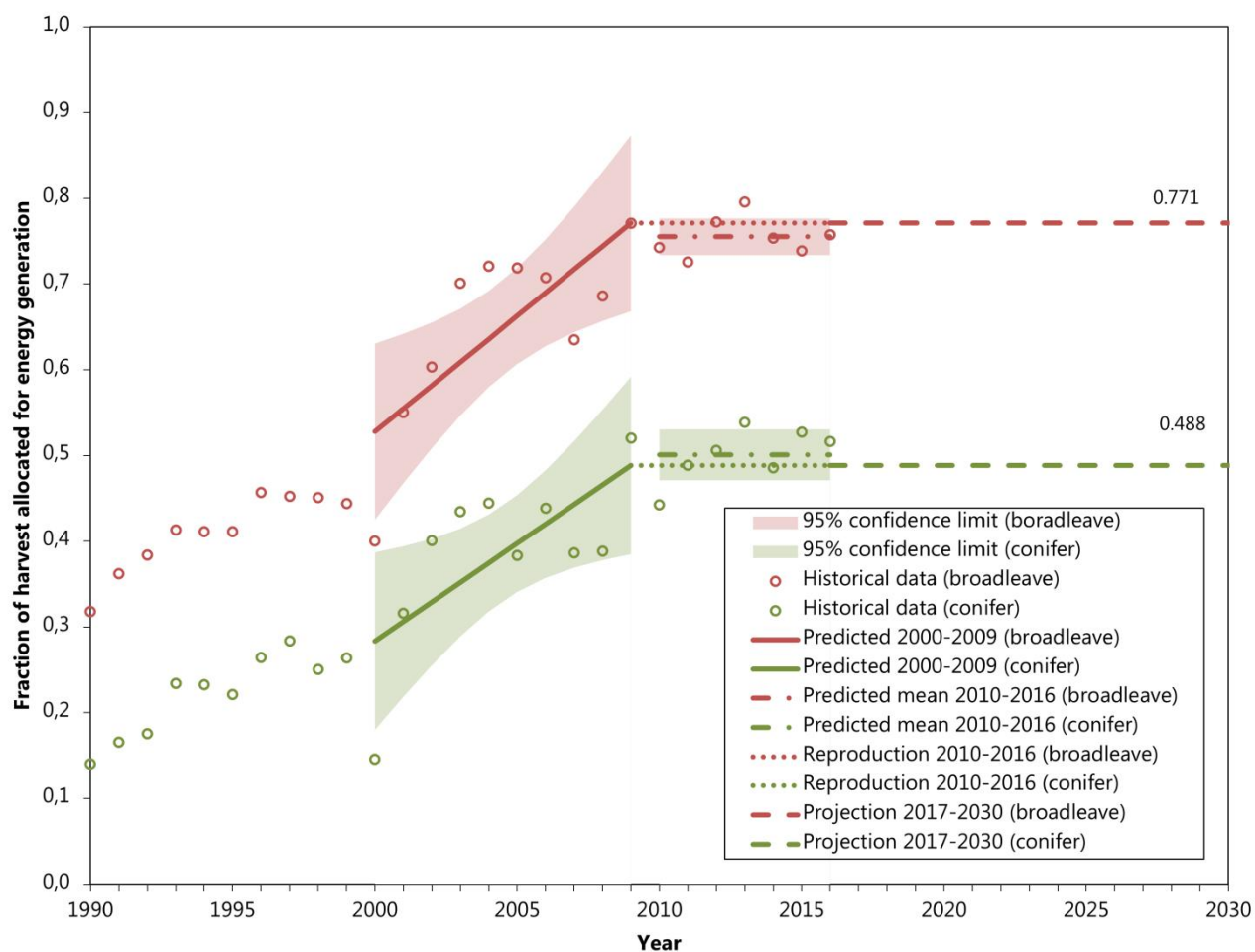


Figure 32. Fraction of domestic harvest allocated for energy generation 1990-2030

Basing the projected fraction on the 2009 prediction meets the criteria of being based on the 2000-2009 data. It falls within the confidence limits of the subsequent period and it is constant.

