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Johannsen, Vivian Kvist; Nord-Larsen, Thomas; Vesterdal, Lars; Suadicani, Kjell; Callesen, Ingeborg

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UNIVERSITY OF COPENHAGEN
DEPARTMENT OF GEOSCIENCES AND
NATURAL RESOURCE MANAGEMENT

Identifying potential uncertainties associated with forecasting and monitoring of carbon sequestration in forests and harvested wood products

Afdækning af potentielle usikkerheder forbundet med fremskrivning og monitering af kulstofbinding i skov og træprodukter

Vivian Kvist Johannsen, Thomas Nord-Larsen, Lars Vesterdal,
Kjell Suadicani og Ingeborg Callesen

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Authors

Vivian Kvist Johannsen, Thomas Nord-Larsen, Lars Vesterdal,
Kjell Suadicani og Ingeborg Callesen

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University of Copenhagen
Department of Geosciences and Natural Resource Management
Rolighedsvej 23
DK-1958 Frederiksberg C
Tel. +45 353 31500
ign@ign.ku.dk
www.ign.ku.dk

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Forord

Rapporten gennemgår effekten af EU kommissionens forslag om ændrede retningslinjer for rapportering af kulstof i skov på Danmarks klimaregnskab og afdækker potentielle usikkerheder forbundet med monitering og fremskrivning af kulstofbinding i skov og træprodukter.

Rapporten er udarbejdet som en del af SINKS2 projektet, finansieret af Energi, Forsynings og Klimaministeriet, og bygger på data fra den integrerede skovovervågning der udføres for Miljø- og Fødevareministeriet.

Frederiksberg, juni 2017

Content

1 Sammendrag

Rapporten gennemgår effekten af EU kommissionens forslag om ændrede retningslinjer for rapportering af kulstof i skov på Danmarks klimaregnskab og afdækker potentielle usikkerheder forbundet med monitering og fremskrivning af kulstofbinding i skov og træprodukter.

EU kommissionens forslag til nye retningslinjer for klimaregnskabet kommenteres i kapitel 4. Et centralt element i det nye forslag er, at kulstofpuljer for skovrejsning ældre end 20 eller 30 år overføres til det eksisterende skovareal. Kulstoftilvæksten i nye skove indgår dermed i referenceniveauet for skov fra de er 20 år gamle, og bliver omfattet af rapportering ift. referenceniveauet. Retningslinjerne for beregning af referenceniveau for skov (Forest Management Reference Level - FMRL), er på linje med tidligere retningslinjer. De foreslåede ændringer adresserer referenceår og sikring af, at beregning af referencen afspejler kendte politikker og tiltag, samt vækst- og hugstforhold. Dele af retningslinjerne opstiller krav om et nationalt skovkulstofregnskab og dokumentation for skovforvaltning, som et element i fastlæggelsen af referenceniveauet. Det sidste element i de ændrede retningslinjer adresserer træprodukter (Harvested Wood Products - HWP), og hvorvidt de fremadrettet skal være del af skovenes kulstofregnskab eller skal behandles særskilt. I dag indgår HWP i LULUCF og rapporterer den del af den danske træhugst, der anvendes til gavntræ i Danmark.

Effekten af skovforvaltning og skovdyrkningspraksis såvel som effekten af globale klimaforandringer på skovenes tilvækst og kulstofpuljernes størrelse er behandlet i kapitel 5. Den generelle tendens i tilvækst og kulstofbalancer i skove i Europa, i Danmark såvel som globalt, er et resultat af mange faktorer, hvoraf menneskelig påvirkning gennem skovforvaltning, skovdyrkning, valg af træarter og gener (provenienser) såvel som ændringer i desposition (positive ift. vækst som fx kvælstof og negative som fx svovl), CO_2 koncentration i atmosfæren, temperatur og nedbør påvirker den registrerede tilvækst på mange måder. Hvilke af disse faktorer, der påvirker mest er ikke klart og afhænger af lokaliteten, men de bidrager alle.

I rapportens kapitel 6 gennemgås de data og metoder, der anvendes til beregningerne af kulstof til LULUCF rapporteringen for de danske skove, og usikkerheden på opgørelserne analyseres. Fra 1881 til 2000 blev der med ca. 10 års mellemrum gennemført Skovtællinger baseret på spørgeskemaer. Da spørgeskemaer blev udfyldt af skovejere, og data således ikke var baseret på direkte målinger, kan der have været variationer i definitioner og opgørelser af arealer. Alle beregninger af vedmasse og kulstof blev baseret på modeller for skovenes vækst i form af tilvækstoversigter. De seneste spørgeskema baserede opgørelser blev lavet i 1990 og 2000.

I 2002 blev spørgeskemaerne erstattet af en stikprøvebaseret national skovstatistik. Denne type skovstatistik anvendes i mange andre lande, bl.a. Sverige og Norge. Danmarks Skovstatistik er bygget op om et landsdækkende 2 x 2 km net. I hvert af nettets celler er der placeret en gruppe bestående af fire prøveflader med en radius på 15 m. Der indgår i alt ca. 43.000 prøveflader i netværket, hvor kun skovdækkede prøveflader måles. De skovdækkede prøveflader identificeres forud for hver målesæson ud fra de nyeste luftfotos. I felten bliver den enkelte prøveflade lokaliseret med stor geografisk præcision, hvilket muliggør sammenkobling med anden geografisk registerinformation. De årlige opgørelser af volumen, biomasse og kulstof opfylder den forventede sikkerhed. Usikkerheden på ændringer over tid gennemgås, og resultaterne angiver klart, at rapportering med 5 års intervaller frem for årlige rapporteringer vil resultere i statistisk sikre ændringer, hvilket årlige rapporteringer ikke gør.

I kapitel 7 er gennemgået beregninger af referenceniveau for udledningen af drivhusgasser fra skov (FMRL). Beregningerne er gennemført for de forskellige dele af skovene, herunder for skovrejsning yngre/ældre end 20 år samt 30 år og viser hvorledes de forskellige forslag om retningslinjer fra EU kommissionen vil påvirke rapporteringen. Den samlede effekt er at skovarealet inkl. skovrejsning over 20/30 år vil have en stigende kulstofpulje som følge af vækst af træer og øget skovareal. Dette vil være omfattet af referenceniveau og det er afvigelser herfra, der vil indgå i det samlede LULUCF regnskab.

For skovrejsningen under 20/30 år vil ændringerne i den samlede kulstofpulje være påvirket af såvel vækst i de unge træer som ændringer i arealet, idet beregningsmetoderne sikrer, at tilvæksten i skovrejsningen krediteres denne. Da der i prognosen forventes en lavere årlige skovrejsning på 1900 ha/år mod en skovrejsning i perioden 1990 - 2015 på ca. 3700 ha/år, falder den samlede kulstofpulje i skovrejsningspuljen. Det samlede optag i skovrejsningen falder derfor i løbet af perioden 2020 - 2035. Puljen af træprodukter forventes i perioden 2020 - 2035 at blive øget, og dermed udgøre HWP puljen et lille optag af kuldioxid. Table 6 giver en samlet oversigt over de forskellige dele af reference niveau beregningerne.

Samlet giver rapporten information om følgende spørgsmål:

A: Vil det danske niveau af LULUCF rapportering for skovrejsning svare til niveauet for skovrydning?

Med de nye retningslinjer for overførsel af skovrejsning over 20/30 år til hovedskovarealet, vil både skovrejsning og skovrydning være mindre puljer end hvis alle ændringer i skovarealet (skovrejsning og -rydning) fortsat blev rapporteret samlet. Ved en 30 årig overførsel vil en større andel af optaget i skovrejsningen blive rapporteret uden for reference niveauet og vil overstige den forventede udledning ved skovrydning. Se Table 6, side 49.

B: Hvordan har den danske LULUCF rapportering ændret sig over tid og hvor stor er usikkerheden på den nuværende metode? Er metoderne sammenlignelige med andre landes og state-of-the-art?

LULUCF rapporteringen for skove har ikke ændret sig over tid. Sikkerheden på estimaterne af skovenes kulstofpuljer er bedre end oprindeligt forudsat i opbygningen af den nationale skovstatistik, men usikkerheden på estimaterne i forhold til ændringernes størrelse understøtter ikke en årlig rapportering, men snarere en rapportering baseret på 5 års intervaller. Se kapitel 6.6, side 35. Indsamlingen af data og de analytiske metoder der anvendes i den danske skovstatistik er helt sammenlignelige med metoderne der anvendes bl.a. i de øvrige skandinaviske lande.

C: Forest Management Reference Level - følger det de foreslåede retningslinjer? Afspejler det de danske skove? Er der brug for nye data og udvikling?

FMRL følger retningslinjerne, og er baseret på en matrix/foryngelsesmodel kombineret med en lager-ændrings tilgang. Dette er anvendt frem for at benytte en kombination af modeller for vækst, hugst, mortalitet og foryngelse. Der er behov for validering af prognoserne der ligger til grund for FMRL inden den endelige indsendelse for Danmark. Dette gælder særligt skovrejsningsarealet, der gradvist indgår i reference niveauet. Se kapitel 7.

D: Hvordan vil de nye forslag fra EU Kommissionen påvirke FMRL for Danmark og Europa?

Hovedeffekten vil være overførslen af den ældre del af skovrejsningen (> 20 eller 30 år) til det samlede skovareal, hvorved kun den unge del af skovrejsningen vil repræsentere skovrejsningspuljen. Rapporteringen af effekten af skovrejsning vil derfor blive mindre synlig, end hvis hele skovrejsningen blev rapporteret særskilt og skovenes effekt på det samlede klimaregnskab vil mindskes. Variationer i omfang af skovrejsning vil påvirke overførslerne over tid såvel som den samlede kulstoflagring i skov uanset retningslinjer for klimaregnskaber. Se kapitel 7.6. Selve FMRL er en beskrivelse af forventning til udviklingen. Forslaget indeholder også forslag til, hvorledes afvigelser fra FMRL skal håndteres, baseret på EU kommissionens målsætninger. Disse forhold er kort kommenteret i Kapitel 4.2.

E: Hvordan vil FMRL være under de forskellige retningslinjer? Herunder hvordan vil effekten være af at håndtere Harvested Wood Products (HWP) separat fra resten af LULUCF?
De samlede resultater er givet i kapitel 7.6, særligt Table 6. Effekten af at adskille HPW fra LULUCF er adresseret i kapitel 4.3.

F: Hvad er, kort fortalt den aktuelle videnskabelige forståelse af globale miljøændringer og klima ændringers effekt på skovenes økosystemer og kulstofbalancer?
Den generelle tendens i tilvækst og kulstofbalancer i skove i Europa, i Danmark såvel som globalt er et resultat af mange faktorer, hvoraf menneskelig påvirkning gennem skovforvaltning, skovdyrkning, valg af træarter og gener (provenienser) såvel som ændringer i desposition (positive ift. vækst som fx kvælstof og negative som fx svovl), CO_2 koncentration i atmosfæren, temperatur og nedbør påvirker den registrerede tilvækst på mange måder afhængig af lokaliteten. Hvilke af disse faktorer, der påvirker mest, er ikke klart, men de bidrager alle, og udredning heraf er stadig blandt de vigtige forskningsemner.

2 Summary

This report analyses the effect of the EU 2030 policy proposal on LULUCF accounting and credits, and how it will influence the Danish accounting and hence contribution to the EU 2030 goals.

The proposal from EU on the accounting rules has been commented in Chapter 4. A pivotal element of the proposal is the transfer of carbon pools in afforestation older than 20 or 30 years to forest remaining forest (FRFL). As a consequence, the fast carbon sequestration in afforestation older than 20 to 30 year, will be included in the Forest Management Reference Level (FMRL), rather than being accounted for in full.

Suggestions for the guidelines on calculation of the FMRL are overall in line with the previous guidelines. Changes include the reference year (now 2000-2009) and ensure that the reference level reflects known policies and actions as well as known growing conditions and management practices. Parts of the guidelines include increased demands of national accounting plan and an extended documentation for the forest management practice used for determining the FMRL. The last element in the suggested guidelines includes Harvested Wood Products (HWP) and whether these should remain part of the forest accounting system of should be handled separately.

The influence of forest management, silvicultural practices, and global climate change has been addressed in Chapter 5. The overall trend in increment and carbon balances of forests in Europe and in Denmark as well as globally is a combined effect of a multitude of factors, of which human induced forest management, silvicultural activities, selection of species and genetics, pests and pathogenes as well as changes in atmospheric deposition (both positive and negative influence), changes of the CO_2 content the atmosphere, changes of temperatures and precipitation patterns is influencing the observed increment in a multitude of ways. However, it is not clear which of these factors that influence the changes the most.

A description is given of the data and methods used for the LULUCF accounting for the forests in Denmark. We further analysed the uncertainty of carbon stocks and carbon stock changes. The analysis of uncertainty indicates that reporting based on 5 year cycles will provide more stable estimates, than annual reporting (Chapter 6).

The Forest Management Reference Level (FMRL) has been addressed for the different parts of the forest area (Chapter 7). If the new suggestion of FMRL including afforestation older than 20 years (I + II in Table 6) or 30 years (I + V in Table 6), the accounting for the Danish forests will be

compared to this FMRL, where the forest carbon stock is expected to increase, and deviations from this trend will cause reporting of either a sink or an emission. Assuming a balanced reference level, the overall accounting effect of the forests will minor, since afforestation younger than 20/30 years will be a minor sink along with HWP, while, deforestation will be a source of emissions. All of these are outside the FMRL and will have direct effect on the Danish accounting.

As for the questions raised the report gives information on:

A: Will the level of the Danish LULUCF accounting for afforestation match the level of accounting due to deforestation?
With the new guidelines with transfer of afforestation over 20 or 30 years to the main forest area, the sum of afforestation and deforestation will be a small sink or potentially a small source in the period 2020-2035. See Table 6, page 49.

B: How have the Danish LULUCF accounting changed over time, and how are the uncertainties of the current methodology? Are the methodologies comparable to other countries and state-of-the-art?
The LULUCF accounting for forests have not changed over time. The uncertainty of carbon stock estimates is smaller than anticipated when designing the Danish National Forest Inventory. However, the uncertainty of carbon stock estimates in relation to the relatively small changes in forest stocks does not support annual reporting, but rather reporting based on 5 year intervals. See 6.6, page 35.

C: Forest Management Reference Level - does it follow the guidelines suggested? Does it reflect the Danish forests? Is there a need for new data/development?
The FMRL follows the guidelines, and is based on a matrix/transition model combined with stock change approach, rather than specified models for growth, harvest, mortality and regeneration. There is a need for validation before the final submission of the FMRL, especially for the growth of the afforestation areas. See Chapter 7.

D: How will the new suggestions by the EU Commission affect the FMRL for Denmark and Europe?
The main effect will be the inclusion of older (>20 or 30 years) afforestation in the FMRL. As a consequence young afforestation (less than 20 or 30 years), will be a smaller sink of carbon dioxide in the period 2020-2035 than if the full afforestation were accounted jointly. See Chapter 7.6. The suggestion also addresses handling of deviations from the

FMRL, based on the EU commission targets. These issues are shortly addressed in Chapter 4.2.

E: How will the FMRL look under different guidelines? Included - how will the effect be of handling Harvested Wood Products (HWP) separately from the rest of the LULUCF?
The summary results are given in Chapter 7.6, especially in Table 6. The influence of separating HWP from LULUCF is addressed in Chapter 4.3.

F: What is - in brief- the current scientific understanding of global environmental change and climate change effects on the forest ecosystem carbon balance?
It is not possible to give a brief summary of the vast amount of research available, but some key findings are given in Chapter 5. The overall trend of biomass increment and increased uptake of carbon in forests across Europe and in Denmark is a global trend likely caused by a combined effect of a multitude of changing factors, of which human induced forest management, silvicultural activities and selection of species and genetics as well as changes in atmospheric deposition (both positive and negative influence), elevated atmospheric CO_2 concentration, increased temperatures and changed precipitation are influencing the observed increment in a multitude of ways. Which of these factor that influence the changes the most is not clear, but they all contribute. Disentangling the individual effects of all these factors is still a major unresolved challenge in ecosystem research today.

3 Background

The Danish Ministry of Energy, Utilities and Climate is in need of input on the EU 2030 policy on LULUCF accounting and credits, and how it will influence the Danish accounting and hence contribute to the EU 2030 goals. Furthermore, the EU Commission has proposed new guidelines for Forest Management Reference Level calculations which also impact the potential contribution of forest to the EU 2030 goals.

The variability of the Danish forest carbon stock changes in previously estimates has caused a need for an additional in-depth analysis of the variance of estimates.

The impact of climate changes, especially changes of atmospheric carbon dioxide, has been raised as a point of interest in terms of how the forests will respond to this, especially if recent changes in carbon stocks in European forests are caused by changing concentration of atmospheric carbon dioxide.

Some of the questions this report will aim to answer are related to the following questions:

A: Will the level of the Danish LULUCF accounting for afforestation match the level of accounting due to deforestation?

B: How have the Danish LULUCF accounting changed over time and what is the uncertainties of the current methodology? Are the methodologies comparable to other countries and state-of-the-art?

C: Forest Management Reference Level - does it follow the guidelines suggested? Does it reflect the Danish forests? Is there a need for new data/development?

D: How will the new suggestions by the EU Commission affect the FMRL for Denmark and Europe?

E: How will the FMRL look under different guidelines? Included - how will the effect be of handling Harvested Wood Products separately from the rest of the LULUCF?

F: What is - in brief- the current scientific understanding of global environmental change and climate change effects on the forest ecosystem carbon balance?

The response to the above questions and subsequent needed clarifications are handled within the SINKS2 project, mainly the Forest QA/QC subproject.

4 EU proposal

This paragraph outlines key elements in the current proposal for EU joint regulation of the GHG reporting (EU Commission 2016) as amending Regulation No 525/2013 and updated by 17th May 2017.

Generally, the proposal suggests EU Commission empowerment to adapt and specify definitions. Furthermore, the European Environment Agency (EEA) is indicated to have an assisting role. It will be important to integrate national and EU data collection systems. In the following paragraphs, the focus are on the articles dealing with forest issues, where the proposal covers all elements of land use, land use change and forestry.

4.1 Article 6 - accounting for afforested land and deforested land:

The basic approach in the proposal aims at transfer of areas to the new land use category 20 years from the date of conversion (Article 5, 3), but by derogation a transfer time of 30 years can be augmented (Article 6, 2). Both time frames are from a biological point of view problematic for afforestation, since a new forest under Danish growing conditions requires at least 50-100 years obtaining a state similar to already existing forest areas of almost steady state. The UK has elected to apply a 100 year transfer period in their UNFCCC accounting, with afforestation being all forest established since 1920 (Thomson et al. 2007). The suggested short period of transfer (20 or 30 years) will cause the pool of afforestation to only be reported for the first initial years of carbon accumulation and as afforestation is continuously transferred to the remaining forest area, it will not be visible as a separate carbon sink which includes the full effect of afforestation. As the two potential sinks can no longer be distinguished, it would be more efficient to report the total forest area under one single, unified pool, including afforestation in the forest pool from the very establishment. There is no climate or scientific reason for keeping the first 20 (or 30) years separate in the reporting.

The forest definitions applied for forest area (given in Annex II of the proposal) determines the afforestation and the deforestation. The forest definitions are given by member states where a majority follow the FAO forest definitions, as is also the case for Denmark.

See also analyses on carbon accounting for afforested land in Chapter 7, where the majority of the estimated increase in carbon stock in the Danish forests in general originates from afforestation of older than 20 years.

