



# ESTIMATING LAND USE/LAND COVER CHANGES IN DENMARK FROM 1990 – 2012

Technical documentation for the assessment of land use/land cover changes for estimation of carbon dioxide fixation in soil

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Technical Report from DCE – Danish Centre for Environment and Energy

No. 38

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## Data sheet

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- Abstract: According to the article 3(4) of the Kyoto Protocol, Denmark is obliged to document sequestration and emission of carbon dioxide from land use and land cover and changes in these. This report documents and describes applied data and developed methods aiming at estimating amounts and changes in land use and land cover for Denmark for since 1990. Estimation of land use and land cover categories and changes in these is predominantly based on existing categorical (i.e. pre-classified) geographical information. Estimations are elaborated for the period from 1990 to 2005, from 2005 to 2011 and from 2011 to 2012. Due to limited availability of historical spatially explicit information, estimations of change in land use and land cover from 1990 up to 2011 do, to some degree, involve decisions based on expert knowledge. Due to a significant increase in the availability of detailed spatially specific categorical information, estimations of annual changes in land use and land cover from 2011 and onwards are based on identification of changes in land use and land cover based spatial on overlays with updated input layers.
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## Preface

This report describes applied data and methods for the estimation of area and change in land use and land cover in Denmark. Applied data and methods have been compiled and developed by the Danish Centre for Environment and Energy (DCE) at Aarhus University together with the Department of Geosciences and Natural Resource Management (IGN) at Copenhagen University. Estimated area and change in land use and land cover form the input to Denmark's obligations to document fixation and emission of carbon dioxide from land use and land cover under article 3.4 of the Kyoto Protocol.

This report contains descriptions of:

- applied input data and, where necessary, pre-processing of these data
- how input layers are combined into one land use / land cover map for 2011
- developed methods for the estimation of changes in land use and land cover for the period from 1990 to 2005 and from 2005 to 2011
- developed methods for the estimation of changes in land use and land cover from 2011 to 2012.



## Summary

According to the article 3.4 of the Kyoto Protocol, Denmark is obliged to document sequestration and emission of carbon dioxide from land use and land cover and changes in these. For this purpose, methods were developed aiming at estimating amounts and changes in land use and land cover for Denmark for since 1990, which is the base year for the Kyoto Protocol. According to the IPCC guidelines, estimation of land use and land cover must cover following land use and land cover categories: Settlement, cropland, grassland, wetland, which is fully water covered, wetland which is partly water covered, forest and other land. Except for the estimation of forest, which is partly based on analyses of satellite images, estimation of land use and land cover categories and changes in these is based on existing categorical (i.e. pre-classified) geographical information. This information includes topographical maps, agricultural registers and field parcel maps, data from nature and habitat monitoring, cadastral maps and building specific information. After pre-processing, such as removal of geometrical errors, all input data are converted into raster layers with a cell size of 25x25 meters and combined into one land use/land cover map for 2011. Since input data often spatially overlap, their combination into one map is based on an evaluation of the geometric precision of each layer. The estimation of changes in land use and land cover is elaborated for the period from 1990 to 2005, from 2005 to 2011 and from 2011 to 2012. For specific land use and land cover categories (e.g. wetlands) availability of historical spatially explicit information is limited. As a consequence, estimations of change in land use and land cover from 1990 up to 2011 does to some extent involve assumption based on expert knowledge. Due to a significant increase in the availability of detailed spatially specific categorical information, estimations of annual changes in land use and land cover from 2011 and onwards are based on identification of changes in land use and land cover based spatial on overlays with updated input layers.

## Sammenfatning

Ifølge artikel 3.4 i Kyotoprotokollen er Danmark forpligtet til at dokumentere binding og udslip af kuldioxid fra arealanvendelse og arealdække samt fra arealændringer. Til dette formål blev der, for Danmark, udviklet metoder til at estimere omfang og ændringer i arealanvendelse og arealdække siden 1990, som er Kyotoprotokollens basisår. I henhold til IPCC's retningslinjer skal estimeringen af omfang og ændringer i arealanvendelse og arealdække omfatte følgende arealkategorier: Bebyggelse, dyrkede arealer, græsarealer, vådområder, som er dækket af vand hele året, vådområder, som i perioder er dækket af vand, skov og andre arealer. Bortset fra estimeringen af skov, som er delvist baseret på satellitbilledanalyser, er estimeringer af arealanvendelse og arealdække samt ændringer i disse baseret på eksisterende kategorisk (præ-klassificeret) geografisk information. Denne information omfatter topografiske kort, landbrugsregistre og markkort, data fra natur og habitatmonitoring, matrikelkort samt bygningsspecifik information. Efter forbehandling, som fx fjernelse af geometriske fejl, konverteres alle inputdata til rasterlag med en celledimension på 25x25 meter. Rasterlagene kombineres i et samlet kort over arealanvendelse og arealdække for 2011. Fordi inputdata ofte overlapper, er kombinationen til et samlet kort baseret på en vurdering af den geometriske præcision af hvert lag. Estimeringen af arealændringer er lavet for perioderne 1990 til 2005, 2005 til 2011 og for 2011 til 2012. For nogle arealkategorier (fx vådområder) findes der kun meget begrænset historisk rumlig specifik information. Derfor inddrager estimeringerne af arealændringer fra 1990 op til 2011 til en hvis grad antagelser, som er baseret på ekspertviden. En stigende adgang til detaljeret, rumlig specifik kategorisk information betyder, at estimeringer af årlige arealændringer efter 2011 er baseret på identifikation af ændringer i arealanvendelse og arealdække på baggrund af en sammenligning med opdaterede inputlag.