Projection of changes in the HWP pool

Future harvests in Danish forests are projected for the period 2018-2030 (Figure 33). To estimate the inflow to the HWP pool as described above. The future harvest is modelled in 5 year intervals (2015, 2020, 2025, 2030, ...). Values for the intermediate years are estimated through linear interpolation. The future harvest is projected based on the projections described for the forest and afforested land (Chapter 5.1 and 5.2). This gives a harvest volume from the regenerations and additional 30 % volume from intermediate thinnings (based on data from thinning experiments). This results in projected harvests as indicated in Figure 33.

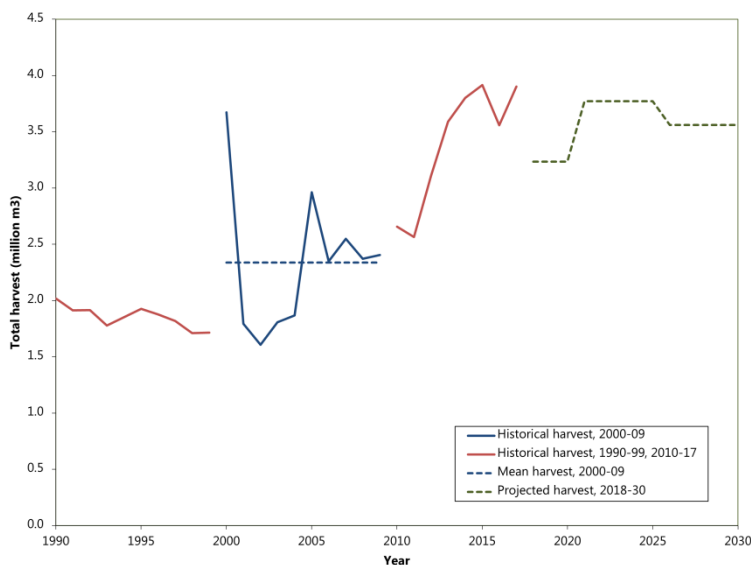


Figure 33. Historical and projected harvest from Danish forests.

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) are: 2 years for paper, 25 years for wood panels and 35 years for sawn wood.

Figure 34 shows the reported (2000-2017) and projected (2018-2030) changes in the HWP pool based on the assumptions and methodology described above. The projections show a consistent sequestration of carbon in the period 2021-20. For the period 2021-2030 the average sequestration is estimated to 37 kt C_{eq} y⁻¹ corresponding to 0.14 kt CO₂ y⁻¹ (for 2021-2025: 49 kt C y⁻¹ - 0,18 kt CO₂ eq Y⁻¹ and for 2026-2030: 32 kt C y⁻¹ - 0,12 kt CO₂ eq Y⁻¹).

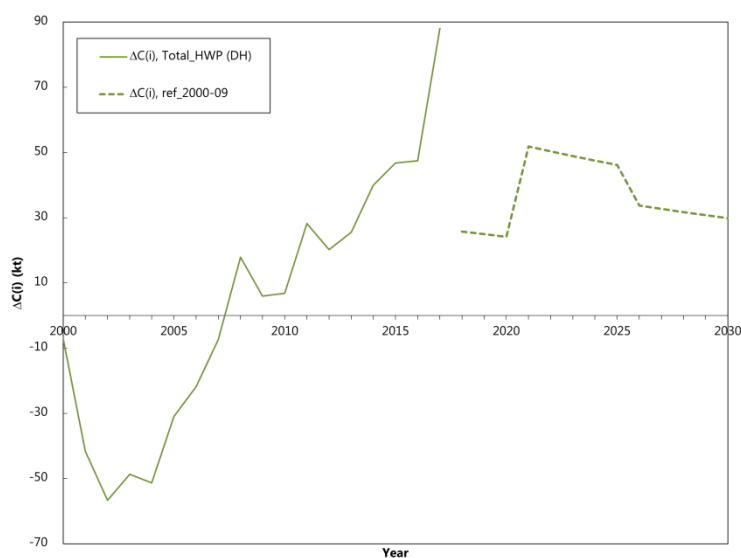


Figure 34. Estimated changes (kt C Y⁻¹) in the HWP pool from 2000 to 2017 and projection to 2030.

