Acquiring and updating Danish forest data for use in UNFCCC negotiations

Johannsen, Vivian Kvist; Nord-Larsen, Thomas; Riis-Nielsen, Torben; Bastrup-Birk, Annemarie; Vesterdal, Lars; Stupak, Inge

Publication date:
2009

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

Citation for published version (APA):
Johannsen, V. K., Nord-Larsen, T., Riis-Nielsen, T., Bastrup-Birk, A., Vesterdal, L., & Stupak, I. (2009). *Acquiring and updating Danish forest data for use in UNFCCC negotiations*. Forest & Landscape, University of Copenhagen. Forest & Landscape Working Papers, No. 44/2009

FOREST & LANDSCAPE

Acquiring and updating Danish forest data for use in UNFCCC negotiations

FOREST & LANDSCAPE WORKING PAPERS 44 / 2009

Vivian Kvist Johannsen, Thomas Nord-Larsen, Torben Riis-Nielsen,
Annemarie Bastrup-Birk, Lars Vesterdal and Inge Stupak Møller

FACULTY OF LIFE SCIENCES
UNIVERSITY OF COPENHAGEN

Title
Acquiring and updating Danish forest data for use in UNFCCC negotiations

Editors
Vivian Kvist Johannsen, Thomas Nord-Larsen, Torben Riis-Nielsen,
Annemarie Bastrup-Birk, Lars Vesterdal and Inge Stupak Møller

Publisher
Forest & Landscape Denmark
University of Copenhagen
Hørsholm Kongevej 11
DK-2970 Hørsholm
Tel. +45 3533 1500
Email sl@life.ku.dk

Series-title and no.
Forest & Landscape Working Papers no. 44-2009 published on www.SL.life.ku.dk

ISBN
978-87-7903-447-0

Citation
Vivian Kvist Johannsen, Thomas Nord-Larsen, Torben Riis-Nielsen, Annemarie Bastrup-Birk,
Lars Vesterdal and Inge Stupak Møller 2009: Acquiring and updating Danish forest data for use in
UNFCCC negotiations. Forest & Landscape Working Papers No. 44-2009, 45 pp.
Forest & Landscape Denmark, Hørsholm.

Foreword

This report is a preliminary update of the Danish data on CO_2 emissions from forest, afforestation and deforestation for the period 1990 - 2008 and a prognosis for the period until 2020.

The report is funded by the Ministry of Climate and Energy and the Ministry of Environment.

The report is based on the data from the Danish National Forest Inventory (NFI), performed for the Ministry of Environment and the SINKS project in relation to Article 3.4 of the Kyoto protocol for the Ministry of Climate and Energy.

Forest & Landscape, Copenhagen University, have compiled the report based on the data from the NFI combined with other relevant data, generated in the research and the general Forest Monitoring for the Ministry of Environment.

Hørsholm, October 20th 2009

Sammendrag

Formål med projektet er at komme med et datagrundlag til UNFCCC forhandlingerne for fastsættelse af en dansk reference niveau for optag og udslip af CO_2 fra de danske skove for perioden 2013-20XX (17-20). Data skal kunne anvendes til de forskellige forslag, der p.t. er relevante i forbindelse med COP15 forhandlingerne vedrørende 'forest management'.

En sådan reference vil med stor sandsynlighed tage udgangspunkt i eksisterende UNFCCC skovdata for enten hele eller dele af perioden 1990-2007, samt åbne mulighed for justeringer såfremt Danmark har gode argumenter for at foretage sådanne justeringer.

Dette notat beskriver 3 delopgaver i projektet:

1. Status over kulstoflagring i de danske skove for perioden 2002-2008 i forhold til Kyoto protokollens artikel 3.3 og 3.4 skov.

2. Genberegning af 1990-2007 skovdata rapporteret til UNFCCC

3. Prognose for kulstoflagringen frem til 2020 og sammenligning med prognoser produceret af Joint Research Centre.

Datamaterialet for dette notat kommer fra følgende hovedkilder:

1. Skovstatistikken (National Forest Inventory - NFI) der udføres af Skov & Landskab for Skov & Naturstyrelsen, Miljøministeriet, der startede i 2002 og kører med årlig opdateringer - med 5 årige runder.

2. Skovtællingerne 1990 og 2000, der er udført af Danmarks Statistik - i samarbejde med Skov- og Naturstyrelsen og Skov & Landskab

3. Kortlægning af skovareal på grundlag af satellit billeder i 1990 og 2005 - med støtte fra European Space Agency (ESA) og Klima- og Energiministeriet

Med udgangspunkt i det kortlagte skovareal i 1990 og i 2005 er der foretaget en beregning af kulstoflagret i såvel gammel skov (skov etableret før 1990 - omfattet af Kyoto protokollens artikel 3.4) som i ny skov (skovrejsning siden 1990 - omfattet af Kyoto protokollens artikel 3.3).

Skovarealet er i såvel 1990 som i 2005 kortlagt til at være større end tidligere opgjort for de tidspunkter.

Ved beregning af kulstoflager i 1990 og i 2000 anvendes aldersklassefordelingen som opgjort i Skovtællingen 1990 og i 2000 som udtryk for det samlede skovareals fordeling til arter og aldre. Med udgangspunkt i NFI'ens konkrete målinger i skov af kulstoflager i de forskellige arts og alders klasser beregnes det samlede stående kulstoflager. For hvert år i perioden 1990 - 2000 beregnes et stående kulstoflager som en glidende gennemsnit, korrigeret for de få skovrydninger der var i perioden.

Idet Skovstatistikken først startede med de første målinger i 2002, er den først repræsentativ fra 2005. Beregning af kulstoflager i perioden 2000-2004 baseret på Skovstatistikkens målinger i 2005 og kulstoflager som beregnet for 2000.

For 2005-2007 er kulstoflageret beregnet udelukkende på grundlag af skovstatistikken, som beskrevet også i Skove og plantager 2006 - med supplerende information om det totale skovareal fra satellitbillede kortlægningen.

Prognosen for kulstoflager i perioden 2008 - 2020 tager også udgangspunkt i Skovstatistikkens målinger af kulstoflager i de forskellige arts og alders klasser. Prognosen fremskriver arealets fordeling til aldersklasser ud fra sandsynligheder for foryngelse af den enkelte aldersklasse. Der forudsættes en konstant fordeling til arter (ingen artsskifte), men en beregning af andelen af arealet der hvert år forynges med samme art. For hvert år kombineres disse beregninger med Skovstatistikkens måling af kulstoflager i hver aldersklasse. Udviklingen i den samlede kulstofpulje kan derefter beregnes.

For perioden 1990 - 2000 er der en stigning i skovenes kulstoflager. For perioden 2000 - 2005 er der et svagt fald i skovenes kulstoflager. Faldet skyldes skovrydninger, mens det gennemsnitlige kulstoflager pr. ha har været stigende i perioden.

I perioden 2005-2007 er der tilstrækkelig data fra Skovstatistikken til at beregne kulstoflager. I de år er der en svag stigning i kulstoflageret i skovene.

For skovrejsningsarealerne er der en jævn stigning i kulstoflageret fra de første skovrejsninger i 1990 og helt frem til 2007. Artssammensætningen af skovrejsningen blev beskrevet i Skovtælling 2000 og danner grundlag for beregning af kulstoflageret i perioden 1990 - 2000. Efterfølgende bidrager Skovstatistikken med en artsfordeling af skovrejsningen.

I forhold til tidligere beregninger af kulstoflager i skovene foretages de nærværende beregninger udelukkende på det samlede kulstoflager. Der anvendes således ikke modeller for tilvækst og ej heller opgørelser af hugst - hvilket tidligere har været den eneste mulighed for at beskrive ændringerne. I de fremtidige rapporteringer vil opgørelser af såvel gamle skove som skovrejsning basere sig på 5 års målinger med Skovstatistikken, hvor året der rapporteres for er midtpunkt i en 5 års periode. Derfor er de nærværende beregninger foretaget på samme måde som de kommende rapporteringer.

I forhold til prognoser udviklet af Joint Research Centre så har de danske skove i perioden 1990 - 2007 haft en øgning af kulstoflageret. Det er dog en mindre øgning end hidtil beregnet, idet de tidligere beregninger med det grundlag der var tilgængeligt overvurderede tilvæksten. Samtidig kan hugsten være underestimeret. Begge dele har ført til et for højt estimat for kulstoflagringen i skovene - på gamle skovarealer.

Der har ikke tidligere været rapporteret skovrydning for Danmark, og det samlede areal er da heller ikke mere end 1783 ha. Informationen medtages i rapporteringen.

For skovrejsningen er de nye beregninger sammenlignelige med de hidtidige rapporteringer og dermed også med Joint Research Centres analyser.

I prognosen for perioden 2008 - 2020 medfører den observerede aldersfordeling i skovene at beregningerne viser en faldende tendens for skovenes kulstoflager. Dette skyldes at skovene aktuelt har en meget stor andel af gamle træer, der står overfor en foryngelse. Hermed forventes de store gamle træer fældet og nye at kommer til. Netto resultatet er, at det samlede kulstoflager falder. Hvis skovene havde en helt jævn fordeling til aldre, ville kulstoflageret være så godt som konstant - forudsat uændret hugst og vækst. Hvis der sker ændringer i forvaltningen af skovene, vil det påvirke udviklingen i skovene. Således vil en forlængelse af omdrift - hvor man venter med at fælde gamle træer - udskyde faldet i kulstoflager. Modsat vil en øget hugst (fx som følge af øget efterspørgsel, øget pris o.lign.) føre til et kraftigere fald i kulstoflageret.

Beregningerne og sammenstillingen af data giver det bedst mulige grundlag til UNFCCC forhandlingerne for fastsættelse af en dansk reference for optag og udslip af CO_2 fra de danske skove for perioden 2008-2020. Kulstoflageret er opdelt på de forskellige puljer og fordelt til gammel og ny skovareal. Prognosen understøttes af opdateringen af data for skovene i perioden 1990 - 2007.

Summary

Data source:

1. National Forest Inventory - NFI - conducted by Forest and Landscape Denmark for The Danish Forest and Nature Agency, Ministry of Environment. The NFI started in 2002 and is a continous forest inventory with partial replacement. The rotation is 5 years. (Nord-Larsen et al 2008)

2. Forest Census 1990 and 2000, conducted by Statistics Denmark - in cooperation with The Danish Forest and Nature Agency and Forest and Landscape Denmark. (Danmarks Statistik 1994, Larsen & Johannsen 2002)

3. Mapping of the forest area based on satellite images in 1990 and 2005, with suppport from ESA - GMES - FM and the Ministry of Climate and Energy. (Prins 2009)

Carbon stock 1990 - 2007:

Based on the mapped forest area in 1990 and in 2005 a calculation of carbon stored in both the old forest (forest established pre-1990 - under the Kyoto Protocol Article 3.4) and in new forests (afforestation since 1990 - under the Kyoto Protocol Article 3.3) was performed. The forest areas in 1990 as well as in 2005 have been mapped to be larger than previously estimated for the times.

The calculation of carbon stock in 1990 and in 2000 used age distribution as reported in census 1990 and Forest in 2000 as an expression of the total forest land allocation to species and ages. Based on the actual measurements of carbon storage in different species and age classes, the total standing carbon stock was calculated. For each of the years 1990 - 2000 calculated a standing carbon stock as a moving average, corrected for the small scale deforestation which was detected.