4.2 Article 8 - accounting for managed forest land

A key element in the accounting for managed forest land is the forest reference level. Based on the criteria listed in Annex IV the proposal includes a number of different sets of criteria.

The guidelines in Annex IV require a clearly scientifically and data based determination of forest reference levels (point *b*-*d*) and a need to ensure consistency (*f* - other projections). Furthermore, the request for a public forest accounting plan is good for the transparency, but will require additional work for each member state. The political priorities indicated in *a*) goals of GHG balance and *c*) conservation of biodiversity, reflect intentions more than reflections of "business as usual" which can cause the FMRL estimations to be influenced by policy initiatives rather than reflecting a clearly defined reference for the development of the forest carbon pools.

The consistency of reporting mentioned in criteria *g*) is naturally relevant, but since the base period for the estimation of FMRL are set to 2000 - 2009 (Article 8, 3), there is no guarantee that it will be able to reproduce the historical data from the subsequent reporting, which may already reflect changes in forest management not implemented in the reference period (e.g. the global financial crisis 2007-2009 started affecting forest management in 2009 but the data for this is too scarce to significantly influence the FMRL estimation).

The process of determining the FMRL and recalculation by the Commission gives rise to concern. The member states are required to ensure national monitoring and accounting plans, and should be able to provide sufficient data and insight into forest management at National level to ensure the development of a reasonable FMRL and consistent reporting. The reference to the LUCAS survey will not provide sufficient information for neither the land use mapping of sufficient resolution, nor the carbon pools related to the LULUCF matrix (Seebach et al. 2012). It will be essential for the transparent accounting and reporting that the data are based on sound sampling principles and are consistent with the historic data, which are generated in the member states by national forest inventories. Therefore the determination of FMRL needs to be based on most current and consistent forest management information for the different regions/nations.

The Article 8 (1b) and (2) addresses accounting issues in case of development in forest pools deviating from the forest reference levels. The use of a 'national threshold value' (Annex IV) is a new tool introduced. It is based on models for increment and harvest and sets a threshold for the proportions of these C fluxes. The use of a CAP has been applied before, with the new descriptions and numbers in the current proposal (0.7 Mt CO_2/yr for Denmark). The application of a limitation of the actual accounting on forest carbon pools in in form of a CAP or the national threshold value will drastically reduce the transparency of the accounting and the effects of forests. The influence can limit both emissions and removals by forests. Furthermore, the proposal includes a suggestion to discount the emissions that fall below the national threshold by a factor of 0.5. There is no scientific reasoning given for these suggestions. Furthermore, the proposal as of 17 May 2017 is not clear in how neither emissions nor removals may be altered in the final accounting.

Under the previous guidelines, the FMRL was only applied to the forest area remaining forest (FRF) excluding all afforestation (AF) and for some countries some default level of deforestation (DF) (Denmark assumed no deforestation in the FMRL). Since the suggestions for Article 6 results in transfer of afforested areas to FRF 20 or 30 years after afforestation, the determination of FMRL needs to take into account the historic afforestation and the development therein. With the change in guidelines it needs to include an increase in forest area and development of the new forest areas. This is a significant change. There are no guidelines in the proposal for estimation of afforestation in the FMRL.

The elements of the national forestry accounting plan is mainly a documentation of methodologies and data as basis for the accounting. The elements on documentation on forest management practices and intensity are more of operational interest and of relevance for potential political initiatives for changing this. It could be argued that this is not a core part of an accounting plan, but a support for policy development. This is reflected in the elements requested on stakeholder consultation, effects of policy scenarios and how this is reflected in the FMRL.

It is essential for the credibility of the carbon accounting system (including all the derived systems for credit trade etc.), that included effects of forest management, harvesting and afforestation incentives or constraints, are clearly defined in the methodology of the FMRL estimation. It is however equally important, that the FMRL is based on data and science. Only in this way can the FMRL become a reasonable measure of the expected development of the forest carbon pools.

4.3 Article 9 - accounting for harvested wood products

The accounting for harvested wood products (HWP) follows the same guidelines as under the current commitment period. See also Chapter 7.4

Given the change in Article 6 indicating transfer of afforested land to managed forest land after only 20 or 30 years, supports the accounting of all HWP related to managed forest land, since only little harvest for wood products happens in young stands. In the proposal it is stated, that if it is not possible to differentiate between HWP on afforested land and on 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.

The option of including products usage in importing countries requires additional data. An uncertain option indicates a Union based market for wood products. This option would increase the HWP pool that can be accounted for in Denmark, as a significant part of the harvest is exported for use in other countries.

A new option under the HWP methodology is to provide information on imported wood used for energy and its origin. The focus is on countries outside the European Union.

It has been suggested to separate the HWP from the overall LULUCF calculation. This might have some secondary effects, which in the Danish case will be of minor influence on the overall reporting due to the small contribution to carbon stocks from changes in HWP.

If HWP reporting is separated from LULUCF, HWP reporting will not distinguish wood inflow from afforestation and forest management. Probably this has no significant consequences for Denmark because the main part of domestic wood inflow to the HWP stock will come from forests older than 40 years.

Separation of HWP and LULUCF causes the HWP to be outside the CAP limit. For Denmark it is expected to have very limited consequences for the reporting, due to the small magnitude of HWP contribution with the current production pattern in the Danish forests and wood industry combined. However, currently we have no evidence of a correlation between the total harvest of industrial wood in the forest and the production of HWP based on the wood industry activities.

5 Increment and carbon balances as influenced by forest management and global changes

In this paragraph is given a short review of how development in forests - increment and carbon balances - are influenced by 1) forest management and 2) global changes in forest growth and carbon balances induced by climate change, CO_2 content in the atmosphere, increasing temperature and other factors.

5.1 Forest management

This paragraph is based on (Graudal, Ulrik Braüner Nielsen, et al. 2013). To assess how much the growth of the forests can be increased, point of departure has been taken in the current species and age class composition of the forests (based on the NFI). The effect on growth of nine silvicultural measures (parameters) and four different combinations (scenarios) of these parameters have been modelled. The nine parameters and the four scenarios are shown in Table 1. Detailed descriptions of the different silvicultural measures are given in Appendix - 10.1. For results of the different specific measures please refer to the detailed original report.

Other scenarios could be analysed as well, using other combinations of the silvicultural measures. However, these four were selected as likely combinations of silvicultural actions in response to increased demand for fuel wood (BIO), increased focus on environment and biodiversity (ENV) or either business as ususal (BAU) or a combination of BIO and ENV (Combi). In the modelling, no additional effect is assumed from global changes in climate (temperature and precipitation), deposition of nitrogen or other chemicals, or atmospheric concentration of carbon dioxide.

Table 1. The nine silvicultural measures (parameters) and the four different combinations of these parameters (scenarios) assessed by modelling in the study. BAU is current practice (Business as usual), BIO focuses on biomass production, ENV focus on environmental values and Combi combines production and environmental concerns.

Silvicultural measure/parameter	**Value/level of parameter**	**Scenarios**			
		BAU	**BIO**	**ENV**	**Combi**
S 1. Afforestation	0 ha/year				
	1,900 ha/year	x	x		
	2,280 ha/year				
	4,560 ha/year			x	x
S 2. Species choice, afforestation (new forests)	As now	x			
	More conifers		x		
	More broadleaves			x	x
S 3. Rotation age	As now	x			x
	Younger		x		
	Older			x	
S 4. Species choice, regeneration in existing forests	As now	x			x
	More conifers		x		
	More broadleaves			x	
S 5. Intensity of regeneration in existing forests	As now	x		x	
	Intensive		x		x
S 6. Areas of forest set-a-side (out of production)	As now	x	x		
	ca. 10 %			x	x
	Ca. 25 % (ENV+50)				
	Ca. 50 % (ENV+100)				
S 7.Thinning intensity (Utilisation degree)	As now	x			x
	More		x		
	Less			x	
S 8. Degree of wood removal for energy (assortment choice)	As now	x			
	More energy wood		x		x
	Less energy wood			x	
S 9. Level of genetic improvement	As now	x			
	More breeding		x	x	
	Intensive breeding				x

Table 2. The effect of the nine silvicultural measures on carbon stock derived from Above ground biomass, dry matter of harvest for fuel wood and use wood respectively, compared to business as usual (as now) being 100 %. Extract of Table 3-3 in (Graudal, Ulrik Bräuner Nielsen, et al. 2013)**.**

Silvicultural measure/parameter	Value/level of parameter	Carbon stock (% compared to 'as now' reference)			Harvest fuel wood	Harvest use wood
		2020	**2050**	**2100**	**2050**	**2050**
S 1. Afforestation	0 ha/year	100	94	79	91	96
	1900 ha/year	100	100	100	100	100
	2280 ha/year	100	101	104	102	101
	4560 ha/year	101	109	129	113	105
S 2. Species choice, afforestation (new forests)	More conifers	100	100	94	98	104
	More broadleaves	100	100	102	102	98
S 3. Rotation age	Younger	97	96	97	100	97
	Older	100	103	100	98	98
S 4. Species choice, regeneration in existing forests	More conifers	100	100	94	99	102
	More broadleaves	100	100	102	108	95
S 5. Intensity of regeneration in existing forests	Intensive	101	108	107	135	100
S 6. Areas of forest set-a-side (out of production)	ca. 10 %	105	111	106	88	93
	Ca. 25 % (ENV+50)	106	119	115	75	75
	Ca. 50 % (ENV+100)	106	123	132	50	51
S 7.Thinning intensity (Utilisation degree)	More	96	90	90	112	111
	Less	105	110	110	88	89
S 8. Degree of wood removal for energy (assortment choice)	More energy wood	100	100	100	188	66
	Less energy wood	100	100	100	162	79
S 9. Level of genetic improvement	More breeding	100	101	110	103	101
	Intensive breeding	100	102	114	104	102

5.1.1 How large is the effect on production and the build-up of carbon stock in the forest?

Table 2 shows the influence of the 9 silvicultural measures on the development of carbon stock in the total forest area for 3 points in time - 2020, 2050 and 2100. For 2050 is given the influence on harvest for wood for energy and the wood for other purposes (use wood). Some of the 9 silvicultural measures presented in Table 1, have positive influence on both living carbon stock and harvest (e.g. increasing afforestation, intensity of regeneration and improvement of genetic material), while other measures have diverging effects on carbon stock and harvest respectfully (e.g. species choice, set aside forest and thinning intensity) (Figure 1 and Figure 2).

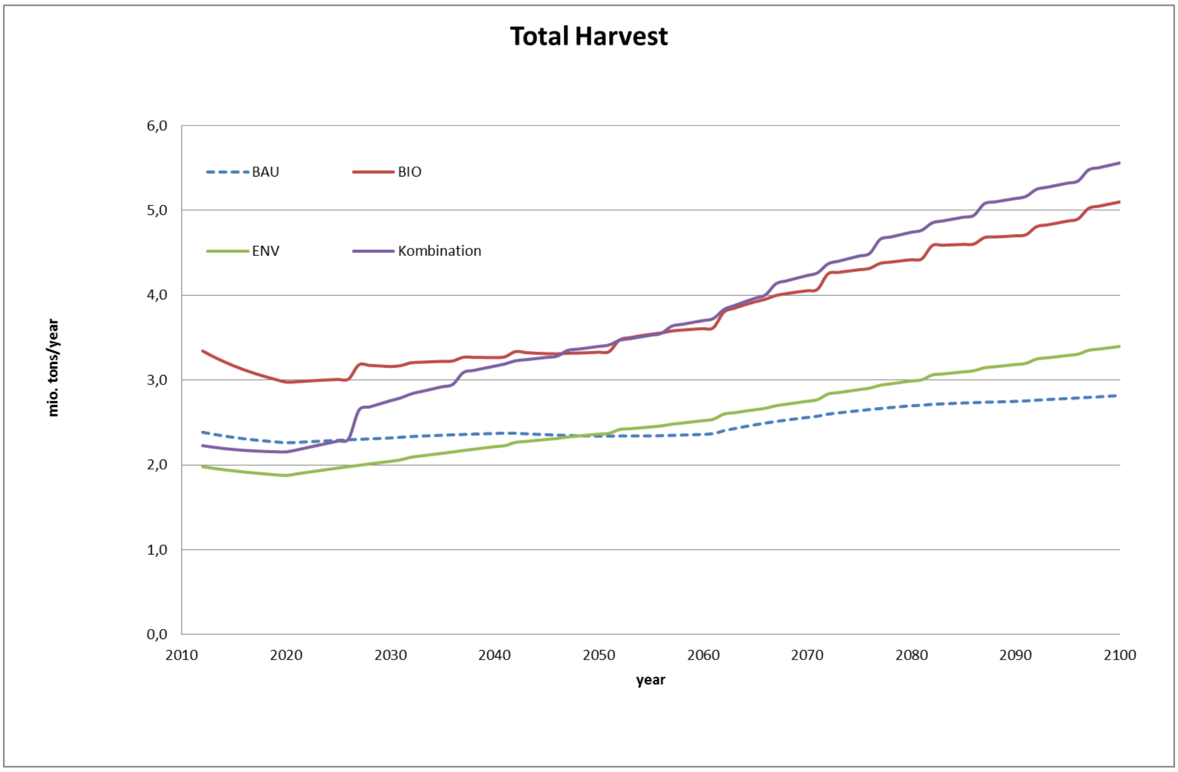

Figure 1. Development of total production for the four scenarios until 2100. Production measured as annual harvest in million ton dry matter of industrial wood and wood for energy

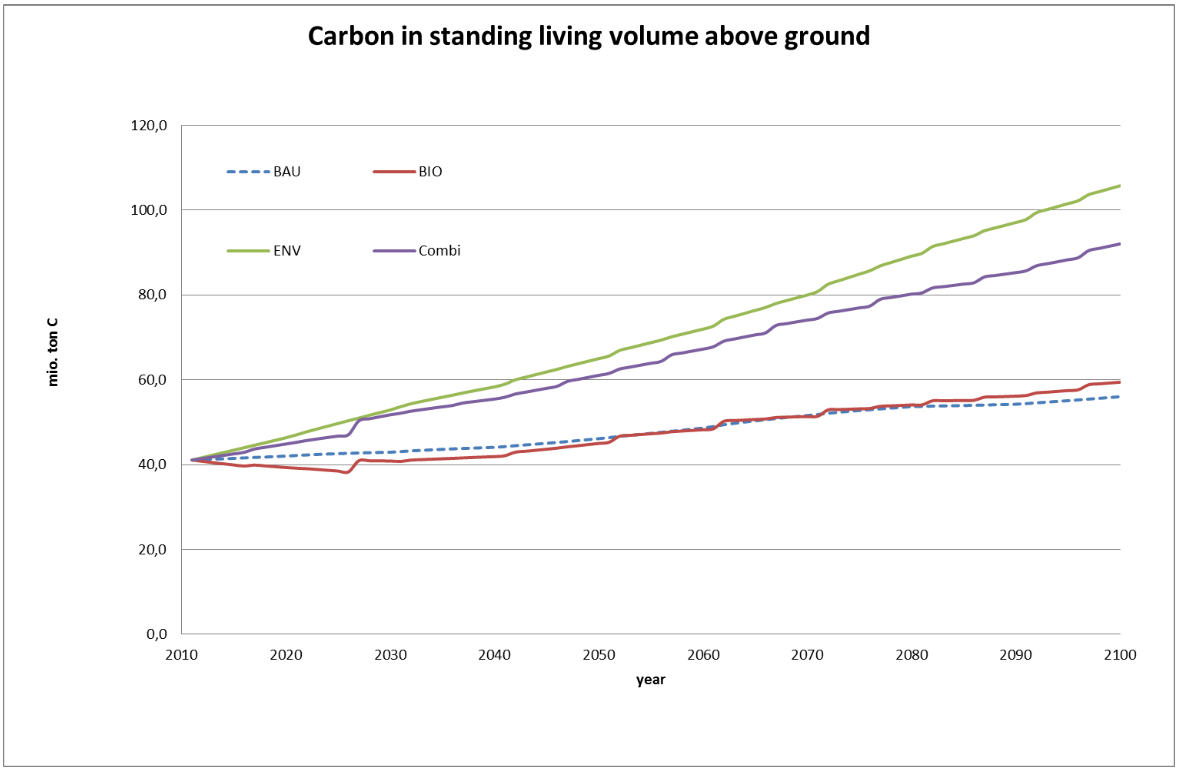

Figure 2. Accumulated amount of carbon in standing volume above ground (million tons)

5.1.2 Summary - forest management

The study focused on the effect of different silvicultural measures on wood production and deals only marginally with the welfare economic effects the measures may have on e.g. recreation, groundwater protection, biodiversity, and landscape values. A qualitative assessment of these effects are discussed in the full study, but not included in this abstract. Conclusions given here are therefore limited to the issue of wood production and supply.

It is possible to increase the sustainable productivity of the Danish forests considerably and provide a significant contribution to Danish energy as well as to the reduction of Danish CO2 emissions. The most important measure to increase production is an expansion of the forest area. A combination of other silvicultural interventions may provide a potential increase of productivity of a similar magnitude as expansion of the forest area, e.g. more intensive initial plantings using fast growing species combined with breeding of fast growing cultivars. Of particular interest is that such high productivity systems can be established without the use of energy demanding fertilizers and pesticides.

In relation to the stability of the prognosis of the BAU scenario, which forms the core of the reference level calculations, the study provides insights into the sensitivity to different elements of the development of the forest area.

The analyses of the study are made at an overall level covering the whole forest area and potential forest area development in Denmark. It is unlikely that such a programme can be implemented at full scale. Implementation will depend e.g. on the size of the forests estates, their development objectives and access to the relevant silvicultural competence. It is also clear that the potential gains only can be achieved through new investments in research and development of silviculture and tree improvement with focus on adaptation and production.

5.2 Global and climate change

Key environmental factors influencing forest growth in Europe have changed over millennia and in particular during the last half century (Figure 3), of which some are summarized in (de Vries et al. 2014). Disentangling individual effects of climate change, i.e. changes in temperature and/or precipitation regimes, from global changes in cycles of fundamental elements like carbon, nitrogen, phosphorus and sulphur is still a major challenge in ecosystem research..