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. These changes result in net emissions from the HWP pool in the period 2018 to 2030. 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.

5.3.3 Uncertainty

The projected changes in HWP are sensitive to the chosen reference period (Figure 35). The figure shows the reported changes in the HWP pool and projections for the second commitment period for the Kyoto Protocol (red lines). Recalculated changes in the HWP pool including export and inherited emissions and projections for the FRL 2021-2030 (expanded to 2059) are shown with green lines. Dotted purple lines show the uncertainty in FRL projections as a function of alternative 10 year reference periods. Shifting the reference period one year forward or backward has (expectedly) little influence in the HWP projection. However shifting the reference period 5 year backward (1995-2004) result in net negative emissions from the HWP pool in the entire period 2018-2030.

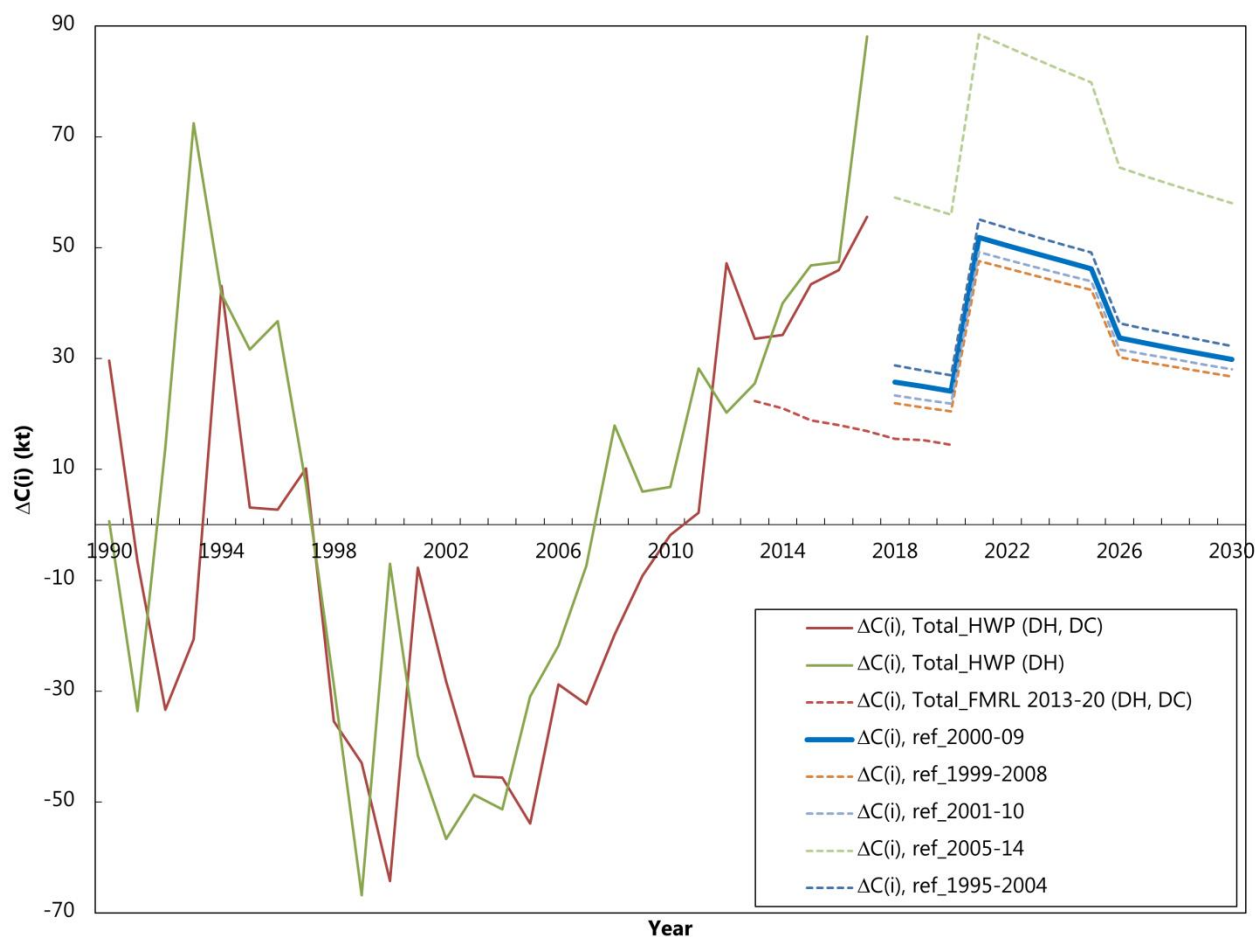


Figure 35. Reported changes in the HWP pool, recalculated changes including export, KP2 projections and FRL 2021-30 projections of changes in the HWP pool.