Since the NFI was initiated in 2002, it is representative from 2005. Calculation of carbon stock in the period 2000-2004 is based on NFI in 2005 and carbon stock as calculated for 2000. For 2005-2007 carbon stock is calculated solely on the basis of the NFI - with additional information about the total forest area from satellite image mapping.

Projections 2008-2020:

The prognosis for carbon stock during the period 2008 - 2020 is based on the NFI data on carbon stock in management classes - species and age classes. Forecasts are based on are allocation to age classes based on probabilities for rejuvenation of each management class. It assumes a constant distribution of species (no species change), but a calculation of percentage of area rejuvenated each year with the same species. For each year, these calculations are combined with NFI data for carbon stocks in each management class. Evolution of the total carbon pool can then be calculated. The probabilities for rejuvenation is estimated based on the forest census data from 1990 and 2000 (Nord-Larsen & Heding 2002). The projections involve no estimation of growth or harvesting.

The projections are performed similarly for old as well as new forests. In the afforestation an annual afforestation of 1900 ha is assumed, with a species distribution similar to the distribution observed in the NFI, except for a constant area with Christmas trees.

The forecast for the period 2008 - 2020 show a decreasing trend of forest carbon stock. This is due to the current high proportion of old trees, which face rejuvenation. Hereby large old trees felled and replaced by new small trees. The net result is that the total carbon stock decreases. If the forests had a completely even distribution of ages, carbon stock would be virtually constant - assuming unchanged harvesting and growth. Changes in forest management, may affect the development of forests. Thus, a postponement of cutting of old trees - will postpone the decline in carbon storage. Conversely, increased logging (e.g. due to increased demand, increased price or similar) may lead to a sharper decline in carbon stock.

CONTENTS

Introduction

The LULUCF sector differs from the other sectors in that it contains both sources and sinks of carbondioxide. LULUCF are reported in the new CRF format. Carbondioxide removed from the atmosphere is given as negative figures and emissions to the atmosphere are reported as positive figures according to the guidelines. For 2006 emissions from LULUCF were estimated to be a sink of approximately 1.8 Gg CO_2 or 2.6% of the total reported Danish emission. The previously used methodology for LULUCF is described in Gyldenkærne et al. (2005).

Compared to the other Scandinavian countries, Danish forests cover only a small part of the country (12.4%) since the dominant land use in Denmark is agriculture. Forests thus cover about 534.000 ha (=5.340 km^2) with an almost equal distribution between broadleaved and coniferous species (Nord-Larsen et al., 2008). Danish forests are managed as closed canopy forests, and the main objective is to ensure sustainable and multiple-use management. The main management system used to be the clear-cut system, but increasingly, principles of nature-based forest management including continuous cover forestry are being implemented in many forest areas, e.g. the state forests (about ¼ of the forest area). Contrary to the situation in the other Scandinavian countries, forestry does not contribute much to the national economy. Forestry contributes less than 1 ‰ to the total Danish GNP. Denmark is the only part of the Kingdom with a forestry sector. Greenland and the Faroe Islands have almost no forest.

Forest legislation and policy

The Danish Forest Act protects the main part of the forest area (about 80%) against conversion to other land uses, and these forests will generally remain forest, although forests may be cleared in relation to e.g. nature restoration projects. The objective to ensure sustainable and multiple-use management is laid down in the Forest Act, carbon sequestration being just one of several objectives.

Approximately 2/3 of the total Danish land area is cultivated and utilised for cropland and grassland. Together with high numbers of cattle and pigs there is a high (environmental) pressure on the landscape. To reduce the impact an active policy has been adopted to protect the environment. The adopted policy aims at doubling the forested area within the next 80-100 years, restoration of former wetlands and establishment of protected national parks.

The policy objective most likely to increase carbon sequestration is the 1989 target to double Denmark's forested area within 100 years. The most important measure aiming at achieving this objective is a governmental subsidy scheme established to support private afforestation on agricultural land. Subsidized afforestation areas are automatically declared forest reserve and are thus protected according to the Forest Act. Secondly, governmental and municipal afforestation is also taking place. Finally, private afforestation is taking place without subsidies. The Danish Forest and Nature Agency, under the Ministry of Environmient, is responsible for policies on afforestation of state-owned and private agricultural land.

The Forest Act includes an obligation of the Ministry of Environment to monitor forest condition and maintain a comprehensive inventory of forest status and trends. The aim of the national inventory is to improve the understanding and management of the Danish Forests and aid forest policy and legislation (Miljøministeriet, 2002). The selected variables should cover the indicators concerning sustainable forest management and meet the data needs for national and international forest statistics.

Green accounting and environmental management are used in the sector as a measure to monitor and reduce its environmental impacts. State forests for example issue yearly green accountings. One of the intentions is to determine whether the use of fossil fuels in forest management can be reduced.

Forest statistics and definitions

Forest census

From 1881 to 2000, a National Forest Census has been carried out roughly every 10 years based on questionnaires sent to forest owners (Larsen and Johannsen, 2002). Since the data was based on questionnaires and not field observations, the actual forest definition may have varied. The basic definition was that the tree covered area should be minimum 0.5 ha to be a forest. There were no specific guidelines as to crown cover or the height of the trees. Open woodlands and open areas within the forest were generally not included. 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. The two last censuses were carried out in 1990 and 2000.

The 1990 National Forest Census was based on reported forest statistics from 22,300 respondents, resulting in information on area, main species, age class distribution and productive indicators. The estimated forest area was 445,000 ha or 10.3% of the land. Of the total forest area 64% was coniferous forest and 34% was deciduous forest (the remainder was temporarily unstocked). The total volume was estimated at 55.2 mio. cub. metres of which 57% was coniferous.

The number of respondents in the 2000 National Forest Census was 32,300, which is considerably higher than in the 1990 survey. The change in the number of respondents probably contributed to the observed increase in forest area and growing stock between the 1990 and 2000 census. The estimated forest area was 486,000 ha or 11.3% of the land. Of the total forest area 60% was coniferous forest and 36% was deciduous forest (the remainder was temporarily unstocked). The total volume was estimated at 77.9 mio. cub. metres of which 63% was coniferous.

National Forest Inventory

In 2002, a new sample-based National Forest Inventory (NFI) was initiated. This type of forest inventory is very similar to inventories used in other countries, e.g. Sweden or Norway. The NFI has replaced the National Forest Census.

The forest definition adopted in the NFI is identical to the FAO definition (TBFRA, 2000). Compared to the National Forest Census, this forest definition is more specific and includes a larger variety of areas. It includes *"wooded areas larger than 0.5 ha, that are able to form a forest with a height of at least 5 m and crown cover of at least 10%. The minimum width is 20 m."* Temporarily non wooded areas, fire breaks, and other small open areas, that are an integrated part of the forest, are also included.

The NFI is a continuous sample-based inventory with partial replacement of sample plots based on a 2 x 2 km grid covering the Danish land surface. At each grid intersection, a cluster of four circular plots (primary sampling unit, PSU) for measuring forest factors (e.g. wood volume) are placed in a 200 x 200 m grid. Each circular plot (secondary sampling unit, SSU) 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 (TSU).

About one third of the plots are assigned as permanent and will be remeasured 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.

Based on analysis of aerial photos, each sample plot (SSU) is allocated to one of three basic categories, reflecting the likelihood of forest or other wooded land (OWL) cover in the plot: (0) Unlikely to contain forest or other wooded land cover, (1) Likely to contain forest, and (2) Likely to contain other wooded land. All plots in the last two categories are inventoried in the field.

In the first years of the NFI (2002-2008) the average number of clusters (PSU) and sample plots (SSU) are 2,196 and 8,604, respectively. On average 1,627 plots (SSU) were identified as having forest or other wooded land cover based on the aerial photos and were thus selected for inventory. During the first rotation of the NFI, measurements were however not obtained for some plots. Missing plot observations were caused by a number of factors including start up problems that resulted in insufficient time to complete the measurements and prohibited access to some plots on privately owned land. In 2005, the Forest Act was revised, so forest owners are obliged to provide access. On average 322 sample plots were missing in the 2002-2008 inventories.

Table 1. Total and selected number of clusters (PSU) and sample plots (SSU) in the National Danish Forest Inventory in the years 2002-2008.

Year	Clusters (PSU)		Sample plots (SSU)		
	Total	Selected*	Total	Selected*	Missing*
2002	2,190	649	8,594	1,399	697
2003	2,199	641	8,626	1,498	436
2004	2,188	685	8,597	1,587	517
2005	2,200	711	8,594	1,590	168
2006	2,179	717	8,531	1,620	187
2007	2,201	772	8,644	1,804	246
2008	2,212	804	8,644	1,893	3

*The number of selected clusters and sample plots are those identified as forest or other wooded land on aerial photos. The number of measured plots represents those inventoried by the field crews. Missing plots include plots identified as having forest or other wooded land cover from the aerial photo which were not inventoried in the field.

Each plot is divided into three concentric circles with radius 3.5, 10 and 15 m. A single calliper measurement of diameter is made at breast height for all trees in the 3.5 m circle. Trees with diameter larger than 10 cm are measured in the 10 m circle and only trees larger than 40 cm are measured in the 15 m circle. On a random sample of 2-6 trees further measurements of total height, crown height, age and diameter at stump height are made and the presence of defoliation, discoloration, mast, mosses and lichens is recorded. The presence of regeneration on the plots is registered and the species, age and height of the regeneration is recorded. Stumps from trees harvested within a year from the measurement are measured for diameter.

Deadwood is measured on the sample plots. Standing deadwood with a diameter at breast height diameter larger than 4 cm is measured according to the same principles as live trees. Lying deadwood with a diameter of more than 10 cm is measured within the 15 m radius sample plot. Length of the lying deadwood is measured as the length of the tree that exceeds 10 cm in diameter and is within the sample plot. The diameter is measured at the middle of the lying deadwood measured for length. In addition to the size measurements of deadwood the degree of decay is recorded on an ordinal scale.

Forest area mapping

Due to differences in methodologies major inconsistencies in forest area and other forest variables are observed between the different forest inventories (i.e. the 1990 and 2000 Forest Census and the 2006 National Forest Inventory). With the objective to obtain time consistent and precise estimate of forest areas to report to UNFCC and the Kyoto protocol, two projects have aimed at mapping the forest area in Denmark based on satellite images. Forest area and forest area change have been estimated for the years 1990 and 2005.

A land use / land cover map was produced for the Kyoto reference year 1990 and for the year 2005 based on EO data (23 August 1990) and other data produced from 1992-2005 and for 2005 using NFI in situ data. Forest maps are developed using Landsat imagery mainly Landsat 5 (TM) and 7 (ETM+) data to classify and estimate the area of forest cover types in Denmark. Portions of 7 scenes covering the whole country were classified into forest and non-forest classes. The approach involved the integration of sampling, image processing, and estimation. The maps were produced by Erik Prins, Prins Enginering as part of the GMES project GSE-FM (Prins 2009).

The product is specified by a Minimum Mapping Unit (MMU) of 0.5 ha, a geometric accuracy of < 15 m RMS and a thematic accuracy of 90% +/- 5% for the six major Kyoto classes: Forest, Grass, Crop, Wetland, Urban, and Other. Forest has a 0.5 ha MMU, however, is subdivided without MMU into conifer, deciduous, mixed, and temporary un-stocked forest.

Methods

Overall approach to estimation of carbon pools 1990 to 2007

Estimation of carbon pools in Denmark from 1990 to 2007 is complicated by the fact that information originates from various sources (National Forest Census data, National Forest Inventory data, maps produced from satellite images and other sources of geographical information), and that the forest definition has changed between inventories. Due to the continuous nature of the current Danish NFI, future inventories of carbon pools will be more consistent.