# 1 Introduction

This report describes the applied data and methodology for an estimation of changes in land use/land cover (LULC) in Denmark for the period between 1990 and 2011 and for the period from 2011 to 2012. Estimated LULC changes were subsequently applied to assess sources and sinks for climate gasses. The estimation of LULC changes was based on mapping of the extent and change between the seven LULC categories, as defined by the IPCC guidelines (IPCC, 2003). These LULC categories are: settlement, cropland, grassland, forest, wetlands – fully water covered, wetlands – partly water covered and other land. Except for forest, the mapping was exclusively based on available, pre-classified spatially specific information.

The report is structured as follows: In section 2, applied datasets and methods for localisation of the different LULC categories and changes in these are presented. Section 3 describes how the different LULC categories were combined into one LULC map for 2011. Section 4 describes how changes for the period from 1990 to 2005 and from 2005 to 2011 were assessed.

The following nomenclature is followed throughout this report.

**Object type:** An object type is here defined as a distinct land use or land cover type. Examples are “building”, “city centre” or “forest”. Each object type has an object code in the dataset from which it originates. The object code can be a number or a text string.

**Input dataset:** Datasets or data sources applied in the analysis. One dataset can include several object types. Examples are the national topographic database, the field parcel map and the registration of protected habitat types.

**Input layer:** Input layers are here defined as the generated maps representing the seven LULC categories and if information exists, changes in these from 1990 to 2011. Examples are settlement, forest etc.

The applied geographical projection for all applied data was UTM ETRS1989 zone 32 N. Except from the forest layer, all input layers are in vector format. Vector data were converted into raster format with a cell size of 25x25 meters corresponding with the forest layer for 2011.

## 2 Input layers

### 2.1 Terrestrial area

The terrestrial area, which is defined as the inland land area above the highest tidal limit, forms the physical frame for the estimation of LULC changes. The coastal area from the inland tidal limit to the seaward extend of vascular plants is very limited in Denmark. In cases where these exist they are often covered by coastal salt marches. These are included in the LULC category grassland. The object type “regions” from the national topographic database Kort10 (Danish Geodata Agency, 2011a) was applied to represent the Danish terrestrial area (except Greenland and the Faroe Islands). The object type covers 43,051 km<sup>2</sup> which corresponds to the total terrestrial area provided in the statistical yearbook for 2012 (Statistics Denmark, 2012). The object type was applied for 1990, 2005 and for 2011, assuming the total terrestrial area of Denmark has not changed during the assessed period.

### 2.2 Settlement

Settlement is defined as developed land including transportation infrastructure and human settlements. For this assessment settlement was divided into build up land, related to urban land uses and into infrastructure, comprising roads and railways.

#### 2.2.1 Settlement - built up

The built up layer was based on 12 object types derived from Kort10 (Danish Geodata Agency, 2011a), The Danish Area Information System (AIS) (National Environmental Research Institute, 1999) and from the cadastre map (Danish Geodata Agency, 2012a) combined with the Danish building register (BBR) (Ministry of Housing, Urban and Rural Affairs, 2012). Applied object types are listed in Table 1. An examination of metadata for Kort10 (Fotdanmark, 2012) elucidated a major change in the geometrical demarcation of built up land between the 2011 and the 2012 registration. While until 2011 cut outs within polygon features were allowed and overlap between built up layers and other layers (e.g. forest) were not accepted, cut outs are from 2012 onwards no longer allowed and overlaps with other layers are now accepted. I.e. if Kort10 data for settlement were applied unprocessed, results would indicate a change in settlement from 2011 to 2012 in the range of 10 % (from 479,513 ha to 528,234 ha), which is unrealistic high. In order to prevent such extreme increase, the settlement layer for 2011 was extended and subsequently shrunk by two cells (50 meters). If this extended settlement layer overlaps with unclassified agricultural land or forest, it was added to settlement. Otherwise it was kept in the original land use class.

Table 1 Object types applied for settlement – built up.

Object name (Danish)	Object name (English)	Original object code	Data source
Landingsbane	Runway	2543	Kort10 (Danish Geodata Agency, 2011a)
Teknisk areal (ekskl. vindmølleparker)	Technical area (excl. wind farms)	2700	Kort10 (Danish Geodata Agency, 2011a)
Bassin	Bassin	2719	Kort10 (Danish Geodata Agency, 2011a)
Bykerne	City center	3112	Kort10 (Danish Geodata Agency, 2011a)
Industri	Industry	3116	Kort10 (Danish Geodata Agency, 2011a)
Lav bebyggelse	Low built up	3117	Kort10 (Danish Geodata Agency, 2011a)
Høj bebyggelse	High built up	3118	Kort10 (Danish Geodata Agency, 2011a)
Rekreativt område	Recreational area	3119	Kort10 (Danish Geodata Agency, 2011a)
Bygning	Building	3210	Kort10 (Danish Geodata Agency, 2011a)
Kirkegård	Cemetery	6329	Kort10 (Danish Geodata Agency, 2011a)
Sommerhusområde	Summer cottage areas	1.3	AIS (National Environmental Research Institute, 1999)
Sommerhusmatrikler	Summer cottage cadastres	-	Cadastre map (Danish Geodata Agency, 2011b)

Object types representing built up land are not readily available historically. Therefore, the estimation of change in built up land was based on the national cadastre map (Danish Geodata Agency, 2011b), combined with the Danish building register (Ministry of Housing, Urban and Rural Affairs, 2011). For each existing building the register contains the building year and a link to the id-number of the cadastre on which the building is located. Based on this information, all cadastres containing buildings were assigned a building year, referring to the first year of establishment of a building. This map was overlaid with the built up layer for 2011, which then was divided into areas built up before 1990, areas built up between 1990 and 2005 and areas built up between 2005 and 2011. The method is illustrated in Figure 1.