5.4 Deforestation

Deforestation occurs in Denmark mainly to give area for nature restoration and urban development. In the previous reporting period's deforestation have been limited in Denmark, but a few years the area have been larger. This has been caused by e.g. nature restoration projects have removed wood vegetation fulfilling the criteria of the forest definition, and thereby accounted as deforestation.

The area influenced was 27 ha Y^{-1} in the period 1990 - 2005, 325 ha Y^{-1} in the period 2005-2011 but the area was higher in the period 2011 - 2015, with a maximum of 2,251 ha Y^{-1} in 2015. The high rate of deforestation in 2011-2015 are caused by a combination of including forest areas with low canopy cover in the forest area in satellite based forest mapping in 1990 - 2011 (mainly under the category Other wooded land) and new guidelines for subsidies for management of permanent grasslands. Although no real change is observed in forest canopy cover, this causes some areas to change land use from 'forest area' to 'grasslands' and hence be accounted as deforestation. This effect is expected to cease in the period 2020-2035.

The deforestation is expected to be 116 ha Y^{-1} in the period 2018 - 2035, corresponding to a change in land use due to new settlements, infrastructure and nature restoration as the main drivers of deforestation in the period.

The assessment of the carbon stock transferred to another land use and hence removed from the forest carbon stock is calculated by combining the spatial reference area of deforestation with the available biomass and forest height maps, produced on the basis of LiDAR data (Nord-Larsen et al 2017). For the estimation of influence on the reference levels, this value is based on emissions from an average total carbon stock of 221 t CO_2_{eq} for each of the 116 ha deforested each year, giving an estimate of 26 kt $\text{CO}_2_{\text{eq}} \text{Y}^{-1}$.

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

6 Conclusion and summary

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

The Danish National Forest Accounting Plan have been composed to fulfill the requirements and specification of the EU Regulation (EU 2018) with specific focus on the Article 6-8 and Annex IV and V. The cross references between the requirements and the current document are given in Annex 8.1. The dataset used for the FRL and the resulting datasets are listed in Annex 8.3 and 8.4 and will be available as online data.

The overall development of the forest area are visualized in Figure 36 for the carbon pools changing most over the period from 2010 to 2050, indicating an increasing total carbon pool and hence a carbon capture of the forests. The contribution from the forest land and the afforestation (in age classes <20, 20<T<30 and >30) indicate the effect of the Article 5 & 6 of the EU Regulation (EU 2018). The reference period is 2000-2009.