In the first step, the sample plots of the National Forest Inventory are allocated to one of three basic categories: 1) non-forest, 2) forest that was established before 1990, and 3) afforestation since 1990, based on an interpretation of satellite image-based forest maps from 1990 and 2005. Carbon pools in forests that were established before 1990 and on afforested lands in 2005 are estimated based on the National Forest Inventory data from 2004-2008 (status year 2005). Also based on this, data of the average carbon pools per hectare are estimated for each county, species and age-class.

Due to the limited number of respondents and the slightly different forest definition in the 1990 National Forest Census it is unlikely that the estimated forest area is similar to the actual area of forest conforming to the FAO definition. Using satellite images from 1990, a forest map has been produced and the forest area for each county has been estimated. Based on the 1990 forest areas, the observed distribution to species and age classes in the 1990 National Forest Census, and the 2005 estimates of carbon pools per hectare the total carbon pools are estimated for 1990.

As it is also unlikely that the 2000 National Forest Census obtained full coverage of all forest owners and because the forest definition may be uncertain it is unlikely that the estimated forest area is similar to the actual forest area. Using the forest area in 1990 and 2005 based on the interpretation of satellite images, information on annual afforestation provided by the Forest and Nature Agency and information on deforestation the forest area that was forest before 1990 and the afforested area since 1990 have been estimated for each county. Using the 2000 National Forest Census data, the species and age class distribution for forest areas that were forest before 1990 and for afforested areas have been estimated. Finally, based on the 2000 forest areas, the National Forest Census 2000 distribution to species and age classes, and the 2005 estimates of carbon pools per hectare, the total carbon pools in forests that were forest before 1990 and the afforested areas are estimated for 2000. Carbon pools per hectare in the intermediate years (1991-1999 and 2001-2004) are found by linear interpolation.

Carbon pools in 2006-2008 are estimated using a similar approach as for 2005 using data from the NFI. Recently afforested areas (after the mapping in 2005) are identified using the reports of the field crews and information from the land register (Generelle landbrugsregister, GLR).

Estimation of forest area in 1990 and 2005 using satellite imagery

All satellite images were pre-processed using standard procedures for rectification. This includes: 1) Collection of ground cover points (GCPs), 2) Evaluation of GCPs and 3) check GCPs. The maps were produced by Erik Prins, Prins Enginering as part of the GMES project GSE-FM (Prins 2009).

The geometric accuracy is derived by comparing respective positions in the geo-rectified image to ground control points as reference. It is expressed by the Root Mean Square error to the reference.

Classification of Land Use / Land Cover

The generation of the land use/land cover map is based on the evaluation of Landsat data. Forest is defined according to the FAO (2004). This means that clearcut forest areas are considered as temporary unstocked forest. Forest present in residential, recreational and urban areas are not included within forest area. The maps were also used to assess the amount of forest in the categories: 1) total forest area, 2) forest established before 1990, 3) afforestation since 1990, and 4) deforestation. Forest established before 1990 is defined as forest existing both in 1990 and 2005, afforestation is defined as the forest not existing in 1990 but in present in 2005, and finally deforestation is assessed as forest present in 1990 but not in 2005.

The classification of land use/land cover was performed using mainly ERDAS IMAGINE 9.2, ArcGIS 9.3, and Idrisi 14 software. ISODATA-algorithm (representing an iterative self-organising data analysis technique) was used for complex land use/land covers, weather supervised algorithms (i.e. maximum likelihood and minimum distance) where chosen where land use and land covers had more homogeneous segments i.e. crop land. Both approaches were used and selected where it was found convenient. The classification was divided into thematic areas for best separation of sub-classes (described below). The outputs were then combined to a final classification result. Manual post-processing was carried out subsequently to improve the quality of the (semi) automatically pre-classified product.

Prior to the classification, the Landsat data was divided into thematic areas representing: Forest, Wetland, Grass, Crops, Urban/land use/settlements, and other. The thematic areas were constructed from vector data that was used to mask out parts of the Landsat scenes from where separate digital classifications were preformed. The masking approach was chosen to increase the variation within the thematic areas and decrease spectral conflict areas i.e. lake versus conifers; crops versus young tree stands etc. The majority of the vector layers used were composed from Top10DK vector data, AIS and maps of protected nature types (so called §3 areas). Eventually the layers were added together (ranking urban areas lowest and §3 highest) to form one mask layer.

Manual Post-Processing

Subsequent to the automated classification, an interactive processing phase was accomplished where areas incorrectly classified were recoded. The manual post-processing was performed using ancillary data including ortho-photo, cadastral information and EU's Land Parcel Information System (LPIS, Generelle landbrugsregister, GLR) information sources.

Filter Operations were applied to improve the quality of the automatically classified forest map. Those filters eliminate incorrectly classified individual pixels or small groups of pixels with a size of 2 or 3 pixels and assign them to surrounding classes. These filter operations have the effect that small gaps in the forest without forest cover were included in the forest area. Similarly, tree covered areas smaller than 0,5 ha in the landscape were eliminated by these filtering operations. Eventually, main classes where small gaps in the forest were filled and forest areas smaller than 0.5 ha were eliminated by carrying out those filtering operations.

In order to measure the achieved accuracy, the satellite image derived forest mask was evaluated against aerial photos and NFI data representing the ground truth using standard GIS procedures. This ongoing evaluation is performed using the 2005 land use/land cover map. In some cases assessments based on the land use/land cover map and the ground truth diverge. Manual correction based on auxiliary information from the NFI and ortho-photos is performed.

Change Detection

By extracting the forest from the 1990 and 2005 land use/land cover maps, changes in forest cover were detected. Hereby, four classes were detected:

1. “Forest established before 1990”. Areas with forest cover in both 1990 and 2005.

2. “Forest established after 1990”. Areas with no forest cover in 1990 which has forest cover on the 2005 map.

3. “Deforested areas”. Areas with forest cover in 1990 but with no forest cover in 2005.

4. “Non-forest areas”. Areas with no forest cover in both 1990 and 2005.

Estimation of forest characteristics using NFI data

Forest area

Based on analysis of aerial photos, each sample plot (SSU) is allocated to one of three forest status categories (*Z*), reflecting the likelihood of forest or other wooded land (OWL) in the plot: (0) Unlikely to be covered by forest or other wooded land, (1) Likely to be covered by forest, and (2) Likely to be covered by other wooded land.

On individual sample plots (*j*) the forest cover percentage (*X*) is calculated as the proportion of the forest area (*A*) to the total plot area of the 15 m radius circle (A_{15}). The average forest percentage ($\bar{X}$) on plots with forest status Z=1 (and 2) is calculated as the sum of the forest percentages times an indicator variable (*R*) that is 1 if *Z* equals 1 (or 2) and 0 otherwise, divided by the number of plots with forest status Z=1 (or 2).

The overall average forest percentage ($\bar{\bar{X}}$) is calculated as the sum of: (1) observed forest cover percentages of the individual sample plots, (2) the number of unobserved sample plots with forest status Z=1 times the average forest cover percentage of sample plots with forest status 1, and (3) the number of unobserved sample plots with forest status 2 times the average forest cover percentage of observed sample plots with forest status *Z*=2 divided by the number of observed and unobserved sample plots. In this context sample plots with forest status 0 are regarded as observed and assumed to have a forest cover percentage of 0. Finally, the overall forest area (A_{Forest}) is calculated as the overall average forest percentage times the total land area (A_{Total}):

Equation	Description
$X_j = \frac{A_j}{A_{15,j}}$	The forest percentage (X) of the *j*th sample plot (SSU) is estimated as the forested area (*A*) divided by the total area of the 15 m radius sample plot ($A_{15,j}$).
$\overline{X}_Z = \frac{1}{n_Z} \sum_Z X_j R_j$	Average forest percentage ($\overline{X}$) of all inventoried plots (SSU) with forest status *Z* based on aerial photos. R_j is an indicator variable that is 1 for inventoried plots and 0 otherwise. n_Z is the number of inventoried plots identified as forest or OWL from the air photos.
$\overline{\overline{X}} = \frac{1}{n}\left(\sum_{j=1}^{n} X_j R_j + N_{21}\overline{X}_1 + N_{22}\overline{X}_2\right)$	Overall average forest percentage ($\overline{\overline{X}}$). *n* is the total number of inventoried and non-inventoried sample plots. N_{21} and N_{22} is the number of non- inventoried sample plots with forest and OWL, respectively.
$A_{Forest} = \overline{\overline{X}} \cdot A_{Total}$	Total forest area. A_{Total} is the total land area, $\overline{\overline{X}}$ is the estimated forest percentage and A_{Forest} is the total forest area.

When estimating the forest area with a specific characteristic (*k*), such as species or age class the proportion of the plot area with the particular characteristic is found by summing the forested plot areas times an indicator variable (*R*) that is 1 if the plot has the *k*th characteristic and 0 otherwise. Subsequently the plot area with the *k*th characteristic is divided by the total forested plot area.

The total forest area with a particular characteristic (A_k) is found as the forest area percentage with the particular characteristic *k* times the total forest area. In case of species and age classes, the species is identified as the main species on the plot to resemble the management classes used in the previous National Forest Census from 2000. The age classes are 10 year intervals derived from field observations.

Equation	Description
$\overline{X}_k = \frac{\sum_{j=1}^{n} R_{jk} A_j}{\sum_{j=1}^{n} A_j}$	Proportion of the forest area with a given characteristic ($\overline{X}_k$). R_{jk} is an indicator variable which is 1 if the the forest area on the *j*'th sample plots has the *k*'th characteristic and 0 otherwise. A_j is the sample plot area and *n* is the total number of inventoried sample plots with forest cover.
$A_k = \overline{X}_k \cdot A_{Forest}$	Total area with a given characteristic (A_k). $\overline{X}_k$ is the estimated proportion of the forest area with the *k*'th characteristic and A_{Forest} is the total forest area.

Estimation of volume, biomass and carbon pools

For estimation of volume, biomass and carbon of individual trees, we use the volume functions developed for the most common Danish forest tree species (Madsen, 1985, Madsen 1987 and Madsen and Heusèrr 1993). The functions use individual tree diameter and height as well as quadratic mean diameter of the forest stand as independent variables. For calculation of biomass and carbon

The first step is to estimate the height of trees with no height measurements. Based on the trees measured for both height and diameter, diameter-height regressions are developed for each species and growth region (Nord-Larsen et al. 2008). The functions use the observed mean height and mean diameter on each sample plot for creating localized regressions using the regression form suggested by Sloboda et al. (1993). For plots where no height measurements are available, generalized regressions are developed based on the Näslund-equation modified by Johannsen (1992).

Equation	Description
$h_{ij} = 13 + \left(\bar{h}_j - 13\right) \cdot \exp\left(\alpha_1 \cdot \left(1 - \frac{\bar{d}_j}{d_{ij}}\right) + \alpha_2 \cdot \left(\frac{1}{\bar{d}_j} - \frac{1}{d_{ij}}\right)\right)$	Site specific dh-regression for calculating height of trees not measured for height. h_{ij} and d_{ij} is the height and diameter of the i'th tree on the j'th sample plot. $\bar{h}_j$ and $\bar{d}_j$ are the average height and diameter of trees measured for height on the *j*th sample plot. α_1 and α_2 are species and growth-region specific parameters
$h_{ij} = 13 + \beta_1 \cdot \exp(-\frac{\beta_2}{d_{ij}})$	General dh-regression for calculating height of trees not measured for height. h_{ij} and d_{ij} is the height and diameter of the i'th tree on the j'th sample plot. β_1 and β_2 are species and growth-region specific parameters

The next step is to estimate the quadratic mean diameter of the trees on the sample plot. As the volume function in principle uses the quadratic mean diameter before thinning, a regression of stump diameter against diameter at breast height is estimated for each growth region and species. Using this regression, the diameter of trees felled within the past year is estimated.