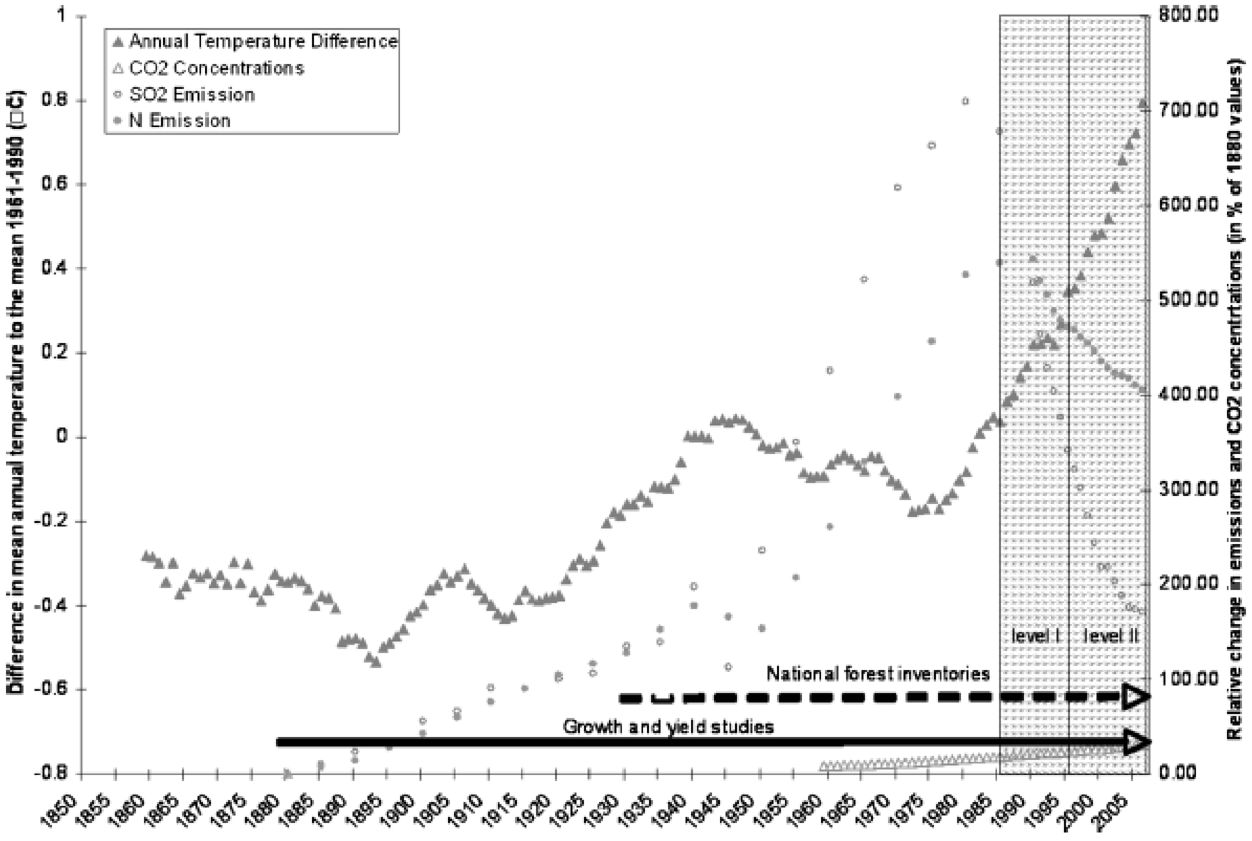

Figure 3. Relative changes in: (i) SO_2 and N emissions in Europe between 1880 and 2007 (data until 1990 based on (Schöpp et al. 2003) **and EEA data from 1990–2007), (ii) CO_2 concentrations since 1960 (station Mauna Loa) in comparison to estimated values from 1880 1880 base 292 ppm and (iii) mean annual temperature deviation with respect to the 1961–1990 reference period for the Northern hemisphere (University of East Anglia data set) averaged using a 10-year moving window. The gray bars in the figure also shows the period ICP Level and Level II forest monitoring networks in Europe, that started in 1986 and 1994 (Cited from Figure 1 in** (de Vries et al. 2014)

Recent work indicates that terrestrial carbon uptake responds significantly to increased atmospheric CO_2 concentrations [CO2] (Keenan et al. 2016; Schimel et al. 2014). This is based on modelling studies including an ensemble of prognostic dynamic global vegetation models (DGVMs), resulting in enhanced carbon uptake at rising [CO2] due to higher rate increase for photosynthesis compared to global respiration, which may also at least in part be caused by increased water use efficiency at increased levels of [CO2].

However, reviews of combined effects of rising [CO2] and elevated temperatures on forest and trees (Saxe & Dragsted 1999b; Saxe & Dragsted 1999a; Stinziano & Way 2014; Ainsworth & Long 2004) reveal a multifaceted picture of non-additive, combined effects. Key results across the published results indicate an increase in biomass with increase in [CO2] and a limited effect of rising temperature, but also that the potential for continued increased biomass/photosynthetic productivity is likely to be limited by water supply and progressive nutrient limitations (Luo et al. 2004) as well as the photoperiod in the field. The analysis by (Stinziano & Way 2014) focused on the boreal forests, currently accounting for 33 % of the Earths total forested area (FAO 2016), and found that while climate changes have the potential to increase productivity of northern forest species, this response is likely to be limited by soil resources and photoperiod in the field and may not occur under the conditions predicted for this region. Furthermore, different plant groups respond differently to exposure to [CO2], with high variability in the response of trees (Ainsworth & Long 2004), which indicates that predictions of future growth and carbon gain in forests are to be interpreted with caution.

Many studies of plant response to elevated CO_2 levels are based on either herbs or tree seedlings of 2-10 years of age, focusing on leaf-level traits such as photosynthesis, respiration, stomatal conductance and transpiration, whereas few handle multifactorial experiments or include mature trees (Way et al. 2015; Stinziano & Way 2014; Dawes et al. 2011; Girardin et al. 2016). Dawes (Dawes et al. 2011) states "Results from studies of older trees in systems with complete plant–soil coupling indicate high interspecific differences in growth responses and overall lower responsiveness in biomass production than initially found in chamber experiments with young trees and otherwise optimal growth conditions". The results were based on 9 years of treatment in FACE experiments in high altitude forest to test effect of elevated CO_2 levels. Larch trees growing under elevated CO_2 levels showed increased biomass production, whereas pine showed no such cumulative growth response. The effect in the larch was smaller than previously observed for seedlings of the same species.

Similarly (Cha et al. 2017) investigated the effects of elevated CO_2 levels on *Quercus acutissima* and *Fraxinus rhynchophylla* seedlings. The dry weight was not changed, but the allocation within the seedlings was affected (lower shoot/root ratio (S/R) leading to higher below ground biomass). The litter decomposition was influenced, depending on species. Several studies suggest deeper rooting distributions under elevated CO_2 levels (Arndal et al. 2017; Iversen 2010; Kongstad et al. 2012; Poorter et al. 2011; Poorter et al. 2013), which may affect ecosystem processes.

Several studies highlight the impact of plant available nitrogen has for the growth, and that limitations in nitrogen may reduce or eliminate the increase in growth induced from increased CO_2 (Klein et al. 2016; Hoosbeek et al. 2011; Nair et al. 2016; Jennings et al. 2016; Cha et al. 2017; Terrer et al. 2016). The increase in nitrogen emissions in the period 1880 - 1990 and especially during the last half century (Figure 3) has influenced the European forests and has contributed to increase in growth in areas, where nitrogen otherwise has been limiting. Although, emissions of nitrogen in Europe have been reduced during the last couple of decades relative emissions are still high (Figure 3).

Water availability and the water use efficiency (WUE) (Keenan et al. 2013; McMahon et al. 2010) of trees are other co-varying factors along with rising atmospheric CO_2 levels, increasing temperature and changes in precipitation patterns. Studies indicate species specific responses in terms of anatomical adaption of lumen area of water conducting cells and leaf stomatal conductance. Some species benefit in terms of better WUE while other species experience reduced growth (Watanabe et al. 2016; Poorter et al. 2013; Fernandez-de-Una et al. 2016; Gimeno et al. 2016). Some of these effects are also influenced by the management of the forest areas, e.g. by influencing the competition between the trees. Analyses also indicate the competition between different layers in the forest (over and under storey) may have opposing responses, as the over storey may increase leaf area and intercept more of the light, under storey is reduced in potential photosynthesis (Kim et al. 2016), leading to no overall effect on aboveground biomass. The respiration of trees originates from all parts of the tree, i.e. stem, roots, leaves, and is also influenced significantly by changes in CO_2 levels, even though the direction may vary between species and plant compartments from increase to reduction (Saxe & Dragsted 1999b; McMahon et al. 2010). Recently, new studies point to that large scale shifts in continental net primary production may be caused be large scale continental climate changes caused by variability in the North Atlantic (Buermann et al. 2016).

Generally the literature documents a huge variation in the observed effects on tree growth from experiments manipulating CO_2 levels and other climate and global changes influencing growth. This short review of effects on forest growth of changes in climate and other global changes is far from a complete overview of the current stage of knowledge, as this would require considerably more time than available for this report. Haworth et al (Haworth et al. 2016) points to the challenges of current review processes of articles and with meta-analyses related to a skewness in publications toward positive studies, driven by a publication bias, a data availability bias and a reviewer bias. This phenomenon is known from other sciences as well, as e.g. medical sciences and methods to address the issues have been developed (Begg & Mazumdar 1994; Duval & Tweedie 2000) but is rarely implemented. This may lead to overestimation of effects of global and climate change.

There is no doubt, that combined effects of global and climate changes, i.e. CO_2 levels, increased temperatures, changes in precipitation patterns will occur. But, whether it will result in increased or reduced carbon storage in e.g. forests will depend strongly on interactions determined by other changes, e.g. emissions and depositions of N, SO2, O3, soil and tree genetics, as well as changes in other aspects of the ecosystems functioning and diversity (insects, fungi and other plants).

5.3 Summary

The overall trend of biomass increment and increased uptake of carbon in forests across Europe and in Denmark is a global trend likely caused by a combined effect of a multitude of changing factors, of which human induced forest management, silvicultural activities and selection of species and genetics as well as changes in atmospheric deposition (both positive and negative influence), elevated atmospheric CO_2 concentration, increased temperatures and changed precipitation are influencing the observed increment in a multitude of ways. Which of these factor that influence the changes the most is not clear, but they all contribute. Disentangling the individual effects of all these factors is still a major unresolved challenge in ecosystem research today.

6 LULUCF accounting for forest

6.1 Principal methods for calculations

Basically two different methods can be applied when calculating changes of carbon pools over time in forests - either "stock change" approach or the "increment and harvest" approach. The largest changes occur in the biomass carbon pools, but the principal method applies for all the carbon pools of the forests.

6.1.1 Stock change

This approach is based on actual assessment of carbon stock at two given points in time and provides estimates of change over time as the difference between the two 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 stock estimates and hence the effect on change estimates. This is the approach utilised in Denmark for accounting of the living and dead carbon stocks of the Danish forests, while GHG emissions from soils are based on area estimates and annual emission rates (Nielsen et al. 2016; Nord-Larsen & Johannsen 2016). The same approach is applied for estimation of Forest Management Reference Level (FMRL) - with more on this issue in Chapter 7.

A special issue arises when changing the area of the different pools, e.g. when transferring afforestation area of a certain age to the pools of forest land as a result of Article 6 (see 4.1). In these situations there need to be a special focus on the age class changing pool. This in order to assign the actual change to the afforestation including the growth/harvest/mortality of the last year, before transferring the age class to the next pool. Therefore, the stock of the age class in focus needs to remain in the donating pool until the end of the year (31.12) and only be transferred by the beginning of the next year (1.1). Hence, the stock change approach requires a specific focus on the age class transition, to ensure a reporting similar to the reporting based on increment and harvest, described below. The area of afforestation in Denmark is relatively small and hence the stock change estimates are less certain, and need further development and validation of the models before the final submission of a new forest reference level for Denmark.

6.1.2 Increment and harvest

This approach is based on combined estimates of growth and harvest, where the latter includes natural mortality. Since measurements of increment are highly influenced by measurement errors over short time intervals, most reporting of increment for forestry is based on growth models.

Growth models are typically based on historical data from experimental plots or inventory data and more or less advanced models. Some models are simple regressions with easily observable parameters (such as tree species, height and diameter) as input while others are process based models requiring detailed information on climate (temperature, precipitation, soil nutrients) and spatial structure of trees and forests (detailed mapping of trees and their dimensions). Overall the models may provide a smooth development, but estimates may be far from the actual growth rates and may require either huge amounts of data or simplified assumptions on the growth factors. Models based on a recent and short time series reflecting current environmental conditions will have the drawback of being based on less data and thus being more uncertain.

Harvest and mortality is occurring more or less randomly in the forests, causing it to be difficult to monitor and hence to model. Most countries using this approach base the harvest estimates on either harvest licenses or reported harvest. Mortality is typically either modelled or the net effect is assumed included in the growth models.

Some generic models have been developed since early 1990's (Sallnas 1990) and been iterated several times and do now provide a system of tools for prognosis as the EFISCEN system (Schelhaas et al. 2016) and others (Black et al. 2011; Böttcher et al. 2012). These systems require a number of input data and parameters, to combines a multitude of models for the prognosis and estimates of carbon stocks. Core elements of the EFISCEN model also include regeneration probabilities. Even though sensitivity analysis have been performed for some of these, the combined uncertainty is significant.

In a Danish context, the data from long term field experiments and well as the NFI could provide some of the data for this type of models, but in terms of reporting it would require significantly more data collection (e.g. on forest floor, dead wood and mortality/regeneration) and the management effects will be difficult to match with the actual initiatives and recorded harvest. The historic records of harvest levels in the Danish forests have been biased, due to missing handling of the small forest owners. Development and verification of a complete model suite for Danish forests (regeneration and recruitment, forest growth, mortality and harvest) would require a considerable effort and work. The currently available growth and yield modes are based on historic data and have been developed over a span of years from 1920 - 2010. The accuracy and the certainty of the predictions will depend on how well the models reflect the current forest management. For afforestation the growth and yield models can supplement the sample based predictions.

6.2 Data used for calculation of CO_2 emissions and removals

The calculation of CO_2 emissions from forests in Denmark are based on data from different sources. From 1881 to 2000, a National Forest Census was carried out roughly every 10 years based on questionnaires sent to forest owners e.g.(Larsen & Johannsen 2002). Since the data was based on questionnaires and not field observations, the actual forest definition may have varied. All values for growing stock, biomass or carbon pools based on data from the National Forest Census were estimated from the reported data on forest area and its distribution to main species, age class and site productivity classes using standard forestry yield tables. The two last censuses were carried out in 1990 and 2000.

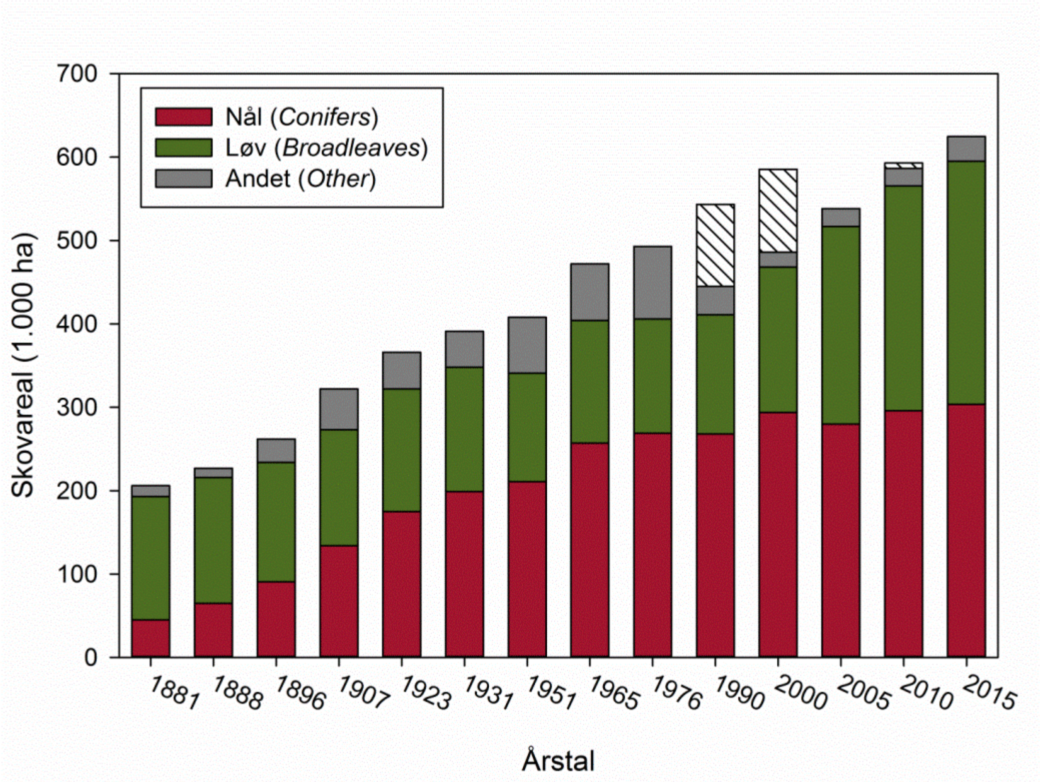

Figure 4. Development in the forest area distributed to broadleaves, conifers and other. "Other" includes unstocked areas in forests and areas where the species is unknown. Before 2005, the estimates are based on questionnaire surveys. The three hatched areas show the total forest area estimated from satellite imagery in 1990, 2000 and 2011.

In 2002, a new sample-based National Forest Inventory (NFI) replaced the National Forest Census. This type of forest inventory is very similar to inventories used in other countries such as Sweden or Norway. The Danish NFI is a continuous sample-based inventory with partial re-placement of sample plots based on a 2 x 2 km grid covering the Danish land surface. In each grid cell, a cluster of four circular plots for measuring forest factors (e.g. wood volume) are placed in the corners of a

200 x 200 m square. Each circular plot has a radius of 15 meters. When plots are intersected by different land-use classes or different forest stands, the individual plot is divided into tertiary sampling units.

About one third of the plots is assigned as permanent and is re-measured in subsequent inventories every five years. Two thirds are temporary and are moved randomly within the particular 2x2 km grid cell in subsequent inventories. The sample of permanent and temporary field plots has been systematically divided into five non-overlapping, interpenetrating panels that are each measured in one year and constitute a systematic sample of the entire country. Hence all the plots are measured in a 5-year cycle. A detailed description of the Danish NFI is presented in (Nord-Larsen & Johannsen 2016).

The forest definition adopted in the National Forest Inventory (NFI) is identical to the Food and Agriculture Organization (FAO) definition (FAO 2016) and includes,

"Wooded areas larger than 0.5 ha with a minimum width of 20 m, that are able to form a forest with a height of at least 5 m and a crown cover of at least 10%."

Temporarily unstocked areas, fire breaks, and other small open areas, that are an integrated part of the forest, are also included.

6.3 Calculation of carbon stocks and CO_2 emissions and removals in forests

For tree species where biomass functions are available, individual tree biomass is estimated from measured diameter and the measured or estimated tree height. For calculation of forest biomass and carbon pools, local individual tree biomass functions are available for the most important tree species in Denmark including Norway spruce (Skovsgaard et al. 2011), beech (Skovsgaard & Nord-Larsen 2012), silver fir, grand fir, Douglas fir, Sitka spruce and Japanese larch (Nord-Larsen & Nielsen 2015). A novel study, using in part the data underlying the previous biomass functions, has resulted in the development of a new set of biomass equations including more species (Nord-Larsen et al. 2017). The new equations will be included in the reporting of carbon stocks for 2016 and onwards.

For tree species where biomass functions are not yet available, total above ground volume for broadleaves and total stem volume for conifers is estimated with species specific volume functions. For species where no volume function is available, a volume function is chosen from species with a similar phenology. Subsequently, total above ground biomass and total stem biomass is calculated applying a species specific basic density (Moltesen 1988). Finally, total above ground biomass for conifers is calculated using a stem to total above ground biomass expansion factor model. The model was derived from the data used for developing the biomass functions for conifers mentioned above. For coniferous species an expansion factor model developed for Norway spruce (Skovsgaard et al. 2011) is applied, whereas for deciduous species an expansion factor model developed for beech (Skovsgaard & Nord-Larsen 2012) is used. The models include also below ground biomass.

Emissions and removals of CO_2 from forests are calculated using the stock change approach, as differences in carbon stocks between subsequent years. To reduce uncertainty of the carbon pool estimates, each estimate is based on data from a full five-year measurement cycle. Consequently, with annual reporting of CO_2 emissions, there is a four-year overlap of the data for the change estimates.