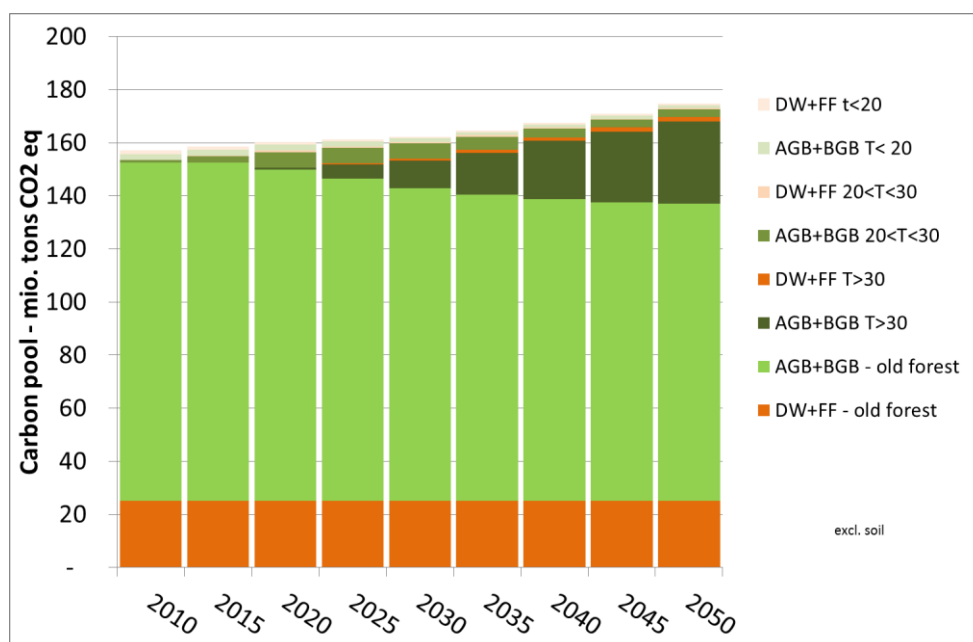


Figure 36 Overall development in the carbon pools in Above Ground Biomass (AGB), Below Ground Biomass (BGB), Dead Wood (DW) and Forest Floor (FF) pools of the different subdivisions of the total forest area depending on age since afforestation (old - before 1990) or age classes <20, <30 or older than 30, including an afforestation of 1,900 ha Y⁻¹.

The carbon pool of the Harvested Wood Products is accounted for, and the predicted changes for the period 2021-2030 are expected to be a sink of -148 kt CO₂ eq Y⁻¹. The HWP pool consists of domestically harvested products, in use either in Denmark or exported.

Below is given the FRL applying a 30-year transition period (Table 6), including HWP (I+II+HWP) or assuming instant oxidation for all harvest (I+II).

Overall, the forest land will have a positive FRL in both periods indicating emissions from the overall forest land including the afforestation over the age of transition. The FRL levels given in the tables above refer to

afforestation of 1,900 ha Y-1. In Annex 8.4.3 are given the full tables for afforestation of 3,200 ha Y-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 and in the forest floor. In areas with higher degree of utilization for e.g. 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. These changes are initiated after the reference period 2000-2009 and the development are yet not recorded by the observations in the NFI. The higher degree of utilization will result in higher traded volume of wood for energy, with the same harvest intensity, as also addressed in Chapter 5.1 and 5.3.

Table 6 Summary of FRL based on 30 year transition age and afforestation of 1.900 ha/yr (see Table 1, p. 36. 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} Y ⁻¹)	925	1.252	1.212	1.293	750	422	416	162
Afforestation - after 1990								
II: Older than 30								
Stock change + \sum soils and gasses + transfer ** (kt CO _{2 eq} Y ⁻¹)	0	142	-164	-276	-366	-445	-537	-450
III: Younger than 30								
Stock change + \sum soils and gasses + transfer** (kt CO _{2 eq} Y ⁻¹)	-230	-975	-653	-622	-529	-402	-292	-376
IV: Deforestation								
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)**	-95	-95	-180	-117	-100	-100	-100	-100
Forest Reference Level 30 year								
I + II ** (kt CO_{2 eq} Y⁻¹)	925	1.394	1.048	1.017	384	-23	-121	-288
I + II + V ** (kt CO_{2 eq} Y⁻¹)	830	1.299	868	901	284	-123	-221	-388
Total forest sector								
I+II+III+IV+V** (kt CO_{2 eq} Y⁻¹)	1.106	350	241	305	-219	-500	-488	-738

* Refer to the state at the end of the period

** Refer to the average for the 5 year period

The FRL is in all the periods estimated 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 most likely will occur.

It's worth noting, that the total forest sector is the same, regardless of the age at which afforestation is transferred to forest land. The overall development of the Danish forests 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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8 Appendices

8.1 Cross reference - EU Regulation & DK-NFAP

The numbering is added for ease of reference in the document.

Table 7 Cross reference table - EU Regulation and the Danish National Forest Accounting Plan

No	Criteria	Text	See pages
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 stabilize the future carbon capture of the forests. See Figure 23, p.46
2	Annex IV A.b	the reference level shall ensure that the mere presence of carbon stocks is excluded from accounting;	See Table 1, p. 36 and 5.1.3 for forest land and 5.2.3 for afforestation.
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 2.4, p. 13
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 5.3, p. 52
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 0, p. 54
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 4.5, p. 31 The FRL documents a stable long term development of the forest resources and an increase in forest area. (see also p. Figure 23, p. 46)
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 5.1.4, 5.2.4, 5.3.2).