As the trees are measured in different concentric circles depending on their diameter, the basal area on each sample plot is estimated by scaling the basal area of each tree (standing or felled) according to the circular area in which the tree has been measured. A similar calculation has been made for the number of stems. Finally, mean squared diameter is calculated from the basal area and stem numbers

Equation	Description
$d_{ij} = \gamma_1 d_{st,ij}^{\gamma_2}$	Regression of diameter at stump height ($d_{st,ij}$) against diameter at breast height (d_{ij}) for estimating the diameter of felled trees.
$g_{ij} = \frac{\pi}{4} d_{ij}^2$	Basal area (*g*) of the *i*th tree on the *j*th plot is calculated from the diameter at breast height (*d*) (1.3 m above ground) assuming a circular stem form.
$G_j = \sum_{i=1}^{m} \frac{1}{A_{c,ij}} g_{ij}$	Basal area per hectare (*G*) the jth sample plot is calculated as the scaled sum of individual tree basal areas. Basal area (*g*) of the *i*th tree on the *j*th sample plot is scaled according to the plot area ($A_{c,ij}$) of the *c*'th concentric circle (c=3,5; 10; 15 m).
$N_j = \sum_{i=1}^{m} \frac{1}{A_{c,ij}}$	Stem number per hectare (*N*) the *j*th sample plot is calculated as the scaled number of individual trees. The *i*th tree on the *j*th sample plot is scaled according to the plot area ($A_{c,ij}$) of the *c*'th concentric circle (c=3,5; 10; 15 m).
$D_{g,j} = \sqrt{\frac{4}{\pi} \frac{G_j}{N_J}}$	The mean squared diameter is calculated from the calculated basal area and stem number for each plot.

Based on the diameter, estimated or measured height of individual trees and the squared mean diameter before thinning, the volume of individual trees is estimated using the species specific volume functions by Madsen (1987) and Madsen and Heusèrr (1993). The volume of trees less than 3 meters tall is estimated using an alternative function. The calculated volumes are total stem volume over bark for conifers and total above ground volume over bark for deciduous species.

Using the above ground volume of the individual tree, the total volume (below and above ground) is estimated using expansion factors (1.8 for conifers and 1.2 for deciduous species). Biomass of the individual tree is subsequently calculated as the total volume times the density. Species specific densities (Moltesen et al, 1988) are found in appendix 1. Carbon in the individual tree is calculated as the biomass times 0.5. Currently a project (funded by the Ministry of Climate and Energy) is ongoing with the goal to improve the expansion factors - providing expansion functions for the main tree species Norway spruce, beech and oak. These new functions will be implemented in the formal reporting of the Danish data, as the project will be finalised in 2009. Some preliminary indicates are that the expansion function for conifers will be slightly lower - reducing the impact of fluctuations in conifer carbon stocks.

Equation	Description
$v_{ij} = F(d_{ij}, h_{ij}, D_{g,j})$	The volume (*v*) of the *i*'th tree on the *j*th sample plots is calculated using the existing volume functions (*F*) using the tree diameter and height and the quadratic mean diameter.
$v_{tot,ij} = v_{ij} \cdot E_{ij}$	The total above and below ground volume (v_{tot}) of the ith tree on the jth sample plot. V_{ij} is the calculated volume of the tree and *E* is the expansion factor (1.2 for deciduous species and 1.8 for conifers).
$B_{ij} = V_{tot,ij} \cdot Density_{ij}$	Biomass (*B*) of the *i*th tree on the *j*th sample plot is estimated as the total volume (V_{Tot}) times the species specific density.
$C_{ij} = B_{ij} \cdot 0.5$	Carbon of the *i*th tree on the *j*th sample plot is calculated as the biomass (*B*) times 0.5.

Total or regional volume, biomass and pools of carbon are estimated based on the estimates of individual tree volumes, biomass and carbon. First, volume, biomass or carbon per hectare is estimated for each of the concentric circles (c=3.5, 10 or 15 m radius) on each plot as the plot area depends on the diameter of the tree. Using the estimates from individual plots, the area weighted mean volume, biomass or carbon per hectare for the three concentric circles is estimated. The overall mean volume, biomass or carbon is estimated as the sum of the average volumes for the three circles. Finally, the total or regional volume, biomass or carbon is estimated as the forest area times the overall mean volume.

Equation	Description
$V_{cj} = \frac{1}{A_{cj}} \sum_{i=1}^{m} R_{c,i} v_{ij}$	Volume, biomass or carbon per hectare (*V*) of the *c*th concentric circle on the *j*th sample plot (*c*=3,5; 10; 15 m). R_c is an indicator variable that is 1 if the *i*th tree is measured on the *c*th circle and 0 otherwise. $A_{c,ij}$ is the area of the *j*th sample plot and *c*th concentric circle; *m* is the number of trees on the *jth* sample plot.
$\overline{V}_c = \frac{\sum_{j=1}^{n} A_{cj} V_{cj}}{\sum_{j=1}^{n} A_{cj}}$	The average area weighted volume, biomass or carbon per hectare ($\overline{V}$) of the *c*th concentric circle. $A_{c,ij}$ is the area of the *j*th sample plot and *c*th concentric circle; *n* is the number of sample plots.
$\overline{\overline{V}} = \overline{V}_{3,5} + \overline{V}_{10} + \overline{V}_{15}$	The overall average volume, biomass or carbon per hectare ($\overline{\overline{V}}$) is estimated as the sum of the average volume, biomass or carbon per hectare ($\overline{V}_c$) for the three concentric circles (*c*=3.5, 10 and 15)

Equation	Description
$V = \overline{\overline{V}} \cdot A_{Skov}$	Total volume, biomass or carbon V is the overall average volume, biomass or carbon per hectare ($\overline{\overline{V}}$) times the forest area A_{Forest}.

The total volume, biomass or carbon pools with a given characteristic are estimated in a similar way as the total figures. First, volume, biomass or carbon per hectare with the given characteristic is estimated for each of the concentric circles (c=3.5, 10 or 15 m radius) on each plot. Using the estimates from individual plots, the area weighted mean volume, biomass or carbon per hectare with the given characteristic for the three concentric circles is estimated. The overall mean volume, biomass or carbon is estimated as the sum of the average volumes for the three circles. Finally, the total or regional volume, biomass or carbon with the given characteristic is estimated as the forest area times the overall mean volume.

Equation	Description
$V_{cj,k} = \frac{1}{A_{cj}} \sum_{i=1}^{m} R_{c,ij} R_{k,ij} v_{ij}$	Volume, biomass or carbon per hectare (V) with the kth characteristic of the cth concentric circle on the jth sample plot (c=3,5; 10; 15 m). R_c is an indicator variable that is 1 if the ith tree is measured on the cth circle and 0 otherwise. R_k is an indicator variable that is 1 if the tree has kth characteristic and 0 otherwise. $A_{c,ij}$ is the area of the jth sample plot and cth concentric circle; m is the number of trees on the jth sample plot.
$\overline{V}_{c,k} = \frac{\sum_{j=1}^{n} A_{cj} V_{cj,k}}{\sum_{j=1}^{n} A_{cj}}$	The average area weighted volume, biomass or carbon per hectare ($\overline{V}$) with the kth characteristic of the cth concentric circle. $A_{c,ij}$ is the area of the jth sample plot and cth concentric circle; m is the number of trees on the jth sample plot.
$\overline{\overline{V}}_k = \overline{V}_{3,5,k} + \overline{V}_{10,k} + \overline{V}_{15,k}$	The overall average volume, biomass or carbon per hectare with the kth characteristic ($\overline{\overline{V}}$) is estimated as the sum of the average volume, biomass or carbon per hectare ($\overline{V}_{c,k}$) for the three concentric circles (c=3.5, 10 and 15)
$V_k = \overline{\overline{V}}_k \cdot A_{Forest}$	Total volume, biomass or carbon with the k^{th} characteristic (V_k) is the overall average volume, biomass or carbon per hectare ($\overline{\overline{V}}_k$) times the forest area A_{Forest}.

Dead wood volume, biomass and carbon

The volume of standing dead trees is calculated similarly to the calculations for live trees. The volume of lying dead trees within the sample plot is calculated as the length of the dead wood times the cross sectional area at the middle of the dead wood. Biomass of the deadwood is calculated as the volume times the species specific density and a reduction factor according to the structural decay of the wood (see Appendix 2). Finally, carbon of each standing or lying dead tree is calculated by multiplying the dead wood biomass with 0.5.

Equation	Description
$v_{s,ij} = F\left(d_{s,ij}, h_{s,ij}, D_{g,j}\right)$	The volume (v_s) of the *i*th standing, dead tree on the *j*th sample plots is calculated using the existing volume functions (*F*) using the tree diameter and height and the squared mean diameter.
$v_{s,tot,ij} = v_{s,ij} \cdot E_{ij}$	The total above and below ground volume ($v_{s,tot}$) of the *i*th standing, dead tree on the *j*th sample plot. v_s is the calculated volume of the tree and *E* is the expansion factor (1.2 for deciduous species and 1.8 for conifers).
$v_{l,ij} = \frac{\pi}{4} d_{l,ij}^2 \cdot l_{l,ij}$	Volume of lying dead trees (v_l) is calculated as the length (*l*) and the ith tree on the jth sample plot times the cross sectional area. The cross sectional area is calculated from the mid-diameter (d_l) of the dead wood.
$B_{s,ij} = v_{s,ij} \cdot D_{ij} \cdot r_{k,ij}$ $B_{l,ij} = v_{l,ij} \cdot D_{ij} \cdot r_{k,ij}$	Biomass of the *i*th standing (B_s) or lying (B_l) tree on the jth sample plot is calculated as the volume (v_s or v_l) times the species specific density (*D*) and a the *k*th reduction factor according to the structural decay of the wood observed in the field.
$K_{s,ij} = B_{s,ij} \cdot 0.5$ $K_{l,ij} = B_{l,ij} \cdot 0.5$	Carbon in standing or lying dead wood (C_s or C_l) is calculated as the biomass (B_s or B_l) times 0.5.

Total or regional volume, biomass and carbon pools of deadwood are estimated based on the estimates of volumes, biomass and carbon for individual dead trees or pieces of dead wood. First, deadwood volume, biomass or carbon per hectare is estimated for each of the concentric circles (*c*=3.5, 10 or 15 m radius). Estimates for lying dead wood are made using the 15 m circle. Using the estimates from individual plots, the area weighted mean volume, biomass or carbon per hectare of deadwood for the three concentric circles is estimated. The overall mean deadwood volume, biomass or carbon is estimated as the sum of the average volumes for the three circles. Finally, the total or regional deadwood volume, biomass or carbon is estimated as the forest area times the overall mean volume.