6.4 Uncertainty on estimates of carbon stocks and carbon stock changes

In a statistical sense, the Danish NFI has a cluster design with unequal cluster size. Design based estimators are available for such designs, but the Danish NFI design is further characterised by the partitioning of sample plots and unequal representation of different tree sizes within the circular sample plots (i.e. trees with diameter at breast height (dbh) <10 cm are measured within a 3.5 m radius circle; trees with dbh<40cm are measured within a 10 m radius circle; trees with dbh>40 cm are measured within a 15 radius circle). Considering, the nature of the design, derivation of an analytical estimator may be a dubious undertaking.

An alternative to the derivation of analytical estimators is the use of resampling methods in which random samples are repeatedly generated from the original data and estimates are obtained for the specific variable (i.e. biomass and derived carbon stocks). One such resampling method is bootstrap sampling in which a random sample of N elements is repeatedly drawn with replacement from the original sample with N elements. Estimates from each bootstrap sample are collected and used for calculation of population mean and variance. Under the assumption of normality, confidence intervals of the carbon pool estimates may be calculated. As the number of bootstrap samples increases, the estimates stabilize around the population mean and variance. The number of bootstrap samples needed depends on the within population variation and the sample size. We used a total of 1000 bootstrap samples, as estimates stabilised within this range (see subsequent figures).

The carbon stocks of soil dead wood are not included in the bootstrap analyses.

6.4.1 Uncertainty of forest area, growing stock and carbon stocks

Calculated from the data collected in the five-year measurement cycle 2011-2015, the living above ground, below ground and total carbon stocks are 33.064, 7.170, and 40.234 mio. tons C, respectively (Table 3). After 1000 bootstraps, the mean estimate and the corresponding confidence intervals had stabilized (Figure 5) and the mean estimate derived from the bootstrap samples deviated around 0.6 % from the estimated mean pools (Table 3).

Table 3. Overall estimate of 2015 forest resources (area, growing stock and derived carbon stocks) and the corresponding estimates obtained with bootstrap sampling of 1.000 samples.

	Variable				
	Forest area	Growing stock	Above ground carbon	Below ground carbon	Total carbon
	Ha	1000 m^2	1000 t	1000 t	1000 t
Estimate	624,699	130,526	33,064	7,170	40,234
Bootstrap sampling					
Mean	620,853	129,740	32,866	7,127	39,992
Std. error	7,033	2,103	534	118	651
Lower 95% confidence limit	607,051	125,612	31,819	6,895	38,715
Upper 95% confidence limit	634,654	133,867	33,913	7,358	41,269

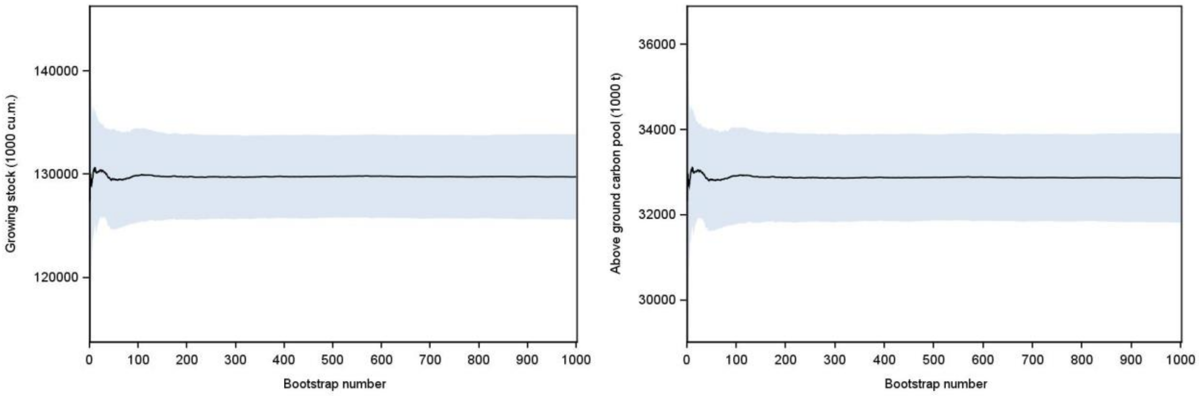

Figure 5. Mean and confidence intervals for the estimates of growing stock and above ground carbon stock with increasing number of bootstrap samples (for the 2011-2015 estimate).

When analysing the forest area, growing stock, and carbon stocks from the 1000 bootstrap samples, the standard error corresponds to 1.1 % of the mean for the forest area and 1.6-1.7 % for the growing stock and the derived carbon stock.

6.4.2 Uncertainty on estimates of changes in carbon stocks

When estimating the change in stocks rather than the stocks themselves, the statistical uncertainty is expected to increase, as the uncertainty depends on both the uncertainty of the estimate for the first and second period and their covariance. In this case, where the annual change is small and the pools are large, the relative uncertainty is expected to be very large.

As with the total pools, the mean and variance of the change estimates stabilized within 1000 bootstrap samples (Figure 6). Compared to the estimates of the mean change obtained from the original sample, the average change in forest area from the boot strap sample deviated 0.8%. However, when considering the change in growing stock and carbon pools, relative deviations from the estimate were much larger (-89 to -173%). The reason for this is that the procedure considers relatively small differences between very large values and thus the relative changes will be large and the number of bootstraps required to minimize the difference between the “true” mean and the bootstrap procedure average will be considerably higher. However, as can be seen from Figure 6, 1000 bootstraps were sufficient to stabilize the variance estimates.

For the one-year change estimates, the standard error obtained from 1000 bootstraps was large compared to the average change (Table 4). For the forest area, the standard error corresponded to 113 % of the mean, and for the change in carbon stocks the standard error corresponded to 60-86 % of the mean. The confidence intervals calculated from the 1000 bootstrap samples in all cases included zero, which means that the change in carbon stocks between subsequent time points one year apart are not statistically significant. One obvious reason for this result is that only about 20% of the data used for the estimates at the two time points are different due to the overlap of five-year data cycles. Another reason is the large relative uncertainty caused by analysing differences between large pools. When changes are less than the standard error, it is relevant to change the period of change observed/reported to be longer than one year. Hence, the next paragraph investigates a similar analysis, but over a five year period.

Table 4. Overall estimate of annual changes in 2014 - 2015 forest resources (area, growing stock and derived carbon stock) and the corresponding estimates obtained with bootstrap sampling of 1.000 samples.

	Variable				
	Forest area	Growing stock	Above ground carbon	Below ground carbon	Total carbon
	Ha	1000 cu.m.	1000 t	1000 t	1000 t
Change estimate	4.053	847	214	47	261
Bootstrap sampling					

Mean	4.020	2.310	513	88	601
Std. error	4.549	1.376	349	76	424
Lower 95% confidence limit	-4.906	-389	-171	-61	-231
Upper 95% confidence limit	12.947	5.010	1.197	238	1.434

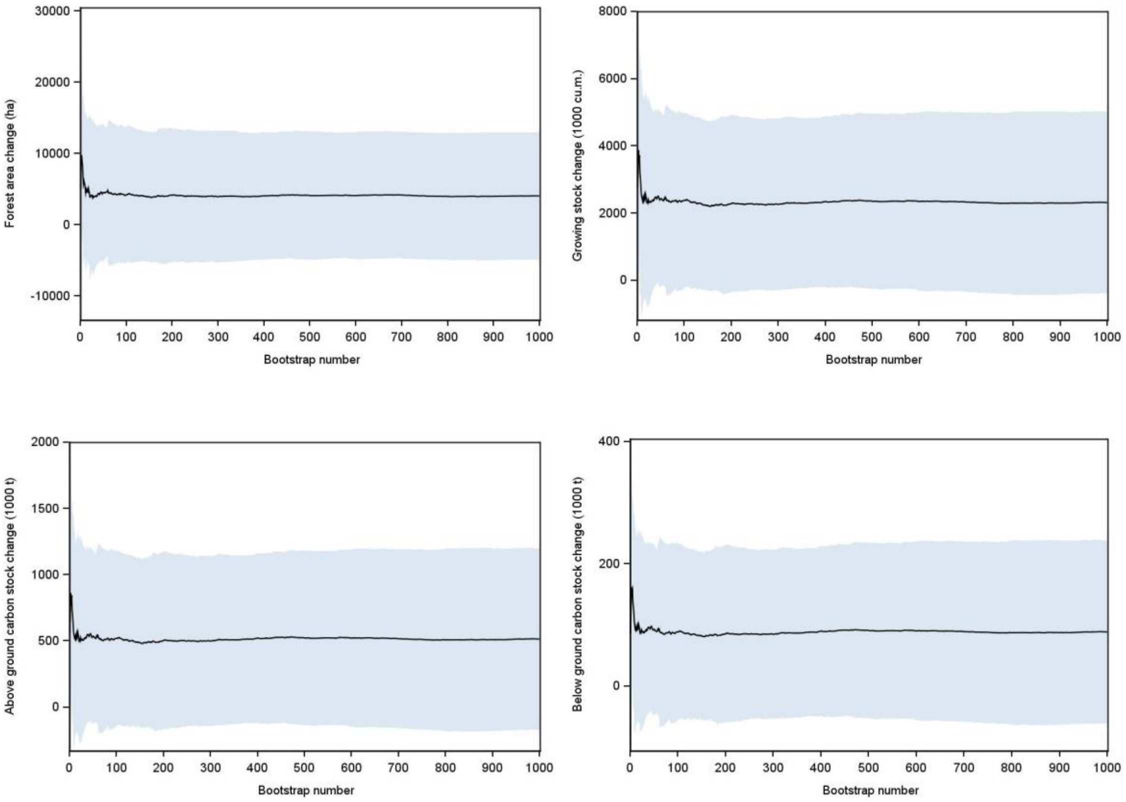

Figure 6. Mean and confidence intervals for the estimates of 2014 - 2015 annual change in forest area, growing stock, above ground carbon and below ground carbon stocks with increasing number of bootstrap samples.

6.4.3 Uncertainty of carbon stock changes based on five-year intervals

If instead of estimation of carbon stock changes would be done at a 5-year interval (corresponding to a full NFI cycle) rather than 1-year intervals the observed change in carbon stocks would be larger. Consequently the relative error would be expected to be smaller.

We conducted a bootstrap sampling for estimating change in forest area, growing stock and carbon pools using data collected in the two periods 2006-2010 and 2011-2015, i.e. five years apart. The difference between estimated carbon stock change and the mean of 1000 bootstraps was 1.3-1.5 %, and the standard error obtained from 1000 bootstraps was ~15% of the mean obtained from the bootstrap procedure. Compared to the bootstrap analysis of changes in carbon stock for one year intervals, the relative errors became much smaller and changes in carbon stocks were statistically significant different from 0, for all parameters analysed (Table 5).

Table 5. Changes of forest area, growing stock, and derived carbon stock estimated at 5 year periods of the Danish NFI (2006-10 and 2011-2015).

Year	Forest area	Growing stock	Above-ground carbon	Below-ground carbon	Total live biomass carbon
	ha	1000 m^3	1000 t	1000 t	1000 t
2011-15	624,782	131,987	33,361	7,215	40,576
2006-10	586,554	116,698	29,579	6,401	35,980
Change estimate	38,228	15,289	3,782	814	4,596
Bootstrap sampling (change)					
Mean	34,976	15,357	3,831	826	4,658
Std. error	7,467	2,207	558	123	680
Lower 95% confidence limit	11,026	11,026	2,737	585	3,324
Upper 95% confidence limit	49,629	19,689	4,926	1,068	5,992

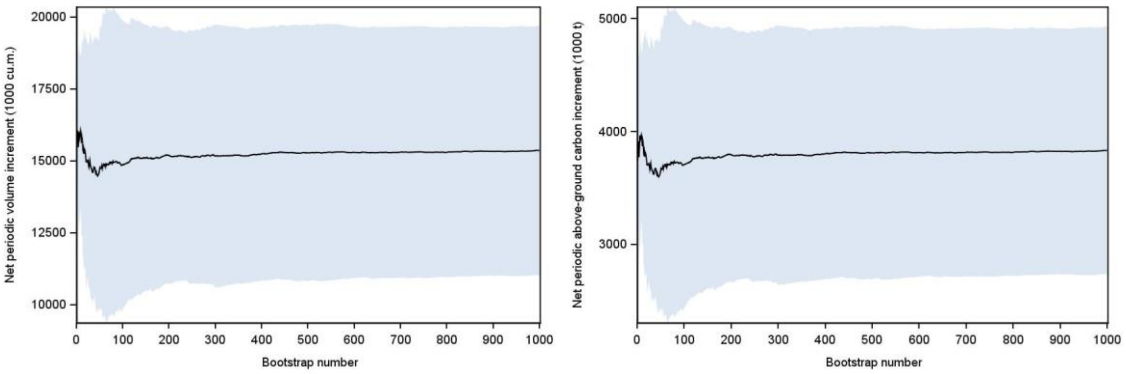

Figure 7. Mean and confidence intervals for the estimates of 2010 - 2015 change in growing stock and above ground carbon stocks with increasing number of bootstrap samples.

6.5 Estimates of carbon stock changes

In this note we have focused on estimating the uncertainty of total carbon pool change estimates from the forest inventory. However, reporting for the UNFCCC or the Kyoto protocol further require a division of the forest area into forest remaining forest (FRMF, article 3.4 of the Kyoto protocol) and afforestation (AF, article 3.3. of the Kyoto protocol). The consequence of such subdivision is further reduction in the number of sample plots representing each class and thus a further increase in the uncertainty. Due to the computational size of the problem when making the bootstraps, we have so far not analysed the effect of such a subdivision, but we expect that it will significantly impact the variance and thus the confidence intervals of carbon pool/carbon pool change estimates.

6.6 Conclusion

We analysed the variance of carbon stock estimates using bootstrap analysis. When considering the total carbon stock, error estimates are small compared to the total stock (1.6-1.7 %). Due to the size of the carbon stocks and the small changes between subsequent years, the error of carbon stock change estimates are substantial (60-86 %) compared to the average change when using the current one-year reporting. In this case, the error is so large compared to the trend, that changes in carbon stocks are not statistically significant. If using 5-year intervals for the reporting, corresponding to the rotation length of the NFI, the relative error becomes lower (~15 % of the mean) and change estimates become statistically significant. This would be in line with the considerations of the design of the Danish NFI, with a continuous sampling, and a 5 year rotation.

7 Forest Management Reference Level – methods and guidelines

In this section we shortly summarise the methodology reviewed for the Forest Management Reference Level (FMRL) for Denmark (Johannsen et al. 2011) and options for including also afforestation in the FMRL as suggested by the EU Commission and further addressed in Chapter 4.

7.1 Forest remaining forest - base year 1990

The Forest Management Reference level for Denmark for the second commitment period (2013-2020) of the Kyoto Protocol focused on the forest area remaining forest (Article 3.4), as was the request in the guidelines. It was assuming no deforestation in the period assessed, consistent with the overall business as usual approach given as key element of the system.

7.1.1 Calculations on NFI data

Based on NFI data, the forest area is estimated as the fraction of the NFI sample plots with forest cover, times the total land area. When estimating the forest area with a specific characteristic, such as forest planted before or after 1990 (article 3.3 or 3.4 of the Kyoto protocol), the proportion of the plot area with the particular characteristic is found by summing the forested plot areas, times an indicator variable, which is 1 if the plot has the characteristic in focus and 0 otherwise. Subsequently the plot area with the characteristic in focus is divided by the total forested plot area. Estimation procedures are described thoroughly by (Nord-Larsen & Johannsen 2016).

Estimation of growing stock (wood volume), forest biomass, and carbon pools are based on the individual tree measurements on the NFI plots and subsequently estimated by different strata of forests or trees (management types, ownership categories, age-classes, tree species, etc.). The estimation procedure is aligned fully with the procedures for LULUCF accounting - see section 4.

7.1.2 Projections for living biomass

Projections of carbon stocks and stock changes set out from estimated carbon stocks and their distribution to age and management classes. The estimates are based on a full five-year rotation of measurements with the NFI from 2005-2009. These carbon stock estimates are available for each forest type (species group) and age class - often referred to as management classes. The stock in each management class is the summary result of the regeneration success, the growth of the trees, the natural mortality and the intermediate thinings/harvests occurring in each management class. This will in summary reflect the effects of changed silvicultural methods, current climate and global changes, harvest intensity (including fuel wood harvest and their potential effects on remaining stock in the forest stands) as they have been implemented until 2009. Hereby the basis for the accounting and the forest management reference level (FMRL) is in line with the suggestions of Article 8 of the proposal from the EU commission (EU Commission 2016), with focus on the most recent silvicultural practices and growth conditions. Furthermore it ensures consistency with the accounting and reporting methods and data.

The species and age-class distribution in 2015-2035 is projected assuming that the forest area in each species and age class, that has not been regenerated, should progress into the subsequent age class after each year. Furthermore, the area regenerated each year 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 a year is termed *the transition probability* whereas the net flow to or from the species classes is termed *the conversion probability*.

Transition probabilities are calculated as 1 minus the probability of regeneration (final harvest/clear cut) (1- $p(harvest)$). The probability of regeneration is derived from an analysis of the two successive forest censuses (Nord-Larsen & Heding 2002). For each species class the aggregated probability that the forest area has been regenerated at any given point in time was modelled from the transition possibilities and the area weighted production class in each county, using a logistic function:

$$p(harvest) = \frac{1}{1 + (\beta_0 + \beta_1 \cdot (1/PK)) \cdot e^{-\beta_2 \cdot T}} ,$$

where PK is production class expressed as total volume production per hectare for a full rotation, T is age and β_0 to β_0 are species specific parameters. The accumulated transition probabilities are illustrated in Figure 8.

By basing the estimation of the transition probability models on the two successive forest censuses the effects of windthrow (especially occurring in conifers e.g. Norway spruce) is included directly in the model. The effect of windthrow on the transition probability is seen from the short rotation ages for most conifers (see lower graphs in Figure 8). The transition probabilities have been tested and utilised in a number of studies (Nord-Larsen & Suadicani 2010; Graudal, Ulrik Bräuner Nielsen, et al. 2013; Johannsen et al. 2011). Overall the models reflect expected silvicultural practices, with minor elements indicating some weaknesses in the data. This is e.g. the case for oak, where there are very limited data for the areas with low production class values (poor soils), which results in slightly shorter rotation age for these stands. However, the influence of PK on these models is very low and the area with oak is small and hence this possible error will only have a minor effect on the overall estimate.