No	Criteria	Text	See pages
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 8.3 and 8.4. 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 5.1.4 and 5.2.4.
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 1.1, p.6
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 2, p. 10
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 5, p. 35 ff. and is consistent with the methods used for the latest NIR report. The national regulations and policies are described in Chapter 3, p 14 ff. The Sustainable forest management are described in Chapter 4, p. 18 ff.
12	Annex IV B.d	information on how harvesting rates are expected to develop under different policy scenarios;	See 0, p. 58
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 5.1.1, p. 38
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 5.1.3 and 5.2.3. For HWP see 0

No	Criteria	Text	See pages
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 4, especially p 18-28
17	Annex IV B.e.iv	historical and future harvesting rates disaggregated between energy and non-energy uses.	See 0, p. 54
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 utilized as HWP comes from stands older than 30 years, all HWP naturally are accounted for referring to managed forest land.
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.
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.
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 0, p. 58
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 0, p. 58
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 have not been included.

8.2 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 natur nær 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.

8.3 Datasets used for the FRL

Access the data here

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

8.3.1 Data: Survival modelling

Excel spreadsheet: NFI_survival_input.xlsx

8.3.2 Data: Baseline data for FRL

Excel spreadsheet: NFI_2010_baseline.xlsx

8.3.3 Data: Growth models for afforestation

Excel spreadsheet: Afforestation_growthmodel.xlsx

8.3.4 Data: Afforestation areas by year

Excel spreadsheet: Afforestation_area_year.xlsx

8.4 Resulting datasets for the FRL

Access the data here

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

8.4.1 Survival curves

Excel spreadsheet: NFI_survival_curve.xlsx

8.4.2 Result: DK_FRL_forest_land_detail

Excel spreadsheet: DK_FRL_forest_land_detail.xlsx

8.4.3 Result: FRL 2010-2050 - with 3.200 ha annual afforestation

Table 8 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})	150,024	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)	757	1,084	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
Σ soils emissions (kt CO _{2 eq} Y ⁻¹)	168	168	168	168	168	168	168	168
Stock change + Σ soils emissions ** (kt CO_{2 eq} Y⁻¹)	925	1,252	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} Y ⁻¹)	0	-176	-958	-1,076	-1,176	-1,270	-965	-1,216
Carbon stock transfer ** # (AG+BG+DW+FF) (kt CO _{2 eq} Y ⁻¹)	0	314	786	786	791	798	454	683
Carbon accumulation - soil (kt CO _{2 eq} Y ⁻¹)	0	-2	-11	-19	-28	-37	-43	-50
CO2 from drained soils (kt CO _{2 eq} Y ⁻¹)	0	6	21	35	49	66	73	82
N2O drained organic soils (kt CO _{2 eq} Y ⁻¹)	0	1	3	5	7	9	10	11
CH4 drained and rewetted organic soils (kt CO _{2 eq} Y ⁻¹)	0	0	0	1	1	1	2	2
Σ soils emissions (kt CO _{2 eq} Y ⁻¹)	0	6	13	21	28	39	42	44
Stock change + Σ soils emissions + transfer ** (kt CO_{2 eq} Y⁻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 Y ⁻¹)	-283	-737	39	54	123	180	-195	0
Carbon stock transfer** # (AG+BG+DW+FF) (kt CO ₂ eq Y ⁻¹)	0	-314	-786	-786	-791	-798	-454	-683
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)	-43	-49	-47	-46	-45	-44	-46	-46
CO ₂ from drained soils (kt CO ₂ eq Y ⁻¹)	46	48	42	36	30	21	22	22
N ₂ O drained organic soils (kt CO ₂ eq Y ⁻¹)	6	7	6	5	4	3	3	3
CH ₄ drained and rewetted organic soils (kt CO ₂ eq Y ⁻¹)	1	1	1	1	1	0	0	0
Σ soils emissions (kt CO ₂ eq Y ⁻¹)	52	49	43	37	32	23	22	22
Stock change + Σ soils emissions + transfer** (kt CO₂ eq Y⁻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 CO₂ eq Y⁻¹)	499	26	26	26	26	26	26	26
V: Harvested Wood Products								
HWP (kt CO₂ eq Y⁻¹)**	-95	-95	-180	-117	-100	-100	-100	-100
Forest Reference Level 30 year								
I + II ** (kt CO₂ eq Y⁻¹)	925	1,396	1,052	1,024	393	-11	-53	-326
I + II + V ** (kt CO₂ eq Y⁻¹)	830	1,301	872	907	293	-111	-153	-426
Total forest sector								
I+II+III+IV+V** (kt CO₂ eq Y⁻¹)	1,106	353	223	268	-288	-652	-727	-1,034