Equation	Description
$V_{D,cj} = \frac{1}{A_{cj}} \sum_{i=1}^{m} R_c v_{s,ij} + R_c v_{l,ij}$	Deadwood volume, biomass or carbon pools per hectare (V_D) for the *c*th circle and the *j*th sample plot. v_s and v_l is the volume of standing and lying deadwood respectively. R_c is an indicator variable that is 1 if the tree is measured in the *c*th circle and 0 otherwise. A_C is the sample plot area of the *c*th circle. *m* is the

	number of trees within the *j*th sample plot.
$\overline{V}_{D,c} = \frac{\sum_{j=1}^{n} A_{cj} V_{cj}}{\sum_{j=1}^{n} A_{cj}}$	The average area weighted deadwood volume, biomass or carbon per hectare ($\overline{V}_D$) of the cth concentric circle. $A_{c,ij}$ is the area of the jth sample plot and cth concentric circle; *n* is the number of sample plots.
$\overline{\overline{V}}_D = \overline{V}_{D,3,5} + \overline{V}_{D,10} + \overline{V}_{D,15}$	The overall average deadwood volume, biomass or carbon per hectare ($\overline{\overline{V}}_D$) is estimated as the sum of the average volume, biomass or carbon per hectare ($\overline{V}_{D,c}$) for the three concentric circles (c=3.5, 10 and 15)
$V_D = \overline{\overline{V}}_D \cdot A_{Forest}$	Total deadwood volume, biomass or carbon V_D is the overall average deadwood volume, biomass or carbon per hectare ($\overline{\overline{V}}_D$) times the forest area A_{Forest}.

Forest floors

Simple measurements of forest floor thickness in each NFI plot will enable estimation of carbon stock changes in the forest floor (or litter pool according to IPCC GPG) by the stock change method when the second round of the NFI has been completed in 2011. Existing national data on forest floor depth/mass relationships can be used to support these estimations.

Changes in soil carbon pools following afforestation were for the first time included in the NIR submitted in 2008 and forest floor C sequestration in afforestation has now been reported until the year 2007. The included soil C pool changes only concern C sequestration due to development of forest floors, i.e. the organic layer on top of the mineral soil. We have included C sequestration in this layer because there are results from national scientific projects in afforestation chronosequences (Vesterdal et al., 2002, 2007) as well as a number of studies on forest floor C in stands established by afforestation of cropland (Vesterdal and Raulund-Rasmussen, 1998; Vesterdal et al., 2008). Forest floor C sequestration rates were estimated from age-C stock regressions in afforestation chronosequences or by dividing the forest floor C stock in afforested stands by age in years. The included stands were up to 40 years and the C sequestration rates therefore apply to the current age range of stands afforested since 1990. The rate for broadleaved stands was 0.09 tC/ha/yr and 0.31 tC/ha/yr for coniferous stands. Average forest floor and mineral soil C pools for broadleaved and coniferous Danish forests based on a database at Forest & Landscape Denmark are given in Table 2.

Mineral soil

Based on chronosequence studies of afforested stands (http://www.sl.kvl.dk/afforest/), no consistent changes have been detected in mineral soil organic matter during the first 30 years following afforestation (Vesterdal et al., 2002; Vesterdal et al., 2007). There is currently too few data available to explore this further.

Better information on C stock changes of Danish forest soils is foreseen for the commitment period. A national project (SINKS) is currently carried out to resample forest soils in a 7x7 km grid (106 forest plots and 26 afforested cropland plots). The main aim is to document that Danish forest soils are not a source for CO2 emissions, as Denmark apply the non-source principle for litter and mineral soil pools under the Kyoto Protocol.

Average forest floor and mineral soil C pools for broadleaved and coniferous Danish forests based on a database at Forest & Landscape Denmark are given in Table 2. The data for the analysis are collected from available data sets from Vesterdal & Raulund-Rasmussen (1998), Vesterdal et al. (1995), Vesterdal et al. (2002a), Vesterdal et al. (2007), Vesterdal et al. (2008), Vesterdal et al. (2002b), Gundersen et al. (1998), Breuning-Madsen & Olsson (1995), Vejre et al. (2003, Nordsoil).

Table 2. Forest floor (FFC) and mineral soil (30 and 100 cm) carbon in coniferous and deciduous Danish forests. Numbers are based on analyses of mature forests. Average carbon pools of the forest floor estimated from NFI data is provided as a reference.

	FFC	Min30	Min100
		ton C/ha	
Deciduous	5.34	64.44	98.07
Conifers	18.17	66.79	121.02
All	12.46	65.86	110.86
NFI	12.52		

Carbon pools 1990

The 1990 carbon pools in live biomass for each species and age class are calculated by first merging county-, region-, and country-wise average carbon pools per hectare for individual species and age classes estimated from the 2004-2008 NFI data. Average carbon pools of species and age classes for which no average carbon pool per hectare have been estimated are found by linear interpolation between individual age classes of the particular species. Estimates of average carbon pools are prioritized according to decreasing spatial resolution (i.e. estimates based on the county-wise estimates are preferred over the regional estimates, which again are preferred over the country-wise estimates). When average carbon pools cannot be estimated by interpolation, extrapolations for the individual species are carried out using the country-wise estimates of average carbon pools.

The resulting dataset with average carbon pools per hectare is merged with the county-wise distribution of the forest area to species and age classes observed in the 1990 forest census. The carbon pools in individual species and age classes are then calculated as:

$$C_{k,r} = \overline{C}_{k,r} \cdot A_{k,r} \text{ ,}$$

where $\overline{C}_{k,r}$ is the average carbon pool per hectare, $A_{k,r}$ is the forest area recorded in the 1990 forest inventory, and $C_{k,r}$ is the total carbon pool of the *k*th combination of species and age class in the *r*th county.

Finally, total carbon pools are estimated as the sum of the county-wise estimates of carbon pools scaled by the forest area obtained from an interpretation of satellite images relative to the forest area observed in the 1990 National Forest Census. It is assumed that the forests not included in the 1990 National Forest Census were dominated by small, less intensively managed forests, Christmas tree plantations on farmland and natural expansion of forest. It is likely that the biomass per hectare of such forests is considerably less than in the forests included in the census. Therefore, carbon per hectare in the forest area exceeding the forest census area is reduced by 50%:

$$C = \sum_{r=1}^{R} \left(\sum_{k=1}^{K} C_{k,r} + 0.5 \cdot C_{k,r} \left(\frac{A_{sat,r}}{A_{census,r}} - 1 \right) \right) \text{ ,}$$

where $A_{sat,r}$ is the forest area estimated from satellite images and $A_{census,r}$ is the forest area estimated in the 1990 National Forest Census for the *r*th county. *R* and *K* are the total number of counties and combinations of species and age class respectively. Other variables are as defined above.

Pools of deadwood per hectare for individual species and age classes are calculated using a similar procedure to the calculation of average carbon pools in live biomass. In the calculations, only average carbon pools for individual species and age classes at the regional and country level are used.

Similarly to the calculations for carbon in live biomass deadwood carbon is estimated as the average pools per hectare times the area found in the 1990 forest census:

$$C_{D,k,r} = \overline{C}_{D,k,r} \cdot A_{k,r} \,,$$

where $\overline{C}_{Dk,r}$ is the average deadwood carbon pool per hectare for the *k*th combination of species and age class in the *r*th county, $A_{k,r}$ is the forest area recorded in the 1990 forest inventory, and $C_{Dk,r}$ is the total deadwood carbon pool of the *k*th combination of species and age class in the *r*th county.

Finally, the total deadwood carbon pools are estimated by scaling the estimated pools with the forest area estimated from satellite images:

$$C_D = \sum_{r=1}^{R}\left(\sum_{k=1}^{K} C_{D,k,r} + 0.5 \cdot C_{D,k,r}\left(\frac{A_{sat,r}}{A_{census,r}} - 1\right)\right)$$

Carbon pools 2000

Carbon pools in 2000 are estimated in much the same way as carbon pools in 1990. First, average carbon pools per hectare for individual species and age classes and at different regional levels are estimated from the 2004-2008 NFI data. These estimates are then merged with the county-wise distribution to individual species and age classes of the 1) forest area established before 1990 and 2) the forest area afforested after 1990 observed in the 2000 National Forest Census.

County-wise carbon pools for individual species and age classes are subsequently estimated for forests established before 1990 and afforestations made after 1990:

$$C_{90,k,r} = A_{90,k,r} \cdot \overline{C}_{k,r}$$
$$C_{00,k,r} = A_{00,k,r} \cdot \overline{C}_{k,r}$$

where A_{90} and A_{00} are the area of forests established before 1990 and afforestations after 1990 recorded in the 2000 National Forest Census, respectively. Other variables are as previously defined.

Total carbon pools in forests established before 1990 and afforestations after 1990 are estimated as the sum of the county-wise estimates of carbon pools scaled by the forest (and afforestation) area in 2000 obtained from an interpretation of satellite images relative to the forest (and afforestation) area observed in the 2000 forest census:

$$C_{90} = \sum_{r=1}^{R} \left(\sum_{k=1}^{K} C_{90k,r} + 0.5 \cdot C_{90k,r} \left(\frac{A_{sat90,r}}{A_{census90,r}} - 1 \right) \right)$$
$$C_{00} = \sum_{r=1}^{R} \left(\sum_{k=1}^{K} C_{00k,r} + 0.5 \cdot C_{00k,r} \left(\frac{A_{sat00,r}}{A_{census00,r}} - 1 \right) \right),$$

Calculations of deadwood carbon pools in forests established before 1990 and afforestations after 1990 are similar to the calculations for live carbon pools.

Carbon pools 2005-2008

Carbon pools in 2005 are estimated using NFI data from 2003-2007, assuming that the development of carbon pools is symmetric around 2005. First, the georeferenced NFI plots are assigned to one of three categories 0) not forest, 1) forest established before 1990 and 2) forest established after 1990 using a GIS analysis and the 2005 land use/land cover map. In a subsequent step, plots with observed trees planted before 1990 (based on observed tree age) are assigned to category 1 and plots with regeneration established after 1990 on land not previously forest (observed in the field) are assigned category 2. The forest area and carbon pool distribution to the three categories is estimated, using the analyses described above.

Due to the difference in resolution, some NFI sample plots identified as having no forest from the satellite images are in fact identified as having forest cover in the field inventory. This problem cannot always be mitigated by a subsequent analysis of the observations by field crews. Hence, estimates of carbon pools in forests established before 1990 and afforestations after 1990 need to be corrected. It is assumed that the distribution of carbon pools to forest established before 1990 and afforestations after 1990 in forested plots identified as having no forest from the satellite image is similar to the distribution observed in the NFI data. Hence, the carbon pools in forests established before 1990 (k=1) and afforestations after 1990 (k=2) is estimated as the total carbon pool (C_{total}) times the fraction of carbon in the kth class relative to the sum of carbon pools in classes 1 and 2.

$$C_{k,corr} = \frac{C_k}{\sum_{k=1}^{2} C_k} C_{total}$$

Carbon pools in 2006 to 2008 are estimated in much the same way as for 2005. Carbon pools in 2006, 2007 and 2008 are estimated using NFI data from 2004-2008, 2006-2008 and 2008, respectively.

Carbon pools after 2008

Carbon pools after 2008 - until 2020 - are based on a projection. The projection takes offset in the NFI based calculation of carbon pools from the full rotation of measurements from 2004-2008 - with midpoint in 2006. For the forests established before 1990, the total forest area is assumed constant, with no significant deforestation. Also, the area of temporarily non-wooded areas, fire breaks, and other small open areas, is assumed constant in the period 2008-2020.

The species and age-class distribution in 2008-2020 is projected assuming that the forest area in each species and age class, that has not been harvested, should progress into the subsequent age class after each year. Furthermore, the area harvested 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 derives 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 harvested 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:

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

where *PK* is production class expressed as total volume production per hectare fr a full rotation, *T* is age and β_0 to β_0 are species specific parameters. Parameters of the transition probability model for individual species and species classes are provided in Appendix 3. The accumulated transition probabilities are illustrated in Figure 1.