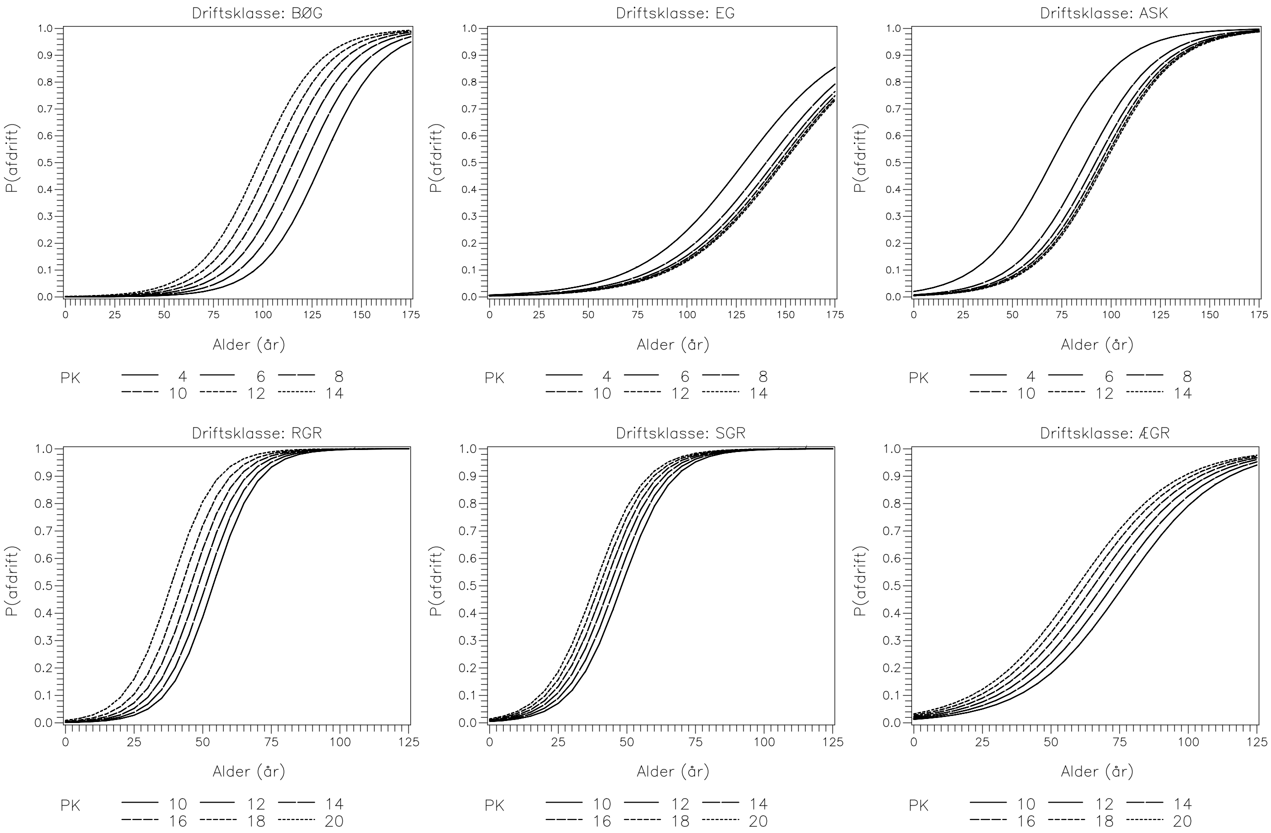

Figure 8. Accumulated clear cut probability (*P(afdrift)*) for different species and production classes (Nord-Larsen & Heding 2002) **From top left to lower right: beech (BØG), oak (EG), ash (ASK), Norway spruce (RGR), Sitka spruce (SGR), and silver fir (ÆGR). The x-axes denote stand age and PK refer to different production classes, i.e. average annual volume production at the optimal rotation age.**

Based on annual projections of the forest area, using the transition and conversion probabilities, the species and age class distribution is estimated for each year. Based on the forest area distribution in each year, carbon pool estimates are obtained assuming that average carbon pools in each species and age class estimated with the NFI data from 2005-2009. This is then applied for the period of 2015-2035. Hereby a prognosis for the development of stock in the forest area is established, which will be consistent with the subsequent reporting for the carbon in the Danish forests.

In this project is was analysed if the NFI could provide data for validation of the transition probabilities, by analysing the data from the period 2002 - 2017, which contains three re-measurements of a number of permanent sample plots. It is possible to estimate survival probabilities for single trees. But this will not provide area based information. Furthermore, a transition to single tree prognosis of the full forest in order to establish a new FMRL will also need to include growth models for single trees and recruitment models, as well as models for mortality and harvest. This type of analysis is outside the scope of this project. With respect to the robustness of such models it is not certain that the predictions will be better than the previous area based approach. Although the resolution of the models is much finer (i.e. modelling individual trees rather than entire species and age classes), the uncertainty of individual model components (individual tree growth, mortality, and harvesting probability) is much larger. Consequently, the variance of estimates may not be improved compared to the previous approach. However, it is certainly relevant to continue working on validation of the transition probabilities, but new methods and potentially data would need to be gathered to accomplish this. Before the final submission of the new Danish FMRL, the analyses and verification on the transition / regeneration probabilities should be performed. This will though require more time and resources.

Overall, the methods for projections of the living biomass, as well as the carbon stocks of the forest floor and the dead wood, follows the guidelines given in the proposal by the EU Commission (EU Commission 2016).

7.1.3 Projections for emissions from forest soil

The review processes and the updated reporting guidelines require that emissions from forest soil are included in the projections. The following methods have been applied, in accordance with the reporting guidelines.

The temporal change in shares of drained and rewetted soils has been assessed based on current trends in forest management. A change in these soil categories was made in 2008 based on expert assessment of observed trends in the past 20 years of active maintenance of pre-existing ditches in forests. For further information see p. 445 in (Nielsen et al. 2016).

CO_2: The expected emission of CO_2 in the forest soils is estimated to 121 Kt CO_2 eq./year. 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 CO_2-C/ha/yr (IPCC: wetland supplement 2013 Chp. 2, Table 2.1). (note: $CO_2eq = \frac{44}{12} \times C$)

N_2O: The emissions of N_2O from the forest soils, with the amount of drained organic soils, are expected to result in an annual emission of 0.05 Kt N_2O /year - corresponding to 4.4 kg N_2O/ha/yr.

With a 'Global Warming Potential' (GWP) of 298 this equals an annual emission of 17 Kt CO_2 eq./year (wetland supplement Chp. 2, Table 2.5 negligible if water table shallower than 20 cm).

CH_4: Based on the changes in drainage status of the organic soils in the forests, the emissions of methane are estimated based on the organic drained soils (2.5 kg CH_4/ha/yr), for the ditches (2.5 % of the area) on organic drained soils (217 kg CH_4/ha/yr) and on the rewetted organic soils (assumed 50/50 poor soils with 122.7 kg CH_4/ha/yr and rich soils with 288,0 kg CH_4/ha/yr), resulting in an annual emission of. 1.13 kt CH_4/year with a GWP of 25 equals an annual emission of 28 Kt CO_2 eq./year. (Wetland supplement, table 2, 2.3-2.5 and 3.3).

7.2 Afforested land

7.2.1 Area - above and under 20 years of age

The average afforestation in the period 1990 - 2005 resulted in 3,678 ha/yr, and in the period 2005-2011 in 3,737 ha/yr. Since 2012 the annual afforestation has been based on detailed field information, resulting in annual updates. In the period from 2015-2035 an annual afforestation of 1,900 ha/yr is expected, but the effect of a higher afforestation (3,200 ha/yr) is included in the analysis of the reference levels. The decline in annual afforestation is based on expected reduced amounts of subsidies for afforestation and a decline in the area afforested without subsidies. The latter is mainly caused by the intensive land use in Denmark and the need for land for other purposes, which may indicate that land area available for afforestation to a large degree already have been exploited. Economic conditions related to agriculture and other land uses (such as changes in subsidy schemes) may change this.

The decline in annual afforestation combined with the transfer of afforestation older than 20 or 30 years to forest remaining forest leads to a decline in the young afforestation area (Figure 9). If the afforestation rates were higher, e.g. 3,200 ha/yr, the area of young afforestation would in rough terms be constant. It should be noted here, that the age of 20, which will be the age of transferring an area from 'afforestation' to the 'forest remaining forest', for Danish silvicultural conditions will be long time before maturity of the first rotation of a forest stand. As can be seen from the transition probabilities (section 7.1.2) typical rotation ages span from 50 to 150 years. The first 20 years represent establishment and parts of the initial growth.

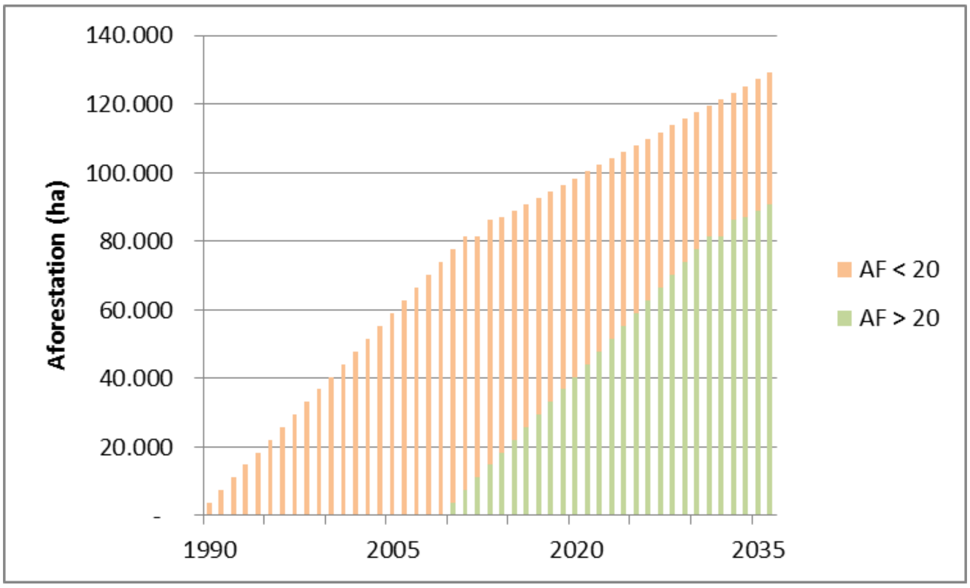

Figure 9. Total afforestation for the period 1990 - 2035 with division of afforestation to younger og older than 20 years, with the first of these starting in 2010. Afforestation of 1.900 ha/year from 2016-2035.

7.2.2 Projections for living biomass

An estimation of the future development of carbon stocks for the afforestation is based on the expected rate of afforestation and the species composition.

The projections for afforestation have been compared to the observed development of afforestation during the period 1990-2012 (Schou et al. 2014). The report by Schou et al. (2014) evaluated afforestation for the period 1990 – 2012, and found that afforestation during this period had not resulted in the carbon accumulation expected from the growth models for the new forests, caused by a multitude of factors which are addressed in the report. Another source of information is the evaluation of afforestation as an instrument for carbon storage, in the case of well managed afforestation with a resulting higher increment and hence carbon storage (Graudal et al. 2013). These two sources form two different inputs for the future development of afforestation in Denmark and form the basis of the prognosis, giving an estimate of future carbon stocks in afforestation areas.

For the afforestation in the period 2015-2035 the average annual afforested area of 1,900 ha is added for each year, assuming a species distribution similar the previous afforestation 1990-2015 and resulting in the same level of carbon stocks. To analyse the sensitivity of the rate of afforestation, a scenario for increased afforestation to 3,200 ha/year is included in the analysis.

The estimate of carbon stock development of the afforestation is based on a mix of three growth and yields models based on C.M. Møller (1933) for beech (Table 11), oak (Table 12) and Norway spruce (Table 13). Based on the analyses by Schou et al. (2014) a mix of 20 pct. beech, 60 pct. oak and 20 pct. Norway spruce is assumed in the prognosis with a crown cover degree of 90 pct. The initial growth of the first 20 years is not directly modelled, but is assumed following a sigmoid growth pattern, resulting in the slow start also identified in the previously mentioned analyses.

The observed magnitude of afforestation is modelled in a matrix model allowing direct estimation of volume of both over all stock and an estimate of the stock of a afforestation in the age class 20 or 30 separately for the use in the change estimates.

7.2.3 Soil and land use change

As a consequence of accounting guidelines, loss of carbon from land-use change has to be included in the accounting, here in the form of the lost biomass from the previous land use. For change from crop land to forest this is estimated to be 6 t C/ha (Nielsen et al. 2016) equalling a loss of 12 t of biomass per ha. With afforestation of 4,000 ha/yr in the period 2008-2012 this results in an emission of 88 Kt CO_2 eq/yr and for the period 2015-2035 an afforestation of 1,900 ha/yr will result in an emission of 41.8 Kt CO_2 eq/yr.

In the afforestation accumulation of carbon in the soils is expected to occur over a period of 50 years. The annual changes in the approx. 100.000 ha established since 1990 is a sink of 13 Kt C /yr or 48 Kt CO_2/yr (Nielsen et al. 2016). This does not include forest floor or dead wood stocks, which are measured directly by the NFI.

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 section 7.1.3), with figures given for approx. 100,000 ha afforestation. In the projections increase in afforestation area is embedded in the calculations.

CO_2: The estimate is based on the area of drained organic soils (50 % of the organic soils - approx. 5,000 ha) in 2013, with an annual emission of 2.6 ton CO_2-C/ha/yr (IPCC: wetland supplement 2013 kap. 2 tabel 2.1) results in 47 Kt CO_2-eq/yr.

N_2O: For the year 2013 the emission of N_2O from the afforestation forest soils, with the amount of drained organic soils, are expected to result in an annual emission of 0.02 Kt N_2O /year - corresponding to 4.4 kg N_2O/ha/yr. With a GWP of 298 this equals an annual emission of 6 Kt CO_2 eq/year (wetland supplement Chp. 2, Table 2.5, negligible if water table shallower than 20 cm).

CH_4: Based on the changes in drainage status of the organic soils in the forests, the emissions of methane are estimated based on the drained organic soils (2.5 kg CH_4/ha/yr), for the ditches (2.5 % of the area) on organic drained soils (217 kg CH_4/ha/yr) and on the rewetted organic soils (235 kg CH_4/ha/yr), resulting in an total annual emission of 0.04 kt CH_4/year with a GWP of 25 equals an annual emission of 1 Kt CO_2 eq/year. (Wetland supplement, table 2, 2.3-2.4 and 3.3).

7.3 Deforested land

Deforestation occurs in Denmark mainly to give area for nature restoration and urban development. The area influenced was 27 ha/yr in the period 1990 - 2005, 325 ha/yr in the period 2005-2011 but the areas was higher in the period 2011 - 2015, with a maximum of 2,251 ha/yr 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 cease in the period 2020-2035. The deforestation is expected to be 116 ha/yr 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, Riis-Nielsen, et al. 2017). For the estimation of influence on the reference levels, this value is based on an average carbon stock of 72 Kt CO_2 eq. for the 116 ha deforested each year.

7.4 Projections of Harvested Wood Products

For detailed information regarding methods and data for the pools of Harvested Wood Products (HWP) and analysis of uncertainties, we refer to Schou et al (2015). For the period 2021-2040 the value for 2013-2020 has been applied - i.e. -65 Kt CO2 eq./year (Schou et al 2015 p. 43).

The reference level for HWP is built on annual inflows and outflows of three categories.

- Paper and paper products
- Wood based panels
- Sawn wood

This accounting approaches used for the period 2013-2020 is suggested to be continued in the period 2021-2040 (EU Commission 2017b), focusing on domestically produced and domestically consumed HWP in the accounting.

The production of HWP in the period 2013 - 2035 is forecasted by the mean annual production in a base period and an index based on the expected harvest in each year. This might seem to be a quite logical way of doing it, but in reality there is a quite poor relation between the harvest in the forests and the production in the wood industry. This is because the production capacity in the wood industry is quite low compared to the harvest of industrial Roundwood in the Danish forests. This has become clear following the global financial crisis that reduced construction and trade of wood, domestically as well as internationally. The production in the wood industry is mostly determined by the outlets of sawn wood, wood based panels and paper and paper products. An increase in the harvest of industrial roundwood in the Danish forests would be positively influenced by a foreign demand for industrial Roundwood.

7.5 Strengths and weaknesses

The strengths are linked closely to the use of the recently observed carbon stocks of the management classes, thereby reflecting updated information of the current management and growth factors. Some of the weaknesses are addressed in the following paragraphs.

7.5.1 Average carbon stocks

In the prognosis of the carbon pools for the period 2015-2035, it is assumed that carbon stocks for individual species and age classes are largely unchanged. This may be questioned. Increasing demand for wood may lead to increased harvesting of wood from the forest, which in turn will affect carbon pools of individual species and age classes and thus overall carbon pools.

In a simulation study on the possibilities of increasing the production of wood in Denmark sustainably, found that a 20% increase in the harvests across all species and age classes lowered forest biomass carbon stocks by 4 % in 2020 and 10 % in 2050 (Graudal et al. 2013). Conversely, lowering projected harvest levels by 20 % led to an increase in overall forest biomass carbon stocks of 5 % in 2020 and 10 % in 2050.

7.5.2 Change in transition probabilities

Change in market demands for wood or changes in forest policy may affect the transition probabilities i.e. overall rotation age. This will in turn lead to changes in the management class distribution and hence future biomass stock and carbon pools. This may be in either direction - towards increased emissions or removals. An example of such effect is when the lucrative market for beech wood collapsed in 2000, foresters postponed harvesting of otherwise mature beech stands in hope of improved prices. Consequently, old beech forests make up a large share of the area with beech (Figure 10) and carbon stocks of beech forests are increasing, whilst carbon stocks of e.g. Norway spruce are relatively constant.

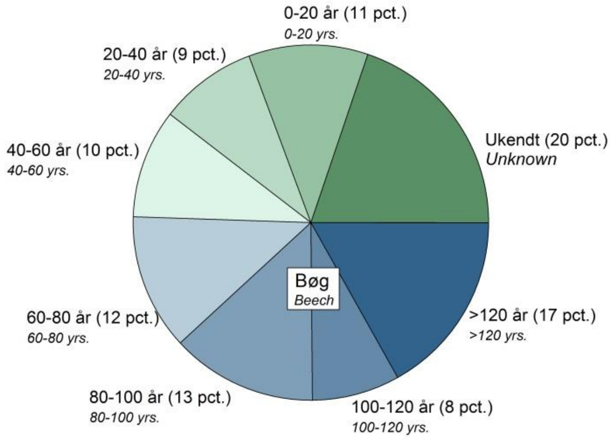

Figure 10. Age distribution of beech in Danish forests. About 25 % of the beech forest area is older than 100 years. Further, a large proportion of the area with unknown age is likely covered by old stands.

From the analyses we observed that a general shortening of rotation ages by 10 years, resulted in a 3 % decrease in carbon stocks in 2020 and 4 % in 2050. However, if rotation ages were increased by 10 years, carbon stocks were unchanged in 2020 and increased by 3 % in 2050.

With about 10 % of the total carbon pool in living biomass contained within beech stands older than 120 years, (under the assumption that 50 % of the age class “Unknown” is older than 120 years) sudden changes in the market for wood may therefore have a significant effect on carbon pools (as indicated above with a shortening of rotation ages).

A similar effect may be seen as a result of windstorms leading to catastrophic windthrows, which usually influence conifers more than broadleaves. The storm on December 3rd 1999, which was the most severe storm in Denmark ever recorded, resulted in only 3-4 % of the above ground biomass carbon stock being windthrown. As this corresponds to the annual harvest of 1-2 years, even serious events of windthrow are not expected to influence overall carbon pools severely. However, this conclusion may be revised as a result of the more extreme weather expected as a result of climate change.

An opposite effect on the transition probability would be if forest management is abandoned in large parts of the forest, for example as the result of leaving some of the state forests as nature reserves. In the study by Graudal et al. (2013), such initiatives were simulated by abandoning forestry on 1) 46,100 ha of biodiversity forest, 2) 50 % of the broadleaved forest (127,150 ha) and 3) 100 % of the broadleaved forest (275,755 ha). In 2020, all three scenarios led to a 5-6 % increase in carbon pools relative to the reference. In 2050, the three scenarios led to an increase in carbon pools of 11-23 %. The simulations did not account for the effect of abandoning forestry on carbon pools in harvested wood products and possible substitution effects.

7.5.3 Changes in conversion probabilities

Changes in forest policies affect the choice of forest tree species grown, which in turn affect the conversion probabilities used in the simulations. As different species have different growth patterns, this in turn affects forest carbon pools positively or negatively in the short or long term. For example, when subsidy schemes are promoting broadleaved species such as beech or oak, initial growth is slow and carbon pools are increasing more slowly than when growing conifers. However, in the long term, carbon pools of the broadleaved species are generally large and such schemes may lead to increased forest carbon stocks.