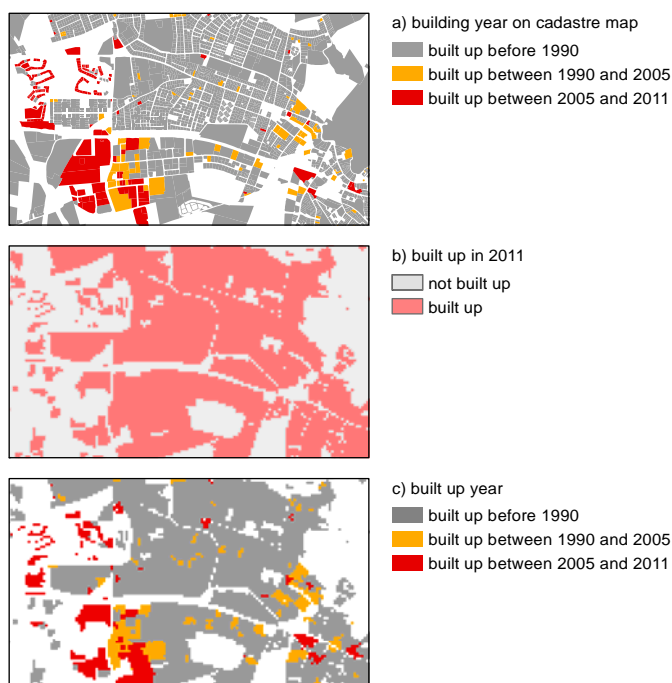


Figure 1 Illustration of change detection in settlement. Applying information from the Danish building register, cadastres were classified into cadastres built up before 1990, built up from 1990 to 2005 and built up between 2005 and 2011 (a). This map was overlaid with the built up layer for 2011, which was derived from Kort10 (b). Subsequently the built up layer was classified into areas built up before 1990, built up between 1990 and 2005 and built up between 2005 and 2011 (c).

### 2.2.2 Settlement - infrastructure

The infrastructure layer was based on 4 object types derived from Kort10 (Danish Geodata Agency, 2011a) (Table 2).

Table 2 Object types applied for settlement – infrastructure.

Object name (Danish)	Object name (English)	Original object code	Original sub-code	Data source
Motorvej	Highway	2100	1	Kort10 (Danish Geodata Agency, 2011a)
Motortrafikvej	Motorway	2700	2	Kort10 (Danish Geodata Agency, 2011a)
Vej > 6 meter bredde	Road > 6 meter width	2100	3	Kort10 (Danish Geodata Agency, 2011a)
Jernbane	Railway	3212	-	Kort10 (Danish Geodata Agency, 2011a)

The estimation of change in infrastructure was based on Kort10 from 2005 (Danish Geodata Agency, 2005) and on the Danish address and road database (DAV) for 1999 (COWI, 2000). No information about infrastructure before 1999 was available. The infrastructure layer for 2011 was overlaid with the infrastructure layers for 2005 and for 1999. Based on this overlay, the infrastructure layer for 2011 was classified into infrastructure, which was established before 1999, between 1999 and 2005 and between 2005 and 2011.

### 2.3 Cropland and Grassland

Cropland is defined as land intensively utilized for agricultural purposes. Grassland, which is part of an annual agricultural rotation cycle, is included in the Cropland category. Grassland is defined as agricultural permanent grassland which is used for grazing and other areas where the vegetation is maintained at a state, which implies that it does not hold trees with a crown cover of at least 10 percent, in which case it would meet the definition for forest. Grassland includes among other extensively managed grassland, dry grassland and heathland. Information about cropland and grassland in 2011 was derived from the agricultural register for 2011 (Ministry of Food, Agriculture and Fisheries, 2011a) in combination with the field parcel map for 2011 (Ministry of Food, Agriculture and Fisheries, 2011b). The field parcel map contains land use information for all field parcels, managed by land managers (e.g. farmers) who have applied for EU subsidies (Land Parcel Information System, LPIS). The field parcel map contains a total of 277 land use classes. These were aggregated into four classes: cropland, grassland, forest and wetland. The aggregation of land use classes is presented in Appendix 1. Furthermore, grassland was also derived from the national registration of protected habitat types (Arealinformation, 2011a) and from management plans for state forests (Danish Nature Agency, 2011) from the management plans for defence holdings (Danish Defence, 2011) and from the registration of habitat types within Natura2000 designations (Arealinformation, 2011b) (Table 3) - each giving information on subset of the Danish land area, except the national registration of protected habitat types which is of national cover.

Table 3 Object types applied for grassland (except object types from agricultural register – see appendix 1).