* 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 (31. December) and is transferred by the beginning of the next year (1. January).

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

8.5 Methodological considerations regarding IPCC guidelines

8.5.1 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. In the Volume 4, chapter 4.3 (IPCC 2006) it is stated "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 are 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 have 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 37. It shows the development of CO₂ 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 IPCC 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).

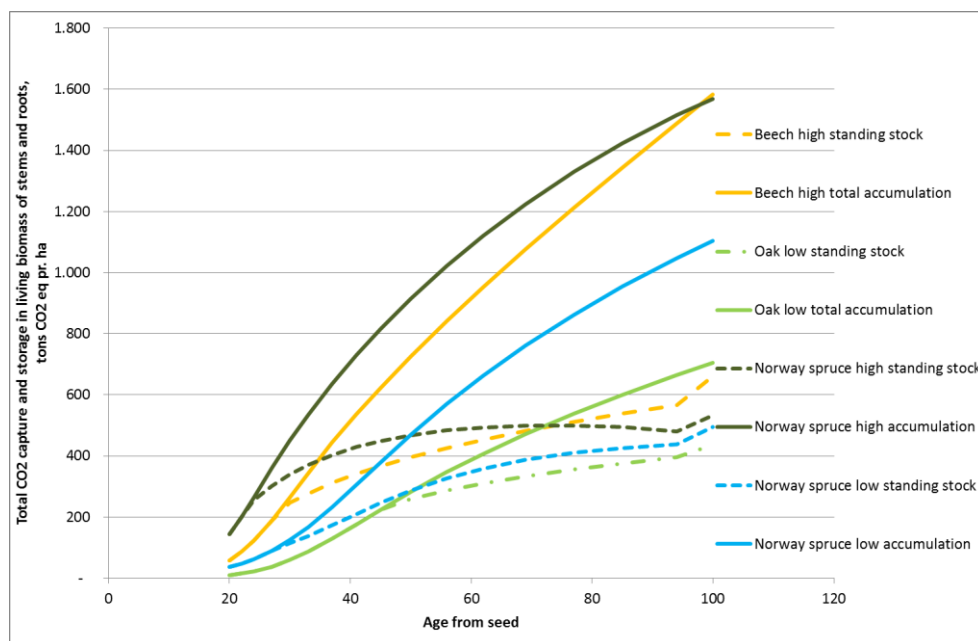


Figure 37 Development of CO₂ accumulation in forest under Danish conditions with beech, oak and Norway spruce, both total accumulation and standing stock in the forest, given the standard forest management regime with intermediate thinnings (Vidar).

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.

8.5.2 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 have 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 the 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 ". But, since the Danish land-use mapping gives knowledge on the previous land-use on a converted area then the Tier 2 method can be used. In the 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 Y⁻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 asks 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 31. December 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. But in both cases the forest accounting has the debits for the loss of biomass.

The IPCC guidelines are not clear at 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).

8.5.3 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 are transferred to the forest land category following (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 (31 December) and is transferred by the beginning of the next year (1 January). 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 old forest land area).

Stock (t CO ₂ 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.

A decline in afforested area from year to year in the relevant compliance period may result in apparent negative stock change for the afforestation category, in case the growth/harvest/mortality of the last year before transition to forest land is not assigned to afforestation (as can be seen from the example).

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.

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