In a simulation study changes in conversion probabilities were simulated in two scenarios favouring conifers and broadleaved species respectively: 1) 50 % of all regenerated broadleaved stands were converted to conifers, and 2) 50 % of all regenerated coniferous stands were converted to broadleaves. The two scenarios had only limited effect on the carbon pools in a 15-25 year perspective. However, increased use of fast growing nurse trees when establishing new forest stands increased carbon pools by 1 % in 2020 and 8 % in 2050 Graudal et al. (2013).

7.5.4 Afforestation - rate and composition

In the estimation of the reference level component for the afforestation a mixture of carbon stock estimates and growth models are applied. The recent sample based estimates of the success of afforestation in terms of degree of crown cover and realised growth have been compared to available growth models (Schou et al. 2014). This has resulted in a mixture of species and growth conditions (as indicated by the site index for the species) providing estimates consistent with the observations during the recent 15 years (2002-2017) with the NFI. The further prognosis of the development of the afforestation is thus based on model assumptions, which need to be verified further before the reference level for Denmark is finally established. This is especially important as a majority of the growth of the afforestation with the new guidelines will be included in the reference level. Hence deviations from the prognosis will have impact on the overall carbon balance for Denmark in relation to the expected values. Previously, the uncertainty of the afforestation and its success also influenced the accounting, but in a more direct way with the full effect - small or large.

The afforestation occurs under soil and growth conditions different from the forest land with long-term continuity (>2-300 years) in Denmark, and hence the growth patterns of both specific tree species and forest ecosystems may deviate from the expected growth pattern, leading to higher uncertainty of the future contribution to the carbon accounting for Denmark.

7.5.5 Overall effects on the carbon pools

In the above description of the uncertainties related to assessing future forest carbon pools, focus has been on the effect of individual measures, while the combined effect of measures may be different. For example, in the event of a major windthrow, forest owners will commonly reduce forest carbon pools when salvaging the storm felled and damaged trees. However, the market for wood will usually react by lowering prices and hence reduce felling in undamaged stands. Consequently, the effect on overall carbon pools will be less and viewed over just a few years, the effect is likely to be none. Similarly, although increased prices on beech would undoubtedly lead to increased felling of beech trees and thus lowering of forest carbon pools, the short term available manpower in the forestry sector is limited. Consequently, sudden, violent increase in harvesting is unlikely and changes in carbon pools will likely be slow.

In the simulation studies by (Graudal et al. 2013) mentioned above different combinations of silvicultural measures were gathered in four scenarios depicting different intensities in growing biomass. The scenarios ranged from a scenario with focus on management of forests for biodiversity, to a scenario aimed at generating the largest possible amount of biomass for energy. The forest carbon stocks in the four scenarios varied significantly from 94 % to 110 % of the reference scenario in 2020 and from 96 % to 141 % of the reference scenario in 2050. These results may indicate the possible range of forest carbon stocks, provided different future political and economic preconditions.

7.5.6 Options and needs for new data and analyses

One objection against the present approach for predicting future forest resource availability, be it carbon stocks or CO_2 emissions, is that it rather simplistically relies on transition probabilities estimated on observed changes between the two forest censuses in 1990 and 2000 for the prediction of the forest remaining forests. The repeated measurements of sample plots in the NFI provide an opportunity to update existing knowledge on both forest tree growth, transition, and conversion probabilities. Such updates would enhance especially short term predictions, where current economic and technical conditions may be assumed to apply.

For long term predictions, economic and technical conditions may change and hence a fixed set of transition and conversion probabilities may no longer apply. Some studies have demonstrated a more direct simulation of the effect of changes in the economic or technical preconditions on resource supply using linear program (e.g. Bergseng et al. 2013). A similar approach can also be used to predict the effect on carbon stocks and emissions.

Afforestation poses a specific challenge both in terms of predicting the carbon of the young stands (less than 20 or 30 years) but even more so for the part of afforestation transferred to the forest remaining forests area. The growth models can reproduce the observed development so far, but future changes in areas utilised for afforestation and species composition may cause deviations from the predicted development. Further analysis of afforestation and its likely development are needed.

7.6 Reference level - summary

Below in Table 6 are the summary figures for the current estimate of the annual changes in carbon stocks for the Danish forests. Emissions from forest soils as well as accounting for HWP are also provided. These are the main components of the Forest Management Reference Levels. The different parts of the LULUCF categories and HWP are given separately, so the effects of the new proposals can be identified easier.

The estimation of the FMRL follows the guidelines proposed in Annex IV (EU Commission 2016; EU Commission 2017a), specifically the robust and credible accounting, including HWP as a specific pool. The reference level takes into account the management for biodiversity, as this is included in the state of the forests as they are now in terms of species and area distribution and current carbon stocks (2000-2009).

The effects of different levels of afforestation in the period 2015-2035 are included in part B of Table 6. The estimates are given as mean values for 5 year intervals, reflecting a relevant reporting period. More detailed information on the separate elements are given in Annex 10.3 with data for the expected afforestation of 1,900 ha/yr in Table 14 to Table 16, while Table 17 to Table 19 provide estimates of carbon stocks for a higher afforestation rate of 3,200 ha/yr.

Table 6. Summary changes in carbon stocks, including emission from soil - CO_2 and other gasses (NO_2, CH_4). Annual afforestation of 1,900 ha/yr as the default (A-table). Overall effect of annual afforestation of 3,200 ha/yr is given in the B-table. For details see Annex 10.3.

A - afforestation 1,900 ha/yr	**2015-2020**	**2021-2025**	**2026-2030**	**2031-2035**
I: FRF - from before 1990				
Area (ha)	524.551	523.651	522.978	522.305
Carbon stock (AG+BG+DW+FF) (ktC)	46.332	46.048	45.550	45.214
Carbon (soils and gasses) (kt CO2/yr)	167	167	167	166
Stock change + soils incl transfer (kt CO2/yr)	228	428	548	328
II: Afforestation - Older than 20 yr				
Area (ha)	31.263	51.503	70.119	84.932
Carbon stock (AG+BG+DW+FF) (ktC)	1.297	2.638	4.082	5.585
Carbon (soils and gasses) (kt CO2/yr)	5	11	17	22
Stock change + soils incl transfer (kt CO2/yr)	-617	-705	-852	-907
III: Afforestation - Younger than 20 yr				
Area (ha)	62.301	52.623	43.609	38.399
Carbon stock (AG+BG+DW+FF) (ktC)	821	715	573	464
Carbon (soils and gasses) (kt CO2/yr)	48	43	39	35
Stock change + soils ex transfer (kt CO2/yr)	-142	-121	-89	-61
IV: Deforestation				
Area (ha)	578	116	116	116
Carbon stock (AG+BG+DW+FF) (ktC)	-36	-20	-20	-20
Carbon (soils and gasses) (kt CO2/yr)	-	-	-	-
Stock change (kt CO2/yr)	105	72	72	72
V: Afforestation - Older than 30 yr				
Area (ha)	613	14.712	33.102	51.503
Carbon stock (AG+BG+DW+FF) (ktC)	39	1.002	2.434	4.044
Carbon (soils and gasses) (kt CO2/yr)	1	7	12	18
Stock change + soils ex transfer (kt CO2/yr)	-19	-194	-336	-446
VI: Afforestation - Younger than 30 yr				
Area (ha)	92.951	89.415	80.627	71.827
Carbon stock (AG+BG+DW+FF) (ktC)	2.078	2.352	2.221	2.005
Carbon (soils and gasses) (kt CO2/yr)	51	47	43	39
Stock change + soils ex transfer (kt CO2/yr)	-893	-632	-605	-522
New Reference Level 20 yr				
I + II (kt CO2/yr)	-389	-277	-304	-578
outside (III+IV) (kt CO2/yr)	-37	-49	-17	11
New Reference Level 30 yr				
I + V (kt CO2/yr)	209	235	212	-117
outside (VI+IV) (kt CO2/yr)	-788	-560	-533	-450
VI: Harvested Wood Products				
HWP (kt CO2/yr)	-61	-20	-20	-20
Total Forest				
I+II+III-IV (kt CO2/yr)	-426	-326	-321	-568

B - afforestation 3,200 ha/yr	**2015-2020**	**2021-2025**	**2026-2030**	**2031-2035**
I: FRF - from before 1990				
Area (ha)	524.551	523.651	522.978	522.305
Carbon stock (AG+BG+DW+FF) (ktC)	46.332	46.048	45.550	45.214
II: Afforestation - Older than 20 yr				
Area (ha)	31.263	51.503	70.119	84.932
Carbon stock (AG+BG+DW+FF) (ktC)	1.296	2.635	4.076	5.577
III: Afforestation - Younger than 20 yr				
Area (ha)	65.499	62.858	60.242	61.429
Carbon stock (AG+BG+DW+FF) (ktC)	838	787	723	722
II: Afforestation - Older than 30 yr				
Area (ha)	31.263	51.503	70.119	84.932
Carbon stock (AG+BG+DW+FF) (ktC)	39	1.002	2.434	4.044
III: Afforestation - Younger than 30 yr				
Area (ha)	65.499	62.858	60.242	61.429
Carbon stock (AG+BG+DW+FF) (ktC)	2.095	2.420	2.364	2.255
New Reference Level 20 yr				
I + II (kt CO2/yr)	-387	-272	-297	-552
outside (III+IV) (kt CO2/yr)	-65	-96	-84	-105
New Reference Level 30 yr				
I + V (kt CO2/yr)	209	238	218	-110
outside (VI+IV) (kt CO2/yr)	-814	-606	-599	-547
Total Forest				
I+II+III-IV (kt CO2/yr)	-423	-340	-353	-628

A few notes on the results in Table 6:

The stock change approach is applied for carbon stocks of above ground biomass (AG), below ground biomass (BG), dead wood (DW) and forest floor (FF). Emissions of GHG from the soil are based on annual emission estimates related directly to the forest area. Except for area (ha) and carbon stock (ktC) all other elements are given in kt CO_2 eq/yr. Applying the stock change approach it is necessary to ensure that change in carbon due to transfer from one pool to another. This occurs for the forest area of 20 or 30 years. To handle this, stock of the area transferred is included in the stock change estimate of the pool it's leaving and not in the pool it enters. Hereby stock change reflects the net changes that have occurred while the area was in the original pool, equalling the accounts that would have been obtained using net increment estimation (applies to III and VI). To avoid double accounting, the transferred stock does not enter the change estimates of the new pool until the subsequent year (applies to II and V). Deforestation is handled directly as a separate pool (V).

I: Forest Remaining Forest - from before 1990 is expected to be a small source of CO_2 emissions, due to the very skewed age distribution of the Danish forests, which have been accentuated during the recent 10 years. However, the best prognosis still expects a regeneration of a major part of these forests within the coming period and hence a temporary decline in the stocks of the forests. Running the prognosis for longer time periods (100+ years) brings the forest area from before 1990 to a steady state forest, but not included here. See Table 14, page 75 for further details on the period 2015-2035.

II: Afforestation , older than 20 years. The area of this will increase during the period and simultaneously the forests of these areas will enter the productive age for Danish forests, leading to a gradual increase in the stocks and resulting in a sink. The annual transfer of carbon stock due to the 20 year age limit, are omitted from the summary number in this pool until the year after the transfer. Hereby, the transfer of afforestation to forest remaining forest does not result in 'technical' emissions that would otherwise result when area with afforestation is decreasing. There are uncertainties in the prognosis of growth of these new forests, which are in some cases established with new species mixtures and different forest management than existing forests from before 1990. Further validation of the prognosis would be required before finally submitting a new reference level for Denmark including afforestation older than 20 years. See Table 15, page 76 for further details.

I+II - New Reference level 20 year - following the suggestion to include both I and II in the Forest Management Reference Level will cause the effect of the older afforestation to be included in the FMRL and hence the accounting for the forest will be compared to this estimate, which will be an increasing sink for the forests. The summary stock change and soil emissions reflect the manged forest area.

III: Afforestation - Younger than 20 years - this area will decline in the period, as the rate of afforestation is expected to be 1,900 ha/yr while it in the period until 2011 was 3,500-4,000 ha/yr. At the same time the area will only hold the carbon stock of new established forests, which by nature is low. Simultaneously the land use change of the 1,900 ha/yr leads to an estimate of an emission of 6 t C/ha, equalling 41.8 Kt CO2/yr. The overall effect will be that areas with afforestation younger than 20 years will decline over the period and the sink of this area will be low in the period. The annual transfer of carbon stocks due to the 20 year age limit are handled as described above (transfer of 7-10 % of the stock in III to II annually), to include the full increment of the new forests in the afforestation pool. See Table 15, page 76 for further details.

IV: Deforestation - will occur on a limited area, and will be a minor source of emissions.

III+IV: Outside reference level - afforestation younger than 20 years and deforestation will together be a small sink for most of the period, and is expected to be a minor source of emissions in the end of the time analysed. The levels are small and reducing the deforestation can make a difference.

V: Afforestation - Older than 30 years - the area of this will increase during the period and the forests of these areas will enter the productive age for Danish forests, leading to a gradual increase in the stocks. This results in an estimate of a sink for these forests, with a lower level than for the case in II with a 20 year age limit. The annual transfer of carbon stocks due to the 30 year age limit, are omitted from the summary number in this pool until the year after the transfer, again to avoid technical emissions due to changes in afforestation across time. There are uncertainties in the prognosis of growth of these new forests, which are in some cases established with new species mixtures and different forest management than existing forests from before 1990. Further validation of the prognosis would be required before finally submitting a new reference level for Denmark including afforestation older than 30 years. See Table 16, page 77 for further details.

I+V - New Reference level 30 year - following the suggestion to include both I and V in the Forest Management Reference Level will cause the effect of the afforestation to be included in the FMRL and hence the accounting for the forest will be compared to this estimate, which will be an increasing sink for the forests. The summary stock change and soil emissions reflect the manged forest area.

VI: Afforestation - Younger than 30 years - this area will gradually decline in the period, as the rate of afforestation is expected to be 1,900 ha/yr while it in the period until 2011 was 3,500-4,000 ha/yr. At the same time the area will only hold the carbon stock of new established forests, which by nature is low. Simultaneously the land use change of the 1,900 ha/yr leads to an estimate of an emission of 6 t C/ha, equalling 41.8 Kt CO2/yr. The overall effect will be that areas with afforestation younger than 30 years will decline over the period but the area will result in a sink in the period. The magnitude of this sink will be larger than the case given in III, since the afforestation is allowed to become larger before the transfer to the forest area. The annual transfer of carbon stocks due to the 30 year age limit are handled as described above (transfer of 5-10 % of the stock in VI to V annually), to include the full increment of the new forests in the afforestation pool. See Table 16, page 77 for further details.

VII: Harvested Wood Products - is estimated to be a small sink in the period. The influence of the HWP estimate is minor compared to the other classes.

In the B part of Table 6 is given some key figures for a scenario where the rate of afforestation is similar to the time span 1990-2015 resulting in an annual afforestation of 3,200 ha/yr. The key effect will be a larger expected sink for the young forests (III and VI). The reference levels for the forest area (either I+II or I+V depending om age of transfer) will be largely unaffected by the different prognosis of afforestation, since it will only affect the very last part of the period (2031-2035) since the new area of afforestation only then reaches the age for transfer. This leaves the influence in the short time span of the 20 years analysed on the young afforestation (increasing sink of 10-20 pct. with a approx. 70 pct. increase in annual afforestation area). (See Table 18 and Table 19 in Annex 10.3 for further details).

Regardless of the choice of time for the transfer (20 or 30 years) and the rate of afforestation (1,900 ha/yr or 3,200 ha/yr) the total Danish forest area will be increasing the carbon pool in the forests as indicated both in A and B part of Table 6 with the sum of I+II+III-IV (kt CO2/yr) resulting in a sink. This is the result of the continuous afforestation and the increasing growth of the new forests. The minor skewed age distribution of the forests established before 1990 does not dominate the overall development of the forest area.

The Reference Level estimation is based on calculations of business as usual prognosis (BAU), with the current management and practices as basis, since this is directly reflected in the observed standing stock by species and age class. Hereby, the reference level is able to reproduce historical data, for the period in which the models for regeneration probabilities have been estimated. The suggested reference level is based on the stock change approach, rather than a combination of models of growth, recruitment, mortality and harvests. This gives in combination with the usage of the NFI based stock estimates (for the reference year 2009) and the regeneration probabilities for the forest area matrix, a robust estimation of the reference level for the Danish forests.

It should be noted, that a review process will take place before the reference levels can be considered as final, including final decisions on the transitions from afforestation to forest land. Here is given the alternatives of transferring afforestation after age of 20 and 30 years to be included in the FMRL estimation. Currently both alternatives results in estimates of sinks and a continued transfer of area and stock to FRF, ensuring net increment are accounted for the afforestation areas in 20 or 30 years in the pools outside the reference level estimates. The emissions due to deforestation will influence the overall results (see Table 15 and Table 16 in Annex 10.3 for further details).

The information in Table 6 gives the option to evaluate the different proposals for accounting and use of reference levels. For choice of method to calculate the reference level, multiple considerations can be included. Here is presented the basis for the estimation and the results based on the choices of age of transfer and the rate of afforestation.

The effect of the accounting, in terms of Article 8, specifically 1, 1a and 2 giving different suggestions for how the deviations from the chosen reference level are handled in the overall accounting (national threshold values, multiplication of emissions by a factor and/or CAP limitations of either emissions or removals) are not addressed here. The suggestions are so far not clearly described and could easily lead to significant loss of transparency in the carbon accounting for forests.

There are not a specific national forestry accounting plan for Denmark, but the current report gives the key elements of the data and accounting procedures for forest carbon stocks in Denmark.

The chapter (5.1) includes scenario modelling based on a report from 2013 (Graudal et al. 2013) in which also forest characteristics, age-class structure and harvesting rates are analysed based on stakeholder consultations on harvest rates and uses of wood. This will also contribute to the forestry accounting plan for Denmark.

8 Conclusions & Perspectives

The proposal from EU on the accounting rules has been commented in Chapter 4.

The influence of forest management, silvicultural practices and global and climate change have been addressed in Chapter 5. The overall trend in increment and carbon balances in forests in Europe and in Denmark as well as globally is a combined effect of a multitude of factors, of which human induced forest management, silvicultural activities and selection of species and genetics as well as changes in atmospheric deposition (both positive and negative influence), CO_2 in the atmosphere, temperature and precipitation is influencing the observed increment in a multitude of ways. It is not clear, which of these factor that influence the changes the most, but they all contribute.

This report gives a description of the data and methods used for the LULUCF accounting for the forests in Denmark. The analysis of uncertainty clearly indicates that reporting based on 5 year cycles will provide more stable estimates, than annual reporting (Chapter 6)

The Forest Management Reference Level has been addressed for the different parts of the forest area (Chapter 7). The information in Table 6 gives the option to evaluate the different proposals for accounting and use of reference levels. If the new suggestion of FMRL includes afforestation older than 20 years (I + II) or 30 years (I+V) the accounting for the Danish forest will be compared to this FMRL. Overall the effect of the forests will be minor. Depending on the age limit for transfer of afforestation and the amount of deforestation the forest may be a small sink or even a small source of emissions. The prognosis for HWP will be a small sink, with the current usage of wood in Denmark. Some countries include exported industrial round wood and wood products in their HWP accounting, but it may require additional data to document this for Danish exported wood. It is unlikely that Denmark with the new guidelines will be restricted by the suggested CAP on the forest accounting.