Object name (Danish)	Object name (English)	Original object code	Source
Brandbælte	Fire break	BRL	Management plans for defence holdings (Danish Defence, 2011)
Bæltevej	Tank track	BÆL	Management plans for defence holdings (Danish Defence, 2011)
Frit areal (overdrev)	Open area	FRI	Management plans for defence holdings (Danish Defence, 2011)
Slette, Overdrev (græsset)	Grazed plain	GRÆ	Management plans for defence holdings (Danish Defence, 2011)
Hede	Heather	HED	Management plans for defence holdings (Danish Defence, 2011)
Slette, Overdrev (overdrev)	Dry meadow	ORE	Management plans for defence holdings (Danish Defence, 2011)
Slette, Overdrev (slette)	Plain	SLE	Management plans for defence holdings (Danish Defence, 2011)
Hede	Heather	STO	Management plans for defence holdings (Danish Defence, 2011)
Vildtager	Gaming area	VAG	Management plans for defence holdings (Danish Defence, 2011)
Brandbælte	Fire break	BRL	Management plans for state forests (Danish Nature Agency, 2011)
Bæltevej	Tank track	BÆL	Management plans for state forests (Danish Nature Agency, 2011)
Hede	Heather	HED	Management plans for state forests (Danish Nature Agency, 2011)
Slette, Overdrev (overdrev)	Dry meadow	ORE	Management plans for state forests (Danish Nature Agency, 2011)
Slette, Overdrev (slette)	Plain	SLE	Management plans for state forests (Danish Nature Agency, 2011)
Vildtager	Gaming area	VAG	Management plans for state forests (Danish Nature Agency, 2011)
Hede	Heather	3060	Map of protected habitat types (Arealinformation, 2011a)
Overdrev	Dry meadow	3070	Map of protected habitat types (Arealinformation, 2011a)
Klithede	Dune heather	2140	Natura2000 habitat types (Arealinformation, 2011b)
Våd hede	Wet dune	4010	Natura2000 habitat types (Arealinformation, 2011b)
Tør hede	Dry heather	4030	Natura2000 habitat types (Arealinformation, 2011b)
Enekrat	Dune with juniper	5130	Natura2000 habitat types (Arealinformation, 2011b)
Tør overdrev på kalkholdigt sand	Dry meadow on limestone	6120	Natura2000 habitat types (Arealinformation, 2011b)
Kalkoverdrev	Dry meadow on limestone	6210	Natura2000 habitat types (Arealinformation, 2011b)
Surt overdrev	Acid dry meadow	6230	Natura2000 habitat types (Arealinformation, 2011b)
Hede	Heather	6139	Kort10 (Danish Geodata Agency, 2011a)

### 2.3.1 Changes in cropland and grassland

Information about agricultural land use has not been available at field parcel scale for the whole country before 2011. Therefore, the estimation of LULC changes including cropland and grassland was based on information at field block scale extracted from agricultural registers from 1998, 2005 and 2011 (Ministry of Food, Agriculture and Fisheries, 1998a; 2005a; 2011a). Field blocks are aggregates of up to 10 field parcels. Information about agricultural land use at this scale has been available since 1998. The Danish map of field blocks is being adjusted continuously. Consequently, field block boundaries have been altered over the years and are not consistent in time and space.

In order to establish one field block map, which is consistent for the assessed period field block maps from 1998, 2005 and 2011 (Ministry of Food, Agri-

culture and Fisheries, 1998b; 2005b; 2011c) were overlaid. As exemplified in Figure 2, field blocks which have been either split up or were merged over these years, were identified and merged into one field block. Due to this aggregation, the total number of field blocks was reduced from 291,671 (in 2011) to 203,969 (aggregated field block map).



Figure 2 Illustration of aggregation of field block maps for 1998, 2005 and 2011. Field block which were either divided or merged between 1990 (a), 2005 (b) and 2011(c), where identified and merged into one aggregated field block map (e).

As information on agricultural land use for the years 1998 and 2005 was only available at the scale of field blocks, LULC changes including agricultural land use could not be precisely located. The estimation of changes between cropland and grassland based on field block information was based on following assumption: The area of grassland, which is the same in two years (e.g. 2005 and 2011) within one field block, is assumed to have the same location in the two years. I.e. within one field block, change between cropland and grassland between two years was assumed only to take place, if the proportions of grassland and cropland within the field block had changed. The estimation of land use change at field block scale is illustrated in Figure 3.

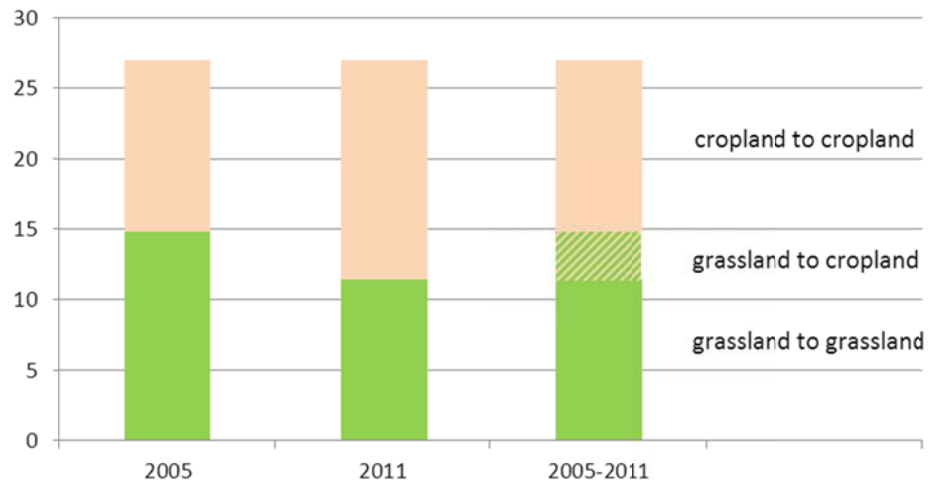


Figure 3 Illustration of estimation of land use changes from 2005 to 2011 within one field block. The area of one land use type, which is the same in both years is assumed not to have changed location and is thus assigned to no change (here: “cropland to cropland” and “grassland to grassland”). The area of one land use, which is not the same in the two years, is assigned to a change (here: “grassland to cropland”).