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. This also results in short rotation ages for most conifers (see lower graphs in figure 1).

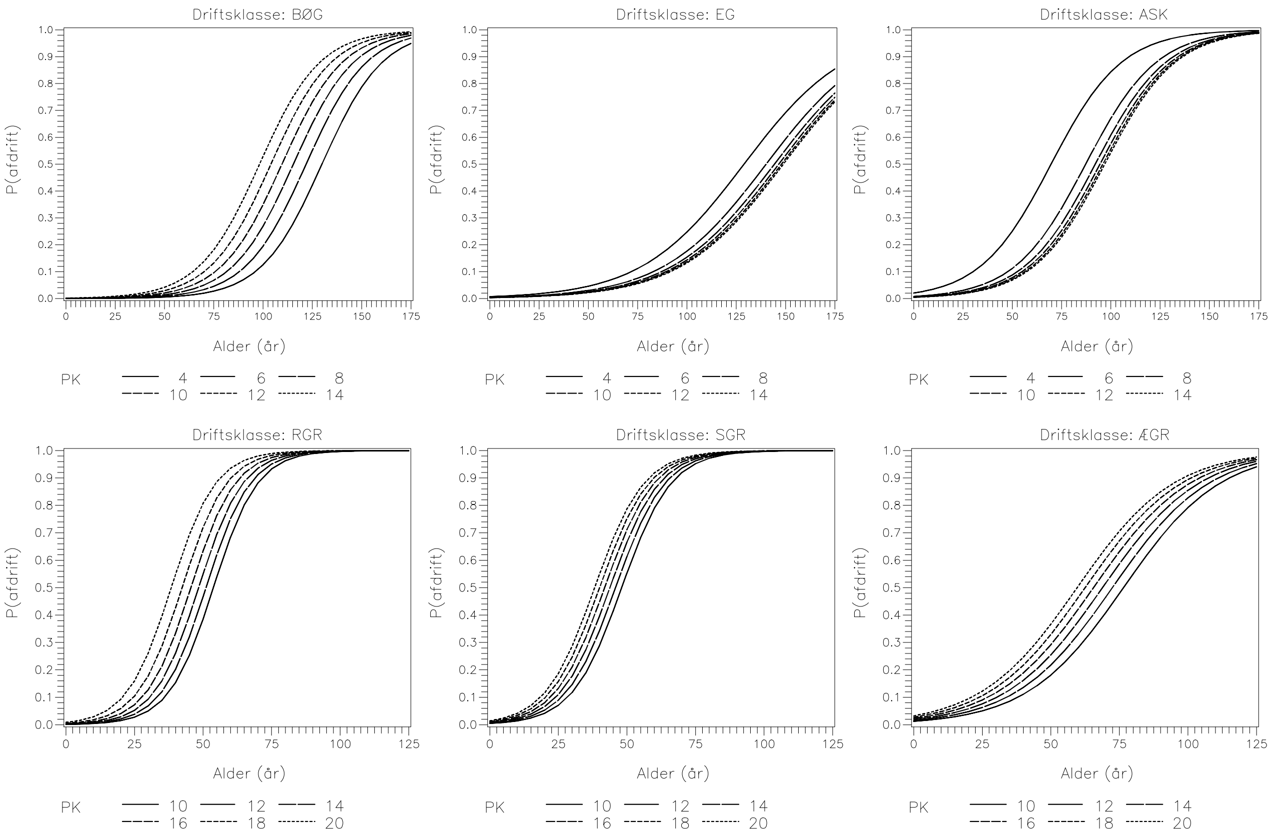

Figure 1. Accumulated clear cut probability for different species and production classes (Nord-Larsen & Heding 2002).

Based on annual projection of the forest area for all species and age classes a management class distribution is estimated for each year. Assuming the NFI values for carbon pools in each management class can be applied for the period of 2008-2020 - annual estimates of carbon is calculated. For soil carbon a constant value is applied.

A similar approach is utilised for the forests established after 1990. For the afforestation in the period 2008-2020 the average annual afforested area of 1900 ha is added for each year, assuming a species distribution similar to the analysis of the NFI data for total forest area in 2004-2008.

The forest area and carbon pool distribution to the three categories is estimated, using the analyses described for the previous periods.

Results

Forest area

Based on satellite images, the mapped Danish forest area ha in 1990 (January 1st) is 555,037 ha (12.9 pct. of the total land area). Compared to the 1990 forest census, the mapped forest area is 110,000 ha or 25 pct. larger. The difference is probably caused by the large number of forest owners not included in the forest census. In 2006 (January 1st) the mapped forest area is 598,254 ha (13.9 pct. of the total land area). Compared to the NFI, the mapped forest area is 47,000 ha or 8 pct. larger. The difference is only little larger than the statistical uncertainty and may in part be caused by difficulties in identifying forested sample plots during the first years (2002-2004) of the NFI and problems with separating forest and other wooded land on the satellite images.

Afforestation has been estimated to 45,000 ha in the period from 1990 to 2005. This number is larger than the reported afforestation in the same period reaching 30,962 ha for the same period and 35,834 ha for the period 1990-2007 (Vesterdal et al., 2009). The difference could be explained by the area of natural forest expansion. Deforestation in the 15 years of 1990 to 2005 is assessed to be about 1800 ha. Comparing this figure to documented deforestation at Mols Bjerge and Thy would give an area of around 1100 ha. In addition to this, are the areas of restoration projects in Northern Jutland and Anholt. These deforestations are know to have occoured around 1996 and 2002-2003 respectively. Hence - it was possible to allocate the deforestation for these areas to those years.

The area of forest established before 1990 is estimated as the forest area in 1990 corrected for deforestation but not for windthrow areas. Denmark has experienced several larger windthrows (including windthrows in connections with the storms in 1967, 1981, 1999, and 2005).

Table 3. Estimated total forest area, forest area established before 1990, deforestation and afforestation in 1990-2005. Estimated areas are based on the interpretation of maps produced form satellite images.

Year	Total area included in the reporting	Forest area established before 1990	Deforestation	Afforestation
1990	555,037	555,037	0	0
1991	555,289	555,037	0	253
1992	556,101	555,037	0	1,064
1993	557,469	555,037	0	2,432
1994	558,890	555,037	0	3,853
1995	560,759	555,037	0	5,722
1996	561,970	554,730	307	7,241
1997	563,595	554,730	307	8,866
1998	567,098	554,730	307	12,368
1999	568,784	554,730	307	14,055

2000	576,881	554,730	307	22,152
2001	581,431	554,730	307	26,701
2002	584,664	554,730	307	29,934
2003	587,439	553,826	1,211	33,613
2004	590,938	553,254	1,783	37,685
2005	592,455	553,254	1,783	39,201
2006	598,254	553,254	1,783	45,000
2007	605,104	553,254	1,783	51,850
2008	606,006	553,254	1,783	52,753

Carbon pools

In this section a few comments are given to the resulting estimations of carbon pools. The full set of data are given in Appendix 4 (period 1990 - 2007) and 5 (2008-2020), respectively.

Forest established before 1990

For the area of forests established before 1990 there is an increase in carbon stock for the period 1990 to 2000. There is one year (1996) with deforestation, but still the total carbon stock is increasing. For the same area there is a small decrease in the total carbon stock in the period 2000 to 2005. This is mainly due to deforestation, while the average carbon stock pr. ha is slightly increasing. In the period 2005-2007 the NFI provides sufficient data for the calculation of total carbon stock, indicating a slight increase in that period as well.

Afforestation

In the afforestation a steady increase in carbon stock is found. The species composition is based on the information from the 2000 Forest Census for the period 1990-2000. Subsequently the NFI provides information on the afforestation area and the carbon pools in these areas - up till 2007. The estimates for the carbon pools in the afforestation are similar to previous estimates, with a slight increase due to the new knowledge on species composition and average carbon stock in those areas based on the NFI data.

Deforestation

Deforestation amount to only 1783 ha during the period 1990 - 2005. The carbon pools of the areas deforestated are estimated based on the geographical location and the NFI data.

Prognosis for 2008 - 2020

The prognosis provides estimates of carbon pools for both forest area established before 1990 and for afforestation. The total carbon stock of the forest established before 1990 is estimated to decline slowly in the period 2008 - 2020. There is not included any deforestation, so the forest area is constant - as is the carbon pool in the soil.

For the afforestation the carbon pools are steadily increasing also in the period 2008 - 2020. Both the increasing maturity of the stands and the increasing area contributes to this.

Table 4. Estimated forest area, live biomass carbon, carbon in dead wood and soil carbon (in forest floor and in mineral soil). Estimates of forest area are in hectares and estimates of carbon are in 1000 tonnes. Full data are given in appendix 4 & 5.

			1990	1996	2000	2005	2010	2015	2020
Forests established before 1990	Area		555.037	554.730	554.730	553.254	553.254	553.254	553.254
	Live biomass	Above ground	29.313	30.654	31.559	32.524	34.625	34.223	33.826
		Below ground	4.721	4.935	5.080	5.299	5.638	5.589	5.545
	Dead wood		466	500	522	589	602	604	606
	Forest floor		7.498	7.410	7.355	6.909	6.564	6.564	6.564
	Mineral soil		60.801	60.768	60.768	60.606	58.448	58.448	58.448
	Total		102.800	104.268	105.284	105.927	105.878	105.428	104.989
Forests established after 1990	Area		0	13.291	22.152	39.201	53.672	63.172	72.672
	Live biomass	Above ground	0	57	95	218	365	553	830
		Below ground	0	10	16	34	53	81	124
	Dead wood		0	2	3	9	5	8	12
	Forest floor		0	15	25	66	124	197	283
	Minearl soil		0	1.456	2.427	4.511	5.879	6.920	7.961
	Total		0	1.540	2.567	4.838	6.426	7.759	9.209
Deforestation	Area		0	307	0	0	0	0	0
	Live biomass	Above ground		-17	0	0	0	0	0
		Below ground	0	-3	0	0	0	0	0
	Dead wood		0	0	0	0	0	0	0
	Forest floor		0	-4	0	0	0	0	0
	Minearl soil		0	-34	0	0	0	0	0
	Total		0	-58	0	0	0	0	0

Comparison with previous data submissions to UNFCCC and JRC scenarios

The revision of the forest data back to 1990 influences the accounting significantly. The change to the stock change approach focuses on the forest area and the carbon pools for each year and the changes from year to year. Previous submissions of data have been based on models for forest growth combined with recorded harvesting. The stock change approach on the other hand relies on observed values of forest biomass and the transformation of the biomass to carbon and CO_2 equivalents.

In comparison with the previous data submissions to UNFCCC the new data reduces the removals in the period 1990 - 2000. This is primarily due to the revised forest area estimates which have lead to an increase in the forest area of about 25% in 1990 and thus a larger initial carbon stock than previously expected. Also, the present analysis is based on the stock change approach to carbon reporting. This shift in methodology implies that growth models are no longer used in combination with harvesting statistics to estimate removals. As the official harvest statistics only include what is being reported by forest owners, these may significantly underestimate the actual harvest which has probably led to overestimation of actual carbon sequestration, previously. Also, the use of growth models in estimating forest growth may be biased when models are applied across a wide range of growth conditions and management practises leading to overestimation of carbon sequestration.