As for the questions raised the report gives information on:

A: Will the level of the Danish LULUCF accounting for afforestation match the level of accounting due to deforestation?
With the new guidelines with transfer of afforestation over 20 or 30 years to the main forest area, the sum of afforestation and deforestation will be a sink in the period 2020-2035, with the largest sink with a transfer age of 30 years. See Table 6, page 49.

B: How have the Danish LULUCF accounting changed over time and how are the uncertainties of the current methodology? Are the methodologies comparable to other countries and state-of-the-art?

The LULUCF accounting for forests have not changed over time and are in line with the methodologies used in e.g. other Scandinavian countries. The uncertainty of carbon stock estimates is smaller than anticipated when designing the Danish National Forest Inventory. However, the uncertainty of carbon stock estimates in relation to the relatively small changes in forest stocks does not support annual reporting, but the data do not support annual reporting, but rather reporting based on 5 year intervals. See 6.6, page 35.

C: Forest Management Reference Level - does it follow the guidelines suggested? Does it reflect the Danish forests? Is there a need for new data/development?

The FMRL follows the guideline, and it is based on a matrix/transition model combined with stock change approach, rather than specified models for growth, harvest, mortality and regeneration. There is a need for validation before the final submission of the FMRL. See Chapter 7.

D: How will the new suggestions by the EU Commission affect the FMRL for Denmark and Europe?

The main effect will be the inclusion of afforestation in the FMRL causing this to be a sink. This will leave the young afforestation (less than 20 or 30 years) as a separate pool, resulting in these being a small sink in the period 2020-2035. See Chapter 7.6.

E: How will the FMRL look under different guidelines? Included - how will the effect be of handling Harvested Wood Products (HWP) separately from the rest of the LULUCF?

The summary results are given in Chapter 7.6, especially in Table 6. The influence of separating HWP from LULUCF is addressed in Chapter 4.3.

F: What is - in brief- the current scientific understanding of global environmental change and climate change effects on the forest ecosystem carbon balance?

It is not possible to give a brief summary of the vast amount of research available, but some key findings are given in Chapter 5. The overall trend of biomass increment and increased uptake of carbon in forests across Europe and in Denmark is a global trend likely caused by a combined effect of a multitude of changing factors, of which human induced forest management, silvicultural activities and selection of species and genetics as well as changes in atmospheric deposition (both positive and negative influence), elevated atmospheric CO2 concentration, increased temperatures and changed precipitation are influencing the observed increment in a multitude of ways. Which of these factor that influence the changes the most is not clear, but they all contribute. Disentangling the individual effects of all these factors is still a major unresolved challenge in ecosystem research today.

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10 Appendix

10.1 Details of the afforestation and forest management options

The afforestation and forest management options in Table 1 are more or less self-explanatory but require some additional explanation to be fully understood. This is based on (Graudal, Ulrik Bräuner Nielsen, et al. 2013).

10.1.1 S1. Afforestation

Four levels of afforestation are considered:

- BAU - 1900 ha/year
- None - 0 ha/year
- Medium - 2280 ha/year
- High - 4560 ha/year

1900 ha/year is the current afforestation rate (Business as usual). The 4650 ha/year would correspond to fulfilment of the Danish forest policy goal from 1989 of doubling the forest area within a tree generation or reaching a national forest land cover percentage of approximately 25% within 80 years. In projecting the future forest area the upper limit has been set at 25%.

10.1.2 S2. Species choice in afforestation

Species choice will affect the future development of the new forest areas. The modelling is based on three different choices:

- BAU: Species distribution as in existing forests according to the National Forest Inventory (NFI). Species groups considered: *Fagus sylvatica, Quercus spp, Acer spp.,* other broadleaved species, *Picea spp, Abies spp,* and other conifer species.
- Broadleafs: Only broadleaved species. Species groups considered: *Fagus sylvatica, Quercus spp, Acer spp.,* other broadleaved species
- Conifers: Only conifer species. Species groups considered: *Picea spp*, *Abies spp,* and other conifer species.

10.1.3 S3. Rotation age

The rotation age of a species is the age at which it is expected to regenerate (by re-planting or through natural regeneration) and can be expressed as a probability of transition. Transition probabilities have been derived from an analysis of two successive National Forest Inventories in

1990 and 2000 (Danmarks Statistik & Skov- og Naturstyrelsen 1994; Larsen & Johannsen 2002). The logistic function developed (Nord-Larsen & Heding 2002) and accumulated transition probabilities for different tree species and production classes are shown in Figure 8.
The modelling is based on three different transition probabilities:

- BAU: Transition probability (rotation age) as observed in the development of the forest area 1990-2000 (Nord-Larsen & Heding 2002).
- Low: Lower rotation age. The transition probability is increased for a given age by calculating the transition probability at the age plus 10 years.
- High: Higher rotation age. The transition probability is reduced for a given age by calculating the transition probability at the age minus 20 years for broadleaved species and minus 5 years for conifers for age classes above 20 years and 5 years, respectively.

10.1.4 S4. Species choice, regeneration (existing forest)

When mature forest stands are regenerated it can happen either with the same species or by introducing another tree species. In recent years, public support has been provided to exchange conifers (exotic species in Denmark) with broadleaves (indigenous species). The modelling operates with three different species choice in regeneration:

- BAU: Regeneration with the same species as already growing on the area. The current tree species composition will be maintained.
- Conifers: Transition towards conifers. Broadleaved areas are regenerated with 50% of the current species, while the other 50% are regenerated with conifers.
- Broadleafs: Transition towards broadleaves. Conifer areas are regenerated with 50% of the current species, while the other 50% are regenerated with broadleaves.

10.1.5 S5. Cultivation method: intensity of regeneration and use of nurse trees

Choice of cultivation method reflects how new stands are established whether regeneration of existing forest or establishment of new forest. Current prevailing cultivation is a fairly gradual regeneration with one species and in the case of planting with a relatively low number of seedlings per hectare. It is, however, possible to enhance the development of the new stand by increasing the number of seedlings and/or mix species by introducing ‘nurse trees’. Nurse trees are typically fast growing species (like *Populus spp.*, *Larix spp.*, or *Alnus spp.*), which provide faster production of biomass and create a good micro climate for the new stand. Two cultivation models are considered:

- BAU: No adjustment of current practice

- Nurse: Increased planting density and use of nurse trees (in cultivation with broadleaves only)

The effect of nurse trees are limited to age classes below 30 years and will increase gradually as regeneration and afforestation progress. The yield models used are graduated according to soil fertility after (Bergsted 1981; Jansen et al. 1996).

Use of genetically improved nurse trees (in cultivation with broadleaves only) is part of S9.

10.1.6 S6. Untouched forest: Forest set-a-side

Untouched natural forest is considered an important measure to promote and conserve biodiversity. Forest set-a-side for this purpose will at the same time imply less availability of potential biomass harvest but higher build-up of standing volume (at least for a while). To assess the effect of forest set-a-side, four different levels of areas set-a-side are modelled:

- BAU: No forest set-a-side
- Low: Approximately 10% of the forest area (20% of the broadleaved forest area). 46.103 ha are set-a-side, while 534.844 ha at the outset are included in the simulations.
- Medium: Approximately 25% of the forest area (50% of the broadleaved forest area). 127.150 ha are set-a-side, while 453.797 ha at the outset are included in the simulations.
- High: Approximately 50% of the forest area (100% of the broadleaved forest area). 275.755 ha are set-a-side, while 305.192 ha at the outset are included in the simulations.

Only broadleaved forest in Denmark is considered natural. Selection of areas set-a-side are from the oldest age classes until the area requirement is fulfilled. Subsequently, the age of these areas are projected and the gradual build-up of standing volume incorporated in the projections corresponding to the oldest age classes registered in the NFI, stands older than 150 years. No harvest from the areas are calculated.

10.1.7 S7. Utilisation degree, harvest/thinning intensity

In this context, the degree of utilisation or harvest intensity is defined as the share of the increment that is harvested. The utilization degree will affect the standing volume of biomass in the forest. Three different levels of utilization are considered:

- Utilisation degree is 1. Potential harvest equals increment.
- Utilization degree is 1.2. Potential harvest is 20% higher. The standing volume will decrease to 90% after 20 years of simulation.

- Utilisation degree is 0.8. Potential harvest is 20% reduced. The standing volume will increase to 110% after 20 years of simulation.

10.1.8 S8. Assortment choice, degree of wood removal for energy

Assortments describe how the harvest is utilised. How much of the individual tree (share of stem, branches, foliage, roots) are used? And for what purpose is it used (timber, industrial wood or fuel)?

Three different scenarios for use of the biomass are modelled, designed as examples of basically different choices:

- BAU: Assortment relation reflecting market demand for timber/industrial wood and in particular of higher dimensional wood (Traditional assortment - BAU)
- More fuelwood: Assortment relation reflecting a general high market demand and in particular for fuel wood (fuel)
- Less fuelwood: Assortment relation reflecting a general high market demand but relatively less for fuel (only high energy wood proportion in conifers)

The scenarios are tabulated below (Table 7 - Table 9). For each scenario is given the percentage share of timber/industrial wood (usew), fuel wood (fuel), and the remnant un-used wood/biomass left in the forest (tab). The assortment relations (sortgrp) are given for a series of diameter classes (dkl). The scenarios are differentiated between the two major regions of Denmark (Jutland and The Islands).

Region and species	Sortgrp	dkl5	dkl15	dkl25	dkl35	dkl45	dkl55	dkl65	dkl75	dkl100
Jutland – broadleaved species	Usew	0	10	30	50	60	65	65	60	45
	Fuel	50	50	50	35	25	20	20	25	40
	Tab	50	40	20	15	15	15	15	15	15
Jutland – conifers	Usew	0	40	50	70	70	60	60	50	50
	Fuel	50	30	35	20	20	30	30	0	40
	Tab	50	30	15	10	10	10	10	10	10
The Islands – broadleaved species	Usew	0	10	30	50	60	70	65	60	45
	Fuel	50	60	60	40	30	20	20	25	40
	Tab	50	30	10	10	10	10	15	15	15
The Islands - conifers	Usew	0	40	50	70	70	60	60	50	50
	Fuel	50	35	35	20	20	30	30	40	40
	Tab	50	30	15	10	10	10	10	10	10

Table 7. Assortment relation (sortgrp) in percentage by diameter class (dkl) reflecting market demand for timber/industrial wood and in particular of higher dimensional wood (Traditional assortment - BAU)

Region and species	Sortgrp	dkl5	dkl15	dkl25	dkl35	dkl45	dkl55	dkl65	dkl75	dkl100
Jutland – broadleaved species	Usew	0	0	10	30	35	55	60	50	40
	Fuel	95	95	85	65	60	40	35	45	55
	Tab	5	5	5	5	5	5	5	5	5
Jutland – conifers	Usew	0	0	30	60	70	60	50	50	50
	Fuel	95	95	65	35	25	35	45	45	45
	Tab	5	5	5	5	5	5	5	5	5
The Islands – broadleaved species	Usew	0	0	10	40	40	60	60	50	40
	Fuel	95	95	85	55	55	35	35	45	55
	Tab	5	5	5	5	5	5	5	5	5
The Islands - conifers	Usew	0	0	30	65	75	65	55	55	50
	Fuel	95	95	65	30	30	30	40	40	45
	Tab	5	5	5	5	5	5	5	5	5

Table 8. Assortment relation (sortgrp) in percentage by diameter class (dkl) reflecting a general high market demand and in particular for fuel wood (fuel)

Region and species	Sortgrp	dkl5	dkl15	dkl25	dkl35	dkl45	dkl55	dkl65	dkl75	dkl100
Jutland – broadleaved species	Usew	0	0	30	50	60	70	65	60	45
	Fuel	95	95	60	40	30	20	20	25	40
	Tab	5	5	10	10	10	10	15	15	15
Jutland – conifers	Usew	0	0	30	60	70	60	50	50	50
	Fuel	95	95	65	35	25	35	45	45	45
	Tab	5	5	5	5	5	5	5	5	5
The Islands – broadleaved species	Usew	0	0	30	50	60	70	65	60	45
	Fuel	95	95	60	40	30	20	20	25	40
	Tab	5	5	10	10	10	10	15	15	15
The Islands - conifers	Usew	0	0	30	65	75	65	55	55	50
	Fuel	95	95	65	30	30	30	40	40	45
	Tab	5	5	5	5	5	5	5	5	5

Table 9. Assortment relation (sortgrp) in percentage by diameter class (dkl) reflecting a general high market demand but relatively less for fuel (only high energy wood proportion in conifers)

10.1.9 S9. Genetic Tree Improvement

One of the measures that can improve productivity of the forest most is selection and use of improved planting material (Foster et al. 1995; Ruotsalainen 2014).

A Danish applied tree improvement program has been implemented since 1960 with a peak investment period 1980-2000. Three levels of tree improvement are modelled:

- BAU: Implementation of gains from existing seed orchards of main species where focus has been on health on quality

- Medium: Implementation of gains from a new generation of seed orchards of main species with increased focus on productivity
- High: As 1 but with acceleration of results through use of somatic embryogenesis and cutting propagation in the breeding programs of the most productive species to shorten the time for deployment of improved material and increase the genetic gains from each breeding cycle.

The expected gains from the three levels of applying the results of tree improvement are shown in Table 10. The effects are gradually introduced as new plantings are established based on the improved material becoming available.

Effects of improved material can be modelled individually, so e.g. the effect of applying improvement of ‘nurse’ trees (like *Populus spp*) can be done separately.

In simulations beyond 100 years no additional gain is modelled, which is likely to be a conservative assumption.

Level	Art	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
0	RGR	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
0	SGR	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
0	DGR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	SKF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	AGR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	LAR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	POP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	SEG	0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
0	VEG	0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
0	ER	0	0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
0	BOG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	ANL	0	0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
1	RGR	10	10	30	30	40	40	40	40	40	50	50	55	55	65	65	70	70	75	75	80
1	SGR	10	10	30	40	40	40	40	50	50	50	50	60	60	66	66	72	72	78	78	84
1	DGR	10	10	15	20	25	30	35	40	45	50	50	60	60	70	70	80	80	90	90	100
1	SKF	10	10	10	20	20	20	30	30	30	40	40	40	40	46	46	52	52	58	58	64
1	AGR	0	0	30	30	30	40	40	40	40	40	40	50	50	54	54	58	58	62	62	66
1	LAR	0	15	30	30	40	40	50	50	60	60	60	70	70	70	70	70	70	80	80	80
1	POP	0	10	20	30	40	50	60	70	80	90	90	110	110	130	130	150	150	170	170	190
1	SEG	3	4.5	6	7.5	9	10.5	12	13.5	15	16.5	16.5	19.5	19.5	22.5	22.5	25.5	25.5	28.5	28.5	31.5
1	VEG	3	4.5	6	7.5	9	10.5	12	13.5	15	16.5	16.5	19.5	19.5	22.5	22.5	25.5	25.5	28.5	28.5	31.5
1	ER	3	4.5	6	7.5	9	10.5	12	13.5	15	16.5	16.5	19.5	19.5	22.5	22.5	25.5	25.5	28.5	28.5	31.5
1	BOG	5	6	7	8	9	10	11	12	13	14	14	16	16	18	18	20	20	22	22	24
1	ANL	3	4.5	6	7.5	9	10.5	12	13.5	15	16.5	16.5	19.5	19.5	22.5	22.5	25.5	25.5	28.5	28.5	31.5
2	RGR	10	37	37	43	50	50	56	63	63	69	69	78	78	87	87	96	96	105	105	114
2	SGR	10	37	43	50	56	63	69	76	82	89	89	102	102	115	115	128	128	141	141	154
2	DGR	10	10	15	20	25	30	35	40	45	50	50	60	60	70	70	80	80	90	90	100
2	SKF	10	10	10	20	20	20	30	30	30	40	40	40	40	46	46	52	52	58	58	64
2	AGR	0	30	37	37	43	50	50	50	56	63	63	63	63	69	69	76	76	82	82	95
2	LAR	0	15	30	30	40	40	50	50	60	60	60	70	70	70	70	70	70	80	80	80
2	POP	0	10	20	30	40	50	60	70	80	90	90	110	110	130	130	150	150	170	170	190
2	SEG	3	4.5	10	10	20	20	20	20	30	30	30	30	30	40	40	40	40	40	40	40
2	VEG	3	4.5	10	10	20	20	20	20	30	30	30	30	30	40	40	40	40	40	40	40
2	ER	3	4.5	10	10	20	20	20	20	30	30	30	30	30	40	40	40	40	40	40	40
2	BOG	5	6	7	8	9	10	11	12	13	14	14	16	16	18	18	20	20	22	22	24
2	ANL	3	4.5	6	7.5	9	10.5	12	13.5	15	16.5	16.5	19.5	19.5	22.5	22.5	25.5	25.5	28.5	28.5	31.5

Table 10. Expected gains in productivity from tree improvement at three different levels of improvement (0, 1 and 2 – see text) given as percentage increase in 5 year intervals over a 100 year period for different tree species (art). RGR: *Picea abies,* SGR: *Picea sitchensis,* DGR: *Psudotsuga menziesii,* SKF: *Pinus sylvestris,* AGR: *Abies grandis,* LAR: *Larix spp,* POP: *Populus spp.,* SEG: *Quercus robur,* VEG: *Quercus petraea,* ER: *Acer psudoplatanus,* BOG: *Fagus sylvatica,* ANL: Other broadleaved species.