## 2.4 Wetland - fully water covered

Fully water covered wetlands are defined as lakes and other permanent water bodies which are saturated by water throughout the year. These wetlands are represented by the object type lake (original object code 3080) in the registration of protected habitat types (Arealinformation, 2011a). Although registrations of protected habitats do exist for the early 1990’s, changes in habitat types, including lakes are the result of changes in registration methods and increasing precision of the demarcation of habitat boundaries, rather than actual changes in habitats extent. Therefore, estimations of changes involving fully water covered wetlands were treated in combination with the other input layers as described in section 4.

## 2.5 Wetlands - partly water covered

Partly water covered wetlands are defined as land that is covered or saturated by water part of the year and areas with peat extraction. Partly water covered wetlands include: bogs, freshwater meadows, coastal meadows and marshlands. These LULC classes are represented by the object types listed in Table 4. Historical information for these is not readily available. Therefore, estimations of changes involving fully water covered wetlands were treated in combination with the other input layers as described in section 4.



Table 4 Object types applied for wetland (except object types from agricultural register – se appendix 1).

Object name (Danish)	Object name (English)	Original object code	Source
Eng	Wet meadow	ENG	Management plans for defence holdings (Danish Defence, 2011)
Marsk	Coastal marsh	MAR	Management plans for defence holdings (Danish Defence, 2011)
Mose	Mire/bog	MOS	Management plans for defence holdings (Danish Defence, 2011)
Strandeng	Coastal meadow	STG	Management plans for defence holdings (Danish Defence, 2011)
Strandsump	Coastal swamp	STS	Management plans for defence holdings (Danish Defence, 2011)
Eng	Wet meadow	ENG	Management plans for state forests (Danish Nature Agency, 2011)
Marsk	Coastal marsh	MAR	Management plans for state forests (Danish Nature Agency, 2011)
Mose	Mire/bog	MOS	Management plans for state forests (Danish Nature Agency, 2011)
Strandeng	Coastal meadow	STG	Management plans for state forests (Danish Nature Agency, 2011)
Strandsump	Coastal swamp	STS	Management plans for state forests (Danish Nature Agency, 2011)
Fersk eng	Freshwater meadow	3055	Map of protected habitat types (Arealinformation, 2011a)
Mose	Mire / bog	3065	Map of protected habitat types (Arealinformation, 2011a)
Strandeng	Coastal meadow	3075	Map of protected habitat types (Arealinformation, 2011a)
Strandeng	Coastal meadow	1330	Natura2000 habitat types (Arealinformation, 2011b)
Indlandssalteng	Inland salt marsh Periodically wet	1340	Natura2000 habitat types (Arealinformation, 2011b)
Tidvis våd eng	meadow	6410	Natura2000 habitat types (Arealinformation, 2011b)
Højmose	Raised bog Degraded raised	7110	Natura2000 habitat types (Arealinformation, 2011b)
Nedbrudt højmoser bog		7120	Natura2000 habitat types (Arealinformation, 2011b)
Hængesæk	Bog	7140	Natura2000 habitat types (Arealinformation, 2011b)
Tørvelavning	Peat dip	7150	Natura2000 habitat types (Arealinformation, 2011b)
Avneknippemose	Bog with twig rush	7210	Natura2000 habitat types (Arealinformation, 2011b)
Kildevæld	Spring	7220	Natura2000 habitat types (Arealinformation, 2011b)
Rigkær	Rich pond	7230	Natura2000 habitat types (Arealinformation, 2011b)
Vådområde	Wetland	6159	Kort10 (Danish Geodata Agency, 2011a)

## 2.6 Forest

Forest is defined as woody vegetation having a minimum tree crown cover of 10 %, a minimum area of 0.5 ha and a minimum value for tree height which must be able to reach a minimum height of 5 m at the site. In addition, the forest area includes temporarily unstocked areas, smaller open areas in the forest needed for management purposes and fire breaks. Forests in national parks, reserves, or areas under special protection are included. Conifers for production of Christmas trees as well as forest for energy production, except willow plantations, are also reported under forest.

Fruit plantations for commercial purposes, orchards, gardens etc., which might be able to reach the forest definition, are reported in the Cropland layer.

### 2.6.1 Forest mapping for 1990 and 2005

Mapping of forest area in 1990 and 2005 was finalised in 2011. Landsat 5 Thematic Mapper (TM) scenes for 1989-90, 2005-06 and SPOT XS were purchased from Eurimage, USGS EROS Data Center, and Image2006. The imagery was resampled to 25 meters using a quadratic mapping function and

nearest neighbour resampling with a minimum of 20 ground control points per scene.

For the Landsat USGS scenes, the images were systematically Level 1G corrected. All images were re-projected to the UTM 32N coordinate system using the WGS84 datum and a 30 meter resolution as a first step as no ETRS1989 projection is available in the ERDAS IMAGINE software. This was processed by Prins Engineering AS in the part of the Forest Service Element (GSE-FM) of the GMES program in Denmark. These data were subsequently acquired for the SINKS project.

The earliest available set of orthophotos covering the whole of Denmark was from the year 1995. Earlier orthophotos are available for the year 1974 in black and white but covers Denmark only partly. The dataset was used as ancillary layer for image class interpretation and verification of the baseline classification results in the reference year 1990. Orthophotos for the reference year 2004, 2006 were available for entire Denmark. This dataset was similarly used for image class interpretation. The DDO1995 has a resolution of 40 cm in ECW compression. The orthophoto acquisitions from the period 2004-2007 have a resolution of 40 cm and 20 cm (uncompressed). The Danish map of field blocks (Ministry of Food, Agriculture and Fisheries, 2011c) for 2005 was furthermore used for image class interpretation.

Through a morphological post-classification processing on the satellite-based forest maps (LU1990 and LU2005) a more homogenous mapping of the forests in 1990 and 2005 was produced (Seebach et al., 2013).