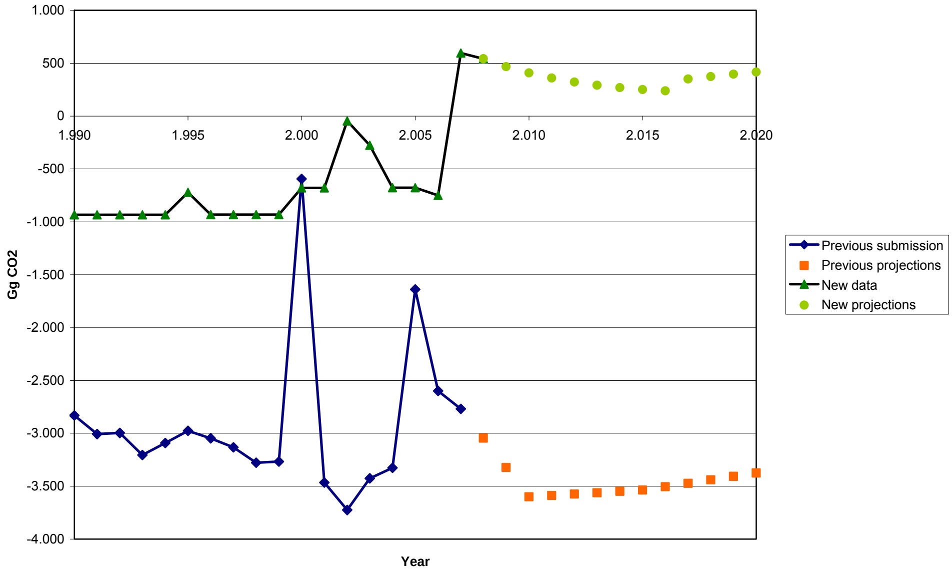

Figure 2. Comparison of previously submitted figures of CO_2 sequestration and present findings for area of forests established before 1990.

For the period 2002-2008 the NFI data indicates a slight emission from the forests. The uncertainty of the NFI in the first years is reflected in the fluctuations of the estimated stock. As more years will bee completed with measurements the estimates of carbon pools in the forests based on the NFI will stabilize and the estimates for 2005-2007 will be harmonised.

The change in reporting method and the new data from the NFI also influences the projection for the period until 2020. Based on the analysis described previously - the Danish forest will in the period until 2020 be a source of CO_2. This is primarily due to the age distribution especially for the common species beech and oak (Figure 3). The large areas with mature trees (more than 25% of the area and 36 % of the biomass in beech is more than 100 years old, Nord-Larsen et al., 2008) indicate pronounced fellings in the coming years, which will lead to increased emissions of CO_2 from the forest.

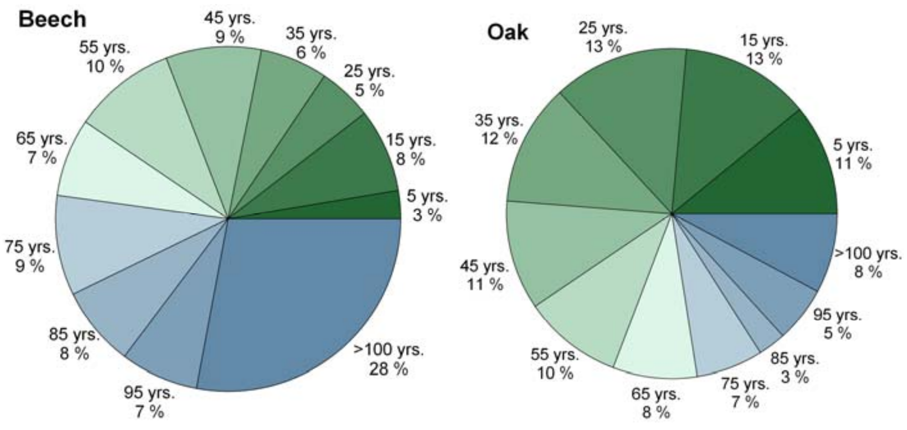

Figure 3. Age-class distribution for the two most common broadleaved forest tree species en Denmark, beech and oak (from Nord-Larsen et al., 2008). Ages indicate the midpoints of ten-year classes.

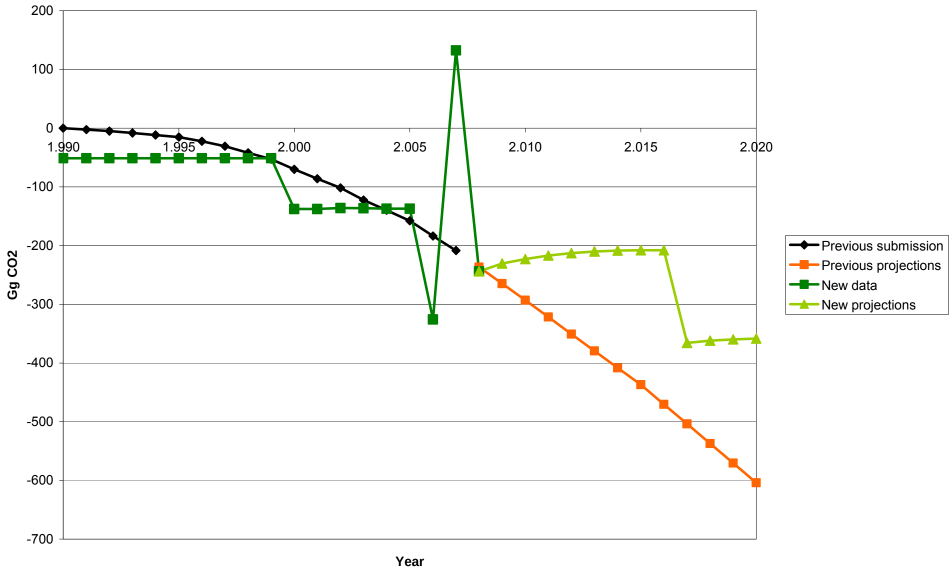

Figure 4. Comparison of previously submitted figures of CO_2 sequestration and present findings for afforestation (carbon pool in mineral soils is assumed constant in these areas).

The afforestation is very similar to previous submissions. The variation is caused by the small sample size of afforestation and hence variability in the estimates of carbon stock in those areas based on the NFI data.

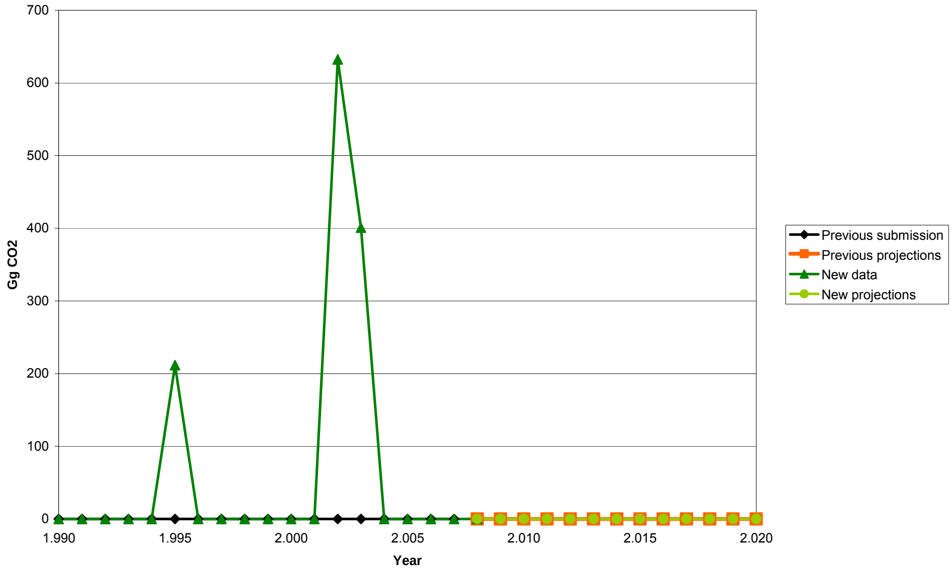

Figure 5. Comparison of previously submitted figures of for emissions of CO_2 from deforestation.

There are small areas of deforestation in Denmark. The analysis of the satellite based forest maps have resulted in a deforestation in the period 1990 - 2006 of 1783 ha. These have mainly been the result of restoration projects. There is only expectation of very minor deforestation in the period until 2020.

Discussion

In the calculation of carbon pools for the years 1990 and 2000 it was assumed that carbon pools for individual species and age classes from 1990 to 2005 are largely unchanged. This assumption may be dubious as changing market conditions and technological advances are likely to change forest management practises. It is likely that increased use of natural regeneration and generally less frequent thinning operations in young deciduous stands combined with a reduction in the price of deciduous wood at the end of the 1990’s have led to increased average carbon pools in deciduous species from 1990 to 2005. Also, the increasing demand for forest fuels may have led to decreasing average carbon pools predominantly in young coniferous forest stands. This indicates that estimates of CO_2 removals may be lower than actual removals.

Another assumption in the estimation of carbon pools in 1990 and 2000 is that the species and age class distribution observed in the National Forest Census is similar to the true species and age class distribution. However, the forests which were not included in the 1990 and 2000 forest census are likely to have specific characteristics that may influence the distribution to species and age classes, as recorded by the National Forest Census, and thus their carbon pools. This has been incorporated in the analysis through reduction of the carbon pools on the additional area found by the satellite image analysis.

In the calculation of the carbon pools for the period 2008-2020 it is assumed that carbon pools for individual species and age classes are largely unchanged. This may be questioned. Increasing demand for wood (for construction and for energy) may lead to increased harvesting of wood from the forest. This may affect carbon pools of individual species and age classes. Simulations of a gradual reduction of standing volume in the forests lead to a 1-2% reduction in the total carbon pool over the entire period.

Change in market demands for wood or changes in forest policy may affect the transition probabilities. 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 increase emissions or removals.

The projection of the carbon pools indicate a slight decrease in carbon pools in forest established before 1990. This is due to the large proportion of old stands in the current Danish forests which will be harvested and regenerated in the projection period. At the same time the carbon pools of the forests established after 1990 is gradually increasing - as expected.

The current project SINKS includes subprojects that will improve the estimation of carbon pools in forest. The SatMon project improves the land use and land use change information for all land use classes (ends in 2013). The Forest Soil Carbon project will provide more detailed knowledge on the carbon pools of forest soils (ends in 2010). Finally, the project on biomass expansion functions for Danish forest tree species (Norway spruce, beech and oak) will provide important national information for more reliable estimation of the carbon stock of the forest biomass (ends in 2009). Currently expansion factors based on data from other countries are utilised, and some of the factors used may be higher than actual values for Danish forest trees. This may have impact on the calculations of carbon pools. As the projects are finalised the results will be incorporated in the reporting on forest data.

In relation to the UNFCCC negotiations

It is important to note that:

- Forest management will in the period 2008 - 2020 be a source of CO_2. The magnitude can be influenced by many factors. The projection is based on an assumption of unchanged demand for wood in the near future, but changed prices on wood or other conditions may alter the conclusions.

- Afforestation will in the period 2008 - 2020 be a sink for CO_2. The magnitude is slightly dependent on the future afforestation rate, but the majority of the removals in the period will come from areas afforested in the period 1990 - 2008.

- Deforestation will occur, but the small total area will be of minor influence on the full LULUCF accounting.

References

Breuning-Madsen, H., Olsson, M., 1995. Jordbundsundersøgelser i EU's Kvadratnet for monitering af skovsundhed, Danmark. Rapport, Geografisk Institut, Københavns Universitet, 15 s + 8 bilag.

Gundersen, P., 1998. Effects of enhanced nitrogen deposition in a spruce forest at Klosterhede, Denmark, examined by moderate NH4NO3 addition. For. Ecol. Manage. 101: 251-268.