10.2 Details of prognosis for afforestation

T	HD1	D1	N1	G1	V1	D2	N2	G2	V2	RTA2	HD3	D3	N3	G3	V3	RTA3	mdHD/dt	mdV/dt	dVtot	BAG
[År]	[m]	[cm]	[/ha]	[m2/ha]	[m3/ha]	[cm]	[/ha]	[m2/ha]	[m3/ha]	[%]	[m]	[cm]	[/ha]	[m2/ha]	[m3/ha]	[%]	[m/år]	[m3/ha/år]	[m3/ha]	t/ha
20	7,7	5,3	5.907	13,1	64,3	4,8	-	-	-	UDEF.	7,7	5,3	5.907	13,1	64,3	20,9	0,4	3,2	64	37
22	8,8	6,1	5.823	17,1	93,4	5,5	-	-	-	UDEF.	8,8	6,1	5.823	17,1	93,4	17,9	0,4	4,3	93	53
24	9,9	6,8	5.717	21,0	128,3	6,2	-	-	-	UDEF.	9,9	6,8	5.717	21,0	128,3	15,5	0,4	5,3	128	73
27	11,8	7,9	5.501	26,8	189,5	7,2	442,0	1,8	12,2	46,8	11,8	7,9	5.059	25,0	177,3	13,3	0,4	7,0	190	101
30	13,7	8,9	4.808	30,2	242,9	8,2	986,0	5,2	40,5	26,2	13,8	9,1	3.822	25,0	202,4	12,8	0,5	8,5	255	115
33	15,6	10,2	3.631	29,6	264,1	9,4	658,0	4,6	39,5	27,8	15,6	10,3	2.973	25,0	224,6	12,6	0,5	9,6	317	128
37	17,7	11,8	2.775	30,3	302,7	10,9	565,0	5,3	51,8	25,9	17,8	12,0	2.210	25,0	251,0	12,7	0,5	10,7	395	143
41	19,6	13,5	2.075	29,7	323,3	12,6	373,0	4,7	49,6	28,4	19,6	13,7	1.702	25,0	273,7	12,9	0,5	11,4	467	156
45	21,2	15,2	1.608	29,2	341,5	14,3	259,0	4,2	47,8	31,2	21,2	15,4	1.349	25,0	293,8	13,4	0,5	11,9	535	167
50	22,9	17,3	1.265	29,7	374,3	16,4	222,0	4,7	58,3	30,9	22,9	17,5	1.043	25,0	316,0	14,0	0,5	12,3	616	180
56	24,6	19,8	975	30,1	407,6	19,0	179,0	5,1	68,0	31,7	24,6	20,0	796	25,0	339,6	14,8	0,4	12,6	707	194
62	26,0	22,4	752	29,6	426,4	21,7	124,0	4,6	65,8	35,6	26,1	22,5	627	25,0	360,6	15,7	0,4	12,8	794	206
69	27,5	25,4	591	30,0	458,0	24,9	101,0	5,0	75,2	37,1	27,5	25,5	490	25,0	382,8	16,8	0,4	12,9	891	218
77	28,9	28,8	463	30,2	490,1	28,7	81,0	5,2	84,4	39,3	28,9	28,9	382	25,0	405,7	18,0	0,4	13,0	999	231
85	30,0	32,3	363	29,8	509,6	32,3	59,0	4,8	82,5	44,0	30,0	32,3	305	25,0	427,1	19,3	0,4	13,0	1.103	243
94	31,2	36,4	290	30,1	541,3	36,4	49,0	5,1	91,5	46,3	31,2	36,4	241	25,0	449,8	20,9	0,3	12,9	1.217	256
100	31,9	39,2	234	28,2	523,8		-	-	-		31,9	39,2	234	28,2	523,8	20,7	0,3	12,9	1.291	299

Table 11. Growth and yield model for beech used for prognosis in afforestation

T	HD1	D1	N1	G1	V1	D2	N2	G2	V2	RTA2	HD3	D3	N3	G3	V3	RTA3	mdHD/dt	mdV/dt	dVtot	BAG
[År]	[m]	[cm]	[/ha]	[m2/ha]	[m3/ha]	[cm]	[/ha]	[m2/ha]	[m3/ha]	[%]	[m]	[cm]	[/ha]	[m2/ha]	[m3/ha]	[%]	[m/år]	[m3/ha/år]	[m3/ha]	t/ha
20	4,5	2,6	19.645	10,8	32,7	2,4	-	-	-	UDEF.	4,5	2,6	19.645	10,8	32,7	25,3	0,2	1,6	33	19
22	5,1	3,0	19.515	13,7	49,6	2,7	-	-	-	UDEF.	5,1	3,0	19.515	13,7	49,6	20,9	0,2	2,3	50	29
24	5,7	3,3	19.318	16,7	63,4	3,0	-	-	-	UDEF.	5,7	3,3	19.318	16,7	63,4	17,6	0,2	2,6	63	37
27	6,7	3,8	18.790	21,0	88,2	3,4	-	-	-	UDEF.	6,7	3,8	18.790	21,0	88,2	14,1	0,3	3,3	88	51
30	7,8	4,2	17.748	24,8	116,8	3,9	-	-	-	UDEF.	7,8	4,2	17.748	24,8	116,8	11,7	0,3	3,9	117	68
33	9,0	4,7	15.922	28,1	148,0	4,4	2.075,0	3,1	15,9	29,8	9,1	4,8	13.847	25,0	132,1	11,0	0,3	4,5	148	77
37	10,6	5,6	11.746	28,8	174,1	5,2	1.811,0	3,8	22,5	26,0	10,6	5,7	9.934	25,0	151,6	10,7	0,3	5,1	190	88
41	12,1	6,5	8.555	28,3	192,2	6,1	1.146,0	3,3	22,0	27,8	12,1	6,6	7.409	25,0	170,2	10,6	0,3	5,6	231	99
45	13,5	7,4	6.506	27,9	208,6	7,0	763,0	2,9	21,2	29,9	13,5	7,4	5.742	25,0	187,4	10,6	0,3	6,0	269	109
50	15,0	8,5	4.982	28,2	232,4	8,1	620,0	3,2	25,6	29,2	15,0	8,5	4.362	25,0	206,8	10,8	0,3	6,3	314	120
56	16,5	9,7	3.790	28,3	256,5	9,4	477,0	3,3	29,3	29,6	16,6	9,8	3.313	25,0	227,1	11,0	0,3	6,5	364	132
62	17,9	10,9	2.964	27,9	272,6	10,6	325,0	2,9	27,8	32,7	17,9	11,0	2.639	25,0	244,8	11,3	0,3	6,6	409	142
69	19,2	12,3	2.372	28,0	293,6	12,0	260,0	3,0	30,9	33,5	19,2	12,3	2.111	25,0	262,7	11,7	0,3	6,6	458	152
77	20,5	13,7	1.912	28,0	313,9	13,6	207,0	3,0	33,5	34,8	20,5	13,7	1.705	25,0	280,4	12,1	0,3	6,6	509	163
85	21,6	15,0	1.574	27,7	327,6	15,0	153,0	2,7	31,8	38,2	21,6	15,0	1.421	25,0	295,8	12,5	0,3	6,6	556	172
94	22,7	16,4	1.318	27,7	345,2	16,4	130,0	2,7	34,1	39,2	22,7	16,4	1.188	25,0	311,2	13,0	0,2	6,4	606	180
100	23,4	17,3	1.140	26,7	342,2		-	-	-		23,4	17,3	1.140	26,7	342,2	12,8	0,2	6,4	637	198

Table 12. Growth and yield model for oak used for prognosis in afforestation

T	HD1	D1	N1	G1	V1	D2	N2	G2	V2	RTA2	HD3	D3	N3	G3	V3	RTA3	mdHD/dt	mdV/dt	dVtot	BAG
[År]	[m]	[cm]	[/ha]	[m2/ha]	[m3/ha]	[cm]	[/ha]	[m2/ha]	[m3/ha]	[%]	[m]	[cm]	[/ha]	[m2/ha]	[m3/ha]	[%]	[m/år]	[m3/ha/år]	[m3/ha]	t/ha
20	7,8	7,2	5.594	22,9	82,3	6,5	-	-	-	UDEF.	7,8	7,2	5.594	22,9	82,3	22,6	0,4	4,1	82	38
22	8,8	8,0	5.505	28,0	116,1	7,3	-	-	-	UDEF.	8,8	8,0	5.505	28,0	116,1	19,3	0,4	5,3	116	53
24	10,0	8,8	5.405	32,7	157,2	8,0	-	-	-	UDEF.	10,0	8,8	5.405	32,7	157,2	16,7	0,4	6,6	157	72
27	11,9	9,8	5.231	39,2	230,5	8,9	672,0	4,2	23,7	40,4	11,9	9,9	4.558	35,0	206,8	14,6	0,4	8,5	231	94
30	13,8	10,9	4.392	40,8	286,2	10,0	740,0	5,8	39,1	31,9	13,9	11,0	3.652	35,0	247,1	13,5	0,5	10,3	310	113
33	15,8	12,1	3.512	40,3	326,2	11,1	542,0	5,3	41,4	32,0	15,9	12,3	2.970	35,0	284,8	12,9	0,5	11,8	389	130
37	18,0	13,7	2.812	41,3	385,5	12,7	499,0	6,3	57,3	28,6	18,1	13,9	2.313	35,0	328,2	12,6	0,5	13,2	490	150
41	19,9	15,4	2.191	40,7	421,2	14,4	352,0	5,7	57,6	30,3	20,0	15,6	1.839	35,0	363,6	12,7	0,5	14,2	583	166
45	21,5	17,1	1.746	40,2	449,3	16,1	256,0	5,2	57,1	32,4	21,6	17,3	1.490	35,0	392,1	12,9	0,5	14,9	668	179
50	23,1	19,3	1.400	41,0	490,4	18,3	226,0	6,0	70,2	31,7	23,2	19,5	1.174	35,0	420,2	13,5	0,5	15,3	767	192
56	24,7	22,0	1.095	41,5	527,5	21,1	187,0	6,5	81,8	32,2	24,8	22,2	908	35,0	445,7	14,2	0,4	15,6	874	203
62	26,1	24,8	852	41,1	543,8	24,0	134,0	6,1	79,4	35,7	26,1	24,9	719	35,0	464,5	15,1	0,4	15,7	972	212
69	27,3	28,1	672	41,6	569,4	27,5	110,0	6,6	89,2	37,2	27,4	28,2	562	35,0	480,2	16,3	0,4	15,6	1.077	219
77	28,6	31,9	524	42,0	589,6	31,8	88,0	7,0	97,7	39,4	28,6	32,0	436	35,0	491,8	17,7	0,4	15,4	1.186	224
85	29,6	36,0	409	41,6	591,8	36,0	65,0	6,6	93,6	44,2	29,6	36,0	344	35,0	498,2	19,2	0,3	15,1	1.286	227
94	30,5	40,7	322	42,0	600,2	40,7	54,0	7,0	99,8	46,9	30,5	40,7	269	35,0	500,4	21,0	0,3	14,8	1.388	228
100	31,1	44,2	258	39,5	563,1		-	-	-		31,1	44,2	258	39,5	563,1	21,0	0,3	14,5	1.451	257

Table 13. Growth and yield model for Norway spruce used for prognosis in afforestation

10.3 Details of the Table 6

Here is given key elements of calculations of the accounting for forest, with a the principal calculations as basis for the further work.

Table 14. FRF Changes in carbon stocks, afforestation of 1,900 ha/yr, including emission from soil - CO_2 and other gasses (NO_2, CH_4). Carbon stock transfer indicates changes due to transfer of area from I to IV - deforestation.

	2015-2020	2021-2025	2026-2030	2031-2035
I: FRF - from before 1990				
Area (ha)	524.551	523.651	522.978	522.305
Carbon stock (AG+BG+DW+FF) (ktC)	46.332	46.048	45.550	45.214
CO2 from drained soils (CO2 eq/yr)	122	122	122	121
N2O drained organic soils (CO2 eq/yr)	17	17	17	17
CH4 drained and rewetted organic soils (CO2 eq/yr)	28	28	28	28
Carbon (soils and gasses) (kt CO2/yr)	167	167	167	166
Stock change + soils (kt CO2/yr)	228	428	548	328

Table 15. AF 20 years limit and 1,900 ha/yr - changes in carbon stocks, including emission from soil - CO_2 and other gasses (NO_2, CH_4). Carbon stock transfer indicates changes due to transfer of area from III to II.

	2015-2020	2021-2025	2026-2030	2031-2035
II: Afforestation - Older than 20 yr				
Area (ha)	31.263	51.503	70.119	84.932
Carbon stock (AG+BG+DW+FF) (ktC)	1.297	2.638	4.082	5.585
Carbon stock transfer (AG+ BG+ DW+ FF) (ktCO2 eq/yr)	245	247	249	124
Carbon accumulation - soil (CO2 eq/yr)	-15	-25	-34	-41
CO2 from drained soils (CO2 eq/yr)	18	31	43	54
N2O drained organic soils (CO2 eq/yr)	2	4	6	7
CH4 drained and rewetted organic soils (CO2 eq/yr)	0	1	1	1
Carbon (soils and gasses) (kt CO2/yr)	5	11	17	22
Stock change + soils (kt CO2/yr)	-862	-952	-1.101	-1.031
Stock change + soils + transfer (kt CO2/yr)	-617	-705	-852	-907
III: Afforestation - Younger than 20 yr				
Area (ha)	62.301	52.623	43.609	38.399
Carbon stock (AG+BG+DW+FF) (ktC)	821	715	573	464
Carbon stock transfer (AG+ BG+ DW+ FF) (ktCO2 eq/yr)	-245	-247	-249	-124
Carbon loss from conversion (CO2 eq/yr)	42	42	42	42
Carbon accumulation - soil (CO2 eq/yr)	-30	-25	-21	-18
CO2 from drained soils (CO2 eq/yr)	31	23	15	10
N2O drained organic soils (CO2 eq/yr)	4	3	2	1
CH4 drained and rewetted organic soils (CO2 eq/yr)	1	0	0	0
Carbon (soils and gasses) (kt CO2/yr)	48	43	39	35
Stock change + soils (kt CO2/yr)	103	126	160	63
Stock change + soils + transfer (kt CO2/yr)	-142	-121	-89	-61

Table 16. AF 30 years limit and 1,900 ha/yr - changes in carbon stocks, including emission from soil - CO_2 and other gasses (NO_2, CH_4). Carbon stock transfer indicates changes due to transfer of area from VI to V.

	2015-2020	2021-2025	2026-2030	2031-2035
V: Afforestation - Older than 30 yr				
Area (ha)	613	14.712	33.102	51.503
Carbon stock (AG+BG+DW+FF) (ktC)	39	1.002	2.434	4.044
Carbon stock transfer (AG+ BG+ DW+ FF) (ktCO2 eq/yr)	152	759	759	764
Carbon accumulation - soil (CO2 eq/yr)	-0	-7	-16	-25
CO2 from drained soils (CO2 eq/yr)	1	12	24	37
N2O drained organic soils (CO2 eq/yr)	0	2	3	5
CH4 drained and rewetted organic soils (CO2 eq/yr)	0	0	1	1
Carbon (soils and gasses) (kt CO2/yr)	1	7	12	18
Stock change + soils (kt CO2/yr)	-171	-953	-1.095	-1.210
Stock change + soils + transfer (kt CO2/yr)	-19	-194	-336	-446
VI: Afforestation - Younger than 30 yr				
Area (ha)	92.951	89.415	80.627	71.827
Carbon stock (AG+BG+DW+FF) (ktC)	2.078	2.352	2.221	2.005
Carbon stock transfer (AG+ BG+ DW+ FF) (ktCO2 eq/yr)	-304	-759	-759	-764
Carbon loss from conversion (CO2 eq/yr)	42	42	42	42
Carbon accumulation - soil (CO2 eq/yr)	-45	-43	-39	-34
CO2 from drained soils (CO2 eq/yr)	47	42	35	27
N2O drained organic soils (CO2 eq/yr)	6	6	5	4
CH4 drained and rewetted organic soils (CO2 eq/yr)	1	1	1	1
Carbon (soils and gasses) (kt CO2/yr)	51	47	43	39
Stock change + soils (kt CO2/yr)	-590	127	154	241
Stock change + soils + transfer (kt CO2/yr)	-893	-632	-605	-522

Table 17. FRF Changes in carbon stocks, and 3,200 ha/yr, including emission from soil - CO_2 and other gasses (NO_2, CH_4). Carbon stock transfer indicates changes due to transfer of area from I to IV - deforestation.

	2015-2020	2021-2025	2026-2030	2031-2035
I: FRF - from before 1990				
Area (ha)	524.551	523.651	522.978	522.305
Carbon stock (AG+BG+DW+FF) (ktC)	46.332	46.048	45.550	45.214
CO2 from drained soils (CO2 eq/yr)	122	122	122	121
N2O drained organic soils (CO2 eq/yr)	17	17	17	17
CH4 drained and rewetted organic soils (CO2 eq/yr)	28	28	28	28
Carbon (soils and gasses) (kt CO2/yr)	167	167	167	166
Stock change + soils (kt CO2/yr)	228	428	548	328

Table 18. AF 20 years limit and 3,200 ha/yr - changes in carbon stocks, including emission from soil - CO_2 and other gasses (NO_2, CH_4). Carbon stock transfer indicates changes due to transfer of area from III to II.

	2015-2020	2021-2025	2026-2030	2031-2035
II: Afforestation - Older than 20 yr				
Area (ha)	31.263	51.503	70.119	84.932
Carbon stock (AG+BG+DW+FF) (ktC)	1.296	2.635	4.076	5.577
Carbon stock transfer (AG+ BG+ DW+ FF) (ktCO2 eq/yr)	245	247	249	142
Carbon accumulation - soil (CO2 eq/yr)	-15	-25	-34	-41
CO2 from drained soils (CO2 eq/yr)	18	34	48	60
N2O drained organic soils (CO2 eq/yr)	3	5	7	8
CH4 drained and rewetted organic soils (CO2 eq/yr)	0	1	1	1
Carbon (soils and gasses) (kt CO2/yr)	6	15	22	29
Stock change + soils (kt CO2/yr)	-860	-947	-1.094	-1.022
Stock change + soils + transfer (kt CO2/yr)	-615	-700	-845	-880
III: Afforestation - Younger than 20 yr				
Area (ha)	65.499	62.858	60.242	61.429
Carbon stock (AG+BG+DW+FF) (ktC)	838	787	723	722
Carbon stock transfer (AG+ BG+ DW+ FF) (ktCO2 eq/yr)	-245	-247	-249	-142
Carbon loss from conversion (CO2 eq/yr)	70	70	70	70
Carbon accumulation - soil (CO2 eq/yr)	-31	-30	-29	-29
CO2 from drained soils (CO2 eq/yr)	32	25	19	15
N2O drained organic soils (CO2 eq/yr)	4	3	3	2
CH4 drained and rewetted organic soils (CO2 eq/yr)	1	1	0	0
Carbon (soils and gasses) (kt CO2/yr)	47	41	35	30
Stock change + soils (kt CO2/yr)	75	78	93	-35
Stock change + soils + transfer (kt CO2/yr)	-170	-168	-156	-177

Table 19. AF 30 years limit and 3,200 ha/yr - changes in carbon stocks, including emission from soil - CO_2 and other gasses (NO_2, CH_4). Carbon stock transfer indicates changes due to transfer of area from VI to V.

	2015-2020	2021-2025	2026-2030	2031-2035
V: Afforestation - Older than 30 yr				
Area (ha)	613	14.712	33.102	51.503
Carbon stock (AG+BG+DW+FF) (ktC)	39	1.002	2.434	4.044
Carbon stock transfer (AG+ BG+ DW+ FF) (ktCO2 eq/yr)	152	759	759	764
Carbon accumulation - soil (CO2 eq/yr)	-0	-7	-16	-25
CO2 from drained soils (CO2 eq/yr)	1	15	29	43
N2O drained organic soils (CO2 eq/yr)	0	2	4	6
CH4 drained and rewetted organic soils (CO2 eq/yr)	0	0	1	1
Carbon (soils and gasses) (kt CO2/yr)	1	10	18	25
Stock change + soils (kt CO2/yr)	-171	-950	-1.089	-1.202
Stock change + soils + transfer (kt CO2/yr)	-19	-191	-330	-438
VI: Afforestation - Younger than 30 yr				
Area (ha)	96.148	99.649	97.260	94.858
Carbon stock (AG+BG+DW+FF) (ktC)	2.095	2.420	2.364	2.255
Carbon stock transfer (AG+ BG+ DW+ FF) (ktCO2 eq/yr)	-304	-759	-759	-764
Carbon loss from conversion (CO2 eq/yr)	70	70	70	70
Carbon accumulation - soil (CO2 eq/yr)	-46	-48	-47	-46
CO2 from drained soils (CO2 eq/yr)	48	44	38	33
N2O drained organic soils (CO2 eq/yr)	7	6	5	4
CH4 drained and rewetted organic soils (CO2 eq/yr)	1	1	1	1
Carbon (soils and gasses) (kt CO2/yr)	51	45	40	34
Stock change + soils (kt CO2/yr)	-616	81	88	145
Stock change + soils + transfer (kt CO2/yr)	-919	-678	-671	-619

UNIVERSITY OF COPENHAGEN

DEPARTMENT OF GEOSCIENCES
AND RESOURCE MANAGEMENT

ROLIGHEDSVEJ 23
DK-1958 FREDERIKSBERG

TEL. +45 35 33 15 00
IGN@IGN.KU.DK
WWW.IGN.KU.DK