The overall steps in the processing of the satellite images were:

- Geo-referencing the satellite image
- ISODATA Classifier for ISODATA algorithm to perform unsupervised classification of SSC image
- Identification of mixed classes by Cluster Busting Method (Mask)
- Labelling of Classes and combining or recoding of identified classes
- Supervised classification to delineate various land cover features
- Evaluation of supervised classification to give a better appearance by supervised classification using majority filter
- Presentation of classified image by a map composer

Then followed a process of spatial prioritizing, where each of the forest maps (in 1990 and 2005) were overlaid with the following theme layers:

- Lakes
- Summer cottages  
The summer cottages theme layer were an assembly of geodata from two sources – the summer cottage areas and the cadastres (<7500 m<sup>2</sup>) with an auxiliary identification code of a summer cottages (see also Table 1).
- Cropland (Ministry of Food, Agriculture and Fisheries, 2011b).

Table 5 Object types, where forest areas for 1990 and 2005 were reclassified as non-forest.

Object name (Danish)	Object name (English)	Original object code	Data source
Sø	Lake	7219	Kort10 (Danish Geodata Agency, 2011a)
Sommerhusområder	Summer cottage areas	405	AIS (National Environmental Research Institute, 1999)
Sommerhus	Summer cottage	510	Cadastre map ( Danish Geodata Agency, 2011c)

## 2.6.2 Forest mapping for 2011

For 2011 a national forest map was created based on Landsat data acquired during 2010 and 2011.

In order to obtain a satisfactory terrain correction all Landsat data were subject to a first order geometric adjustment using roads >6 m width from FOT (Danish Geodata Agency, 2011a) as reference. The accuracy of the final adjusted images was judged to be better than half a pixel relative to the reference layer. All images are delivered in UTM 32N coordinates (Datum: WGS84).

To reduce any effect causing brightness changes not related to actual ground surface a normalisation procedure was conducted. In this procedure the raw digital numbers (DN) were first converted to at-satellite radiance using scene dependent calibration coefficients and finally planetary reflectance was estimated.

The national forest cover map was accomplished using a mapping approach that combines an object based image analysis (OBIA) with a decision tree classifier (DTC). The DTC was subsequently used to classify each of the remaining land areas into forest or non-forest.

Training samples needed for the DTC were generated by using an unsupervised classification that was run with an output of 25 classes for sub-regions located within each of the mapping zones. These classes were subsequently aggregated to approximately seven main land cover types.

The spectral signature of some pixels containing agricultural crops and forest were sometimes not discriminable. Therefore, a mixed-vegetation class was also created for all pixels which were not unambiguously assignable. Finally, a shapefile delineating all cultivated fields, based on the agricultural register for 2011 (Ministry of Food, Agriculture and Fisheries, 2011b) in combination with the field parcel map for 2011 (Ministry of Food, Agriculture and Fisheries, 2011a), was used to sort out all pixels classified as mixed forest located within the boundaries of fields parcels. The other mixed forest pixels were assigned to the forest class.

A map was generated, including all the forest areas in Denmark. An overall producer's accuracy of 85 % was estimated based on comparison with the sample plots of the National Forest Inventory. (Huber & Tøttrup, 2012).

In the change analysis of forest mapping, based on the comparison to the 1990 and 2005 forest map, some changes could be detected based on the 3 maps. In the forest management temporary unstocked forest areas occur when regenerating forest stands by clear cuts. According to the Danish Forest Act a 10 year period is allowed for regeneration. Hence, deforestation cannot alone be determined by a single mapping, but requires repeated mapping of unstocked conditions of more than 10 year intervals. For the 2011 forest map, forest areas classified as forest in 1990 and 2005, but not on the 2011 forest map, were added to the 2011 map.

Based on forest management plans of the state forest, some areas were identified where forest had been cleared to establish permanent areas with water, lakes or other areas not forested. These areas were removed from the forest map (1.541 ha).

Then a process of spatial prioritizing followed, where the forest map was overlaid with the following theme layers:

- Summer cottages
- Urban areas
- Traffic-related infrastructure

Table 6 Object types, where forest areas for 2011 were reclassified as non-forest.

Object name (Danish)	Object name (English)	Original object code	Data source
Sommerhusområder	Summer cottage areas	405	AIS (National Environmental Research Institute, 1999)
Sommerhus	Summer cottage	510	Cadastre map (Danish Geodata Agency, 2011c)
Høj bebyggelse	High built up	3318	Kort10 (Danish Geodata Agency, 2010)
Lav bebyggelse	Low built up	3117	Kort10 (Danish Geodata Agency, 2010)
Kirkegård	Cemetery	6329	Kort10 (Danish Geodata Agency, 2010)
Rekreativt område	Recreational area	3119	Kort10 (Danish Geodata Agency, 2010)
Sportsanlæg	Sport facility	5500	Kort10 (Danish Geodata Agency, 2010)
Råstofområde	Resource extraction	5130	Kort10 (Danish Geodata Agency, 2010)
Industri	Industry	3116	Kort10 (Danish Geodata Agency, 2010)
Teknisk areal	Technical area	2700	Kort10 (Danish Geodata Agency, 2010)
Landingsbane	Runway	2543	Kort10 (Danish Geodata Agency, 2010)
Motorvej <sup>1</sup>	Highway	2100	Kort10 (Danish Geodata Agency, 2010)
Motortrafikvej <sup>2</sup>	Motorway	2700	Kort10 (Danish Geodata Agency, 2010)
Jernbane <sup>3</sup>	Railway	3212	Kort10 (Danish Geodata Agency, 2010)

<sup>1</sup>A buffer of 12.5 m was applied on both sides of the centreline

<sup>2</sup>A buffer of 10 m was applied on both sides of the centreline

<sup>3</sup>A buffer of 5 m was applied on both sides of the centreline

In the subsequent combination of maps fields which are used for afforestation and registered in the field parcel map were added to the forest layer.