Gyldenkærne, S., Münier, B.E. Olesen, J.E., Olesen, S.E., Petersen, B.M. & Christensen, B.T. 2005. Opgørelse af CO_2-emissioner fra arealanvendelse og ændringer i arealanvendelse LULUCF (Land Use, Land Use Change and Forestry), Metodebeskrivelse samt opgørelse for 1990 – 2003,, Arbejdsrapport fra DMU, nr. 213. (Methodology and Emission CO_2- estimates from LULUCF 1990-2003).

Johannsen, V. K. (2002). Selection of diameter-height curves for even-aged oak stands in Denmark. Dynamic growth models for Danish forest tree species, Working paper 16, Danish Forest and Landscape Research Institute, Hørsholm, Denmark. 70 p.

Larsen, P.H. and Johannsen,V.K. (eds.) (2002). Skove og plantager 2000. Danmarks Statistik, Skov & Landskab og Skov- og Naturstyrelsen. 171 p. ISBN: 87-501-1287-2

Madsen, S.F., 1987: Vedmassefunktioner for nogle vigtige danske skovtræarter. Det Forstlige Forsøgsvæsen 40, 47-242.

Madsen, S.F. og M. Heusèrr, (1993): Volume and stem taper functions for Norway spruce. Forest and Landscape Research 1, 51–78.

Nord-Larsen, T., Johannsen, V. K., Bastrup-Birk, A and Jørgensen, B. B. (eds.) (2008). Skove og plantager 2006. Skov og Landskab and Skov- og Naturstyrelsen, Hørsholm. 185 p. ISBN: 978-87-7903-368-9

Nord-Larsen, T., Heding, N. (2002). Træbrændselsressourcer fra danske skove over ½ ha - opgørelse og prognose 2002. Arbejdsrapport nr. 36, Skov & Landskab (FSL), Hørsholm, 2002. 78s. ill.

Prins, E. 2009. Prins Engineering - http://www.prinsengineering.com

Sloboda, B., D. Gaffrey and N. Matsumura (1993). Regionale und lokale Systeme von Höhenkurven für gleichaltrige Waldbestände. Allg. Forst- u. J. Ztg. 164, 225-228.

Vejre, H., Callesen, I., Vesterdal, L., and Raulund-Rasmussen, K. 2003. Carbon and Nitrogen in Danish forest soils – Contents and distribution determined by soil order. Soil Science Society of America Journal 67: 335-343.

Vesterdal, L., Raulund-Rasmussen, K. 1998. Forest floor chemistry under seven tree species along a soil fertility gradient. Canadian Journal of Forest Research 28: 1636-1647.

Vesterdal, L., Dalsgaard, M., Felby, C., Raulund-Rasmussen, K. and Jørgensen, B.B. 1995. Effects of thinning and soil properties on accumulation of carbon, nitrogen and phosphorus in the forest floor of Norway spruce stands. Forest Ecology and Management 77: 1-10.

Vesterdal, L., Ritter, E., and Gundersen, P. 2002a. Change in soil organic carbon following afforestation of former arable land. Forest Ecology and Management 169: 141-151.

Vesterdal, L., Jørgensen, F.V., Callesen, I., Raulund-Rasmussen, K. 2002b. Skovjordes kulstoflager - sammenligning med agerjorde og indflydelse af intensiveret biomasseudnyttelse. In: Christensen, B.T. (ed.), Biomasse til energiformål - konsekvenser for jordens kulstofbalance i land- og skovbrug. DJF rapport Markbrug nr. 72.

Vesterdal L., Rosenqvist L., van der Salm C., Hansen K., Groenenberg B.-J. & Johansson M.-B. 2007. Carbon sequestration in soil and biomass following afforestation: experiences from oak and Norway spruce chronosequences in Denmark, Sweden and the Netherlands. In: Heil G., Muys B. & Hansen K. Environmental Effects of Afforestation in North-Western Europe - From Field Observations to Decision Support. Springer, Plant and Vegetation 1: 19-52.

Vesterdal, L., Schmidt, I.K:, Callesen, I., Nilsson, L.O., Gundersen, P., 2008. Carbon and nitrogen in forest floor and mineral soil under six common European tree species. For. Ecol. Manage. 255: 35-48.

Zangenberg, C.U. and Hansen, C.P. (1994). Skove og plantager 1990. Danmarks Statistik og Skov- og Naturstyrelsen. 131 p. ISBN: 87-501-0887-5

Appendices

Appendix 1. Density of common Danish tree species

Deciduous	Density g/cm^3	Coniferous	Density g/cm^3
Beech	0,56	Norway spruce	0,38
Oak	0,57	Sitka spruce	0,37
Ash	0,56	Silver fir	0,38
Sychamore	0,49	Pine	0,43
Other deciduous species	0,56	Mountain pine	0,48
		Contorta pine	0,37
		Scots pine	0,43
		Nordmann fir	0,38
		Noble fir	0,38
		Douglasfir	0,41
		Larch sp.	0,45
		Other conifers	0,38

Appendix 2. Reduction factors for calculating biomass of deadwood for different degrees of structural decay for deciduous and coniferous species.

Structural decay	Reduction factor	
	Deciduous species	Coniferous species
1	0,804	0,895
2	0,607	0,632
3	0,429	0,605
4	0,304	0,447

Appendix 3. Parameters for the transition probability

Tabel X. Parameters for the transition probabilities - dependent on species and region

Driftsklasse	β_0	β_1	β_2	Afviklingsstart (region)	
				Jylland	Øerne
BØG	-370,7834	9473,0017	0,0597	90	80
EG	64,8302	-84,7190	0,0303	120	110
ASK	201,6577	-666,4862	0,0567	60	50
ÆR	29,1421	44,7930	0,0427	60	50
ALØ	29,1421	44,7930	0,0427	50	40
RGR	-531,4614	12937,8018	0,1239	50	40
SGR	-174,8721	4867,6015	0,1198	50	40
NGR	92,5424	1	0,2301	5	5
NOB	173021,0121	1	0,2657	40	40
ÆGR	-9,3377	726,5105	0,0590	60	50
FYR	-270,3996	6832,1561	0,0915	50	40
ANÅ	-9,3377	726,5105	0,0590	50	40
BJF	116449,5854	1	0,2565	50	40

Appendix 4. Carbon pools 1990 - 2007.

			1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Forests established before 1990	Area		555.037	555.037	555.037	555.037	555.037	555.037	554.730	554.730	554.730	554.730	554.730	554.730	554.730	553.826	553.254	553.254	553.254	553.254
	Live biomass	Above ground	29.313	29.539	29.766	29.992	30.218	30.445	30.654	30.880	31.107	31.333	31.559	31.769	31.980	32.138	32.314	32.524	32.734	32.886
		Below ground	4.721	4.757	4.793	4.830	4.866	4.902	4.935	4.972	5.008	5.044	5.080	5.127	5.173	5.211	5.252	5.299	5.345	5.354
	Dead wood		466	472	478	483	489	495	500	506	511	517	522	536	550	562	575	589	602	638
	Soil	Forest floor	7.498	7.484	7.470	7.456	7.442	7.428	7.410	7.396	7.383	7.369	7.355	7.269	7.184	7.087	6.994	6.909	6.824	6.831
		Mineral soil	60.801	60.801	60.801	60.801	60.801	60.801	60.768	60.768	60.768	60.768	60.768	60.768	60.768	60.669	60.606	60.606	60.606	60.606
	Total		102.800	103.054	103.308	103.562	103.817	104.071	104.268	104.522	104.776	105.030	105.284	105.469	105.654	105.667	105.742	105.927	106.111	106.316
Forests established after 1990	Area		0	2.216	4.433	6.649	8.866	11.082	13.291	15.506	17.721	19.936	22.152	25.980	29.808	33.581	37.364	39.201	45.000	48.836
	Live biomass	Above ground	0	10	19	29	38	48	57	67	76	86	95	120	145	169	194	218	243	307
		Below ground	0	2	3	5	6	8	10	11	13	14	16	20	23	27	31	34	38	49
	Dead wood		0	0	1	1	1	2	2	2	3	3	3	4	5	7	8	9	10	13
	Soil	Forest floor	0	3	5	8	10	13	15	18	20	23	25	34	42	50	58	66	74	85
		Mineral soil	0	243	486	728	971	1.214	1.456	1.699	1.941	2.184	2.427	2.846	3.265	3.679	4.093	4.511	4.930	5.350
	Total		0	257	514	770	1.027	1.284	1.540	1.797	2.053	2.310	2.567	3.023	3.480	3.931	4.382	4.838	5.294	5.803
Deforestation		Area	0	0	0	0	0	0	307	0	0	0	0	0	0	904	572	0	0	0
	Live biomass	Above ground	0	0	0	0	0	0	-17	0	0	0	0	0	0	-52	-33	0	0	0
		Below ground	0	0	0	0	0	0	-3	0	0	0	0	0	0	-9	-5	0	0	0
	Dead wood		0	0	0	0	0	0	0	0	0	0	0	0	0	-1	-1	0	0	0
	Soil	Forest floor	0	0	0	0	0	0	-4	0	0	0	0	0	0	-12	-7	0	0	0
		Mineral soil	0	0	0	0	0	0	-34	0	0	0	0	0	0	-99	-63	0	0	0
	Total		0	0	0	0	0	0	-58	0	0	0	0	0	0	-172	-109	0	0	0
	Total		102.800	103.311	103.822	104.333	104.844	105.355	105.750	106.318	106.829	107.340	107.851	108.493	109.134	109.425	110.015	110.765	111.405	112.119

Appendix 5. Carbon pools 2008 - 2020.

			2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Forests established before 1990	Area		553.254	553.254	553.254	553.254	553.254	553.254	553.254	553.254	553.254	553.254	553.254	553.254	553.254
	Live biomass	Above ground	34.870	34.739	34.625	34.526	34.438	34.360	34.289	34.223	34.162	34.103	34.016	33.924	33.826
		Below ground	5.669	5.653	5.638	5.626	5.615	5.605	5.597	5.589	5.582	5.575	5.565	5.556	5.545
	Dead wood		602	602	602	602	602	603	603	604	604	605	605	606	606
	Soil	Forest floor	6.564	6.564	6.564	6.564	6.564	6.564	6.564	6.564	6.564	6.564	6.564	6.564	6.564
		Mineral soil	58.448	58.448	58.448	58.448	58.448	58.448	58.448	58.448	58.448	58.448	58.448	58.448	58.448
	Total		106.153	106.005	105.878	105.766	105.668	105.581	105.501	105.428	105.360	105.295	105.199	105.097	104.989
Forests established after 1990	Area		49.872	51.772	53.672	55.572	57.472	59.372	61.272	63.172	65.072	66.972	68.872	70.772	72.672
	Live biomass	Above ground	276	322	365	405	444	481	518	553	588	622	693	762	830
		Below ground	40	47	53	59	65	70	76	81	86	91	102	113	124
	Dead wood		4	5	5	6	6	7	7	8	8	9	10	11	12
	Soil	Forest floor	97	110	124	137	151	166	181	197	213	230	247	264	283
		Mineral soil	5.463	5.671	5.879	6.088	6.296	6.504	6.712	6.920	7.128	7.336	7.545	7.753	7.961
	Total		5.880	6.155	6.426	6.695	6.962	7.228	7.494	7.759	8.024	8.288	8.596	8.903	9.209
Total			112.034	112.160	112.304	112.461	112.630	112.809	112.995	113.187	113.383	113.583	113.796	114.001	114.199