## 2.7 Other land

Other land comprises all LULC, which is not included in the other six LULC categories. It is defined as beaches, sand dunes and rock and has none or very limited carbon stock, both as living or dead biomass or as carbon in the soil. The included object types are listed in Table 7. Other land as represented in the applied input datasets from 2011 was decided to be representative for the whole period from 1990 to 2011. I.e. in the final estimation of LULC changes, the area covered by other land is stable.

Table 7 Object types applied for wetland.

Object name (Danish)	Object name (English)	Original object code	Source
Klit	Dune	KLI	Management plans for defence holdings (Danish Defence, 2011)
Klit	Dune	KLI	Management plans for state forests (Danish Nature Agency, 2011)
Klippe	Rock	KLP	Management plans for state forests (Danish Nature Agency, 2011)
Grå/grøn klit	Grey/green dune	2130	Natura2000 habitat types (Arealinformation, 2011b)
Klittlavning	Dune dip	2190	Natura2000 habitat types (Arealinformation, 2011b)
Enebærklit	Dune with juniper	2250	Natura2000 habitat types (Arealinformation, 2011b)
Visse-indlandsklit	Dune with needle furze	2310	Natura2000 habitat types (Arealinformation, 2011b)
Revling-indlandsklit	Dune with crowberry	2320	Natura2000 habitat types (Arealinformation, 2011b)
Græs-indlandsklit	Inland dune with grass	2330	Natura2000 habitat types (Arealinformation, 2011b)
Sand	Sand	6142	Kort10 (Danish Geodata Agency, 2011a)

### 3 Combination of input layers for 2011

In principal, all input layers, which are described in section 2, were overlaid. For cells, containing information from more than one input layer (i.e. where input layers overlap) layers were prioritised following the hierarchy, which is shown in Table 6. The terrestrial area was applied to delimit the area for analysis. Cells outside the terrestrial area, were defined as open sea, and thus not included in the study. Next, settlement was prioritised over any layer except open sea. Then, the field parcel map was prioritised over any layer except open sea and settlement. The prioritisation hierarchy listed in Table 6 was followed for all input layers.

Table 6 Prioritization hierarchy of input layers for land use map for 2011.

Priority	Input layer	Comment
1	Sea	
2	Wetland (fully water covered)	
3	Field parcel map	If the field parcel does not contain information about the object type (the object type is undefined) settlement, grassland and wetland (partly covered) are prioritised over the field parcel map).
4	Settlement	
5	Forest	
6	Wetland (partly water covered)	If a cell containing the object code grassland from the field parcel map overlaps with wetland (partly covered) the cell is attributed to wetland (partly covered).
7	Grassland	
8	Other land	

Approximately 135,000 ha (or 3 % of the terrestrial area) remained unclassified. I.e. none of the applied input datasets contained information for these cells. Of these, 130,000 ha were narrow zones with a width of equal to or less than 2 cells (50 meters). Assuming these unclassified zones are the consequence of uncoordinated registrations of applied input datasets, cells within these zones were assigned to the LULC category of the closest adjacent cell. The approximately 6,000 ha, which remained unclassified were assigned to the grassland category.

## 4 Estimation of LULC changes from 1990 to 2005 and 2005 to 2011

This section outlines how changes between the different LULC categories between 1990 and 2005 and between 2005 and 2011 were estimated.

Denmark is heavily utilised by agriculture on drained soils. More than two-third of Denmark is ploughed land and due to environmental restrictions the demand for agricultural land is large. To decrease the environmental impact and increase the area with forests and nature areas, the national policy is to double the area with forest from 1980 to 2080 and increase the area designated to nature, including more wetlands and lakes. To protect these areas newly afforested land supported with subsidies is designated as forest reserves. A consequence of this is a more or less uniform LULC conversion from agriculture to settlements, forest land and nature areas. Deforestation is only taking place in relation to restoration of nature areas (e.g. wetlands) or if new settlements are planned and have to be replaced by afforestation at other locations. According to Statistics Denmark, from 1990 to 2011, the agricultural area has been reduced by 5% (Statistics Denmark, 2012). Therefore, it can be assumed that all LULC changes from 1990 and onwards are unidirectional from agricultural land to settlement, forest or nature areas. Abandonment of settlements has not occurred in Denmark in the observed period.

Availability of historic spatially explicit information varies considerably between different datasets and LULC categories. E.g. for settlement it was possible to elaborate a reasonable yearly spatially specific estimation of change from 1990 up to 2011. For the agricultural land use types cropland and grassland, spatially specific information was available since 1998. In comparison, for wetlands and for other land no consistent nationwide and spatially specific historical data exist.

### 4.1 Overlay analysis

The 2011 LULC map was the starting point for the assessment of LULC changes. In principle, for each cell, available historical data were applied to estimate, whether LULC was the same in 2005 as in 2011 or if it had changed. Next, this step was repeated in order to estimate whether LULC had changed between 1990 and 2005. Only for forest and for settlement spatially specific information for the year 1990 was available. For all other input layers, the earliest available dataset was applied. I.e. for agricultural land use, the agricultural register and field block map for 1998 was applied. For wetland and other land and for grassland not included in the agricultural register, no historic information was available. Therefore, for these LULC categories, the most recent layers were applied for all years.

LULC changes were estimated as follows. E.g. for changes between 2005 and 2011, for each cell, available historic information was applied to determine whether LULC in 2005 was the same as in 2011 or whether it had changed. E.g. if a cell contained forest in 2011 and in 2005, LULC was unchanged and assigned to the change trajectory “forest to forest”. However, if the forest layer for 2005 did not contain forest but the field block map for 2005 contained agricultural land use, LULC had changed and was assigned to the change trajectory “agriculture to forest”. Since the LULC types contained in



the field block map (cropland, grassland, afforestation and wetland) could not be allocated precisely within the field block, the changes were distributed to change trajectories according to the proportions of LULC categories within the field block. Figure 4 illustrates the estimation of LULC changes from 2005 to 2011.

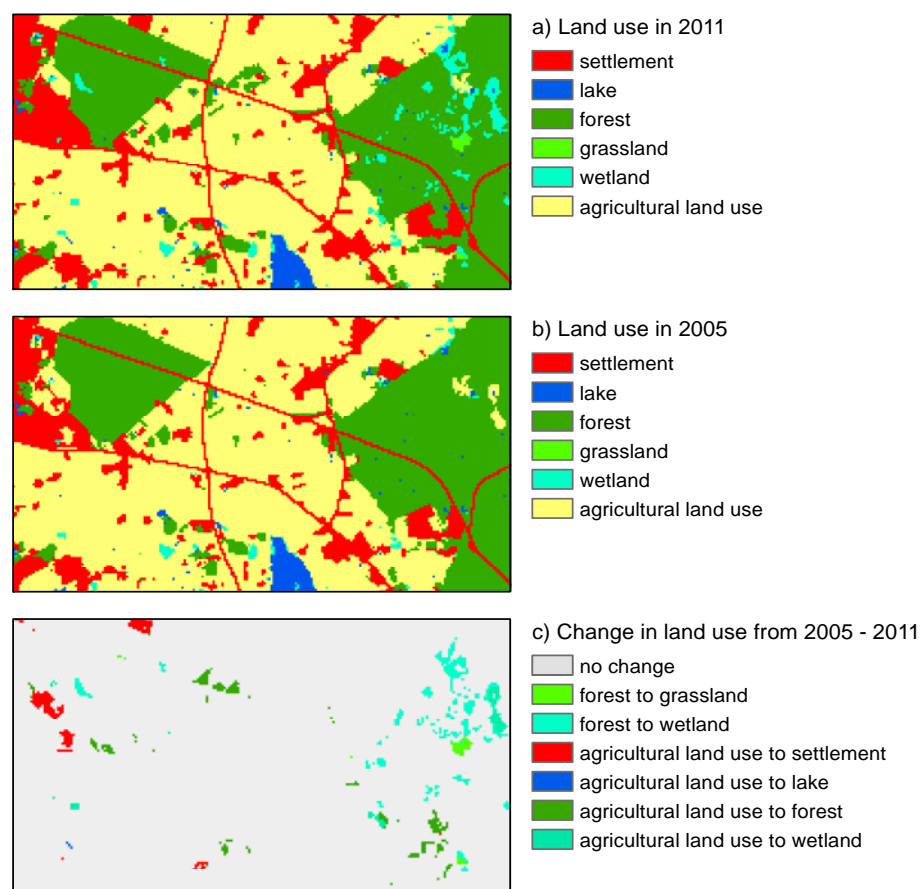


Figure 4 Illustration of determination of land use changes from 2005 to 2011. The land use map for 2011 (a) was overlaid with available land use information for 2005 (b). Based on this overlay, change trajectories were assigned to each cell (c).

The estimation of land LULC changes was based on following pre-assumptions:

- Since 1990, agricultural LULC is assumed not to have emerged from other LULC categories. I.e. agricultural LULC contained in the field parcel map of 2011 was assumed also to have been agricultural LULC in 2005 and in 1990. Changes between cropland, grassland and wetland might have taken place, but are treated isolated as described in section 2.3.1.
- Other land does not change over time. I.e. all other land in the LULC map for 2011 is assigned the land use trajectory “other land – other land – other land”.
- If one cell contains historical information from more than one layer (e.g. if a cell where settlement was established between 2005 and 2011 and the 2005 data indicate that the cell had been either forest or wetland in 2005, forest is prioritised over wetland. Table 7 contains the prioritisation hierarchy applied to determine land use change trajectories.
- If an input layer indicates for a cell that a LULC change has taken place (e.g. settlement, which emerged between 2005 and 2011), but no historical

information for this cell indicates what the LULC was previously, the cell is assigned no change (e.g. “settlement to settlement”).

Table 7 Hierarchy for prioritization of input layers for estimation of LULC changes.

Priority	Input layer for 2005	Input layer for 1990
1	Forest (2005)	Forest (1990)
2	Agricultural land use (field block map) (2005)	Agricultural land use (field block map) (1998)
3	Wetland - fully water covered (2011)	Wetland - fully water covered (2011)
4	Wetland - partly water covered (2011)	Wetland - partly water covered (2011)
5	Grassland (2011)	Grassland (2011)

## 4.2 Expert-based redefinition of land use/land cover changes

As a consequence of large variations in the availability of historical LULC information, the assessment of LULC changes since 1990 must be subject to considerable inaccuracies, due to lacking information on most land uses in 1990, where only a map of forest is available. In order to reduce the bias from potential inaccuracies, especially for the land use classes of importance for the further use of the land use matrix and changes over time, a number of trajectories of LULC change involving forest where, after discussions among project members, re-defined as follows:

1. If input layers showed a LULC change from forest in 1990 and 2005 to grassland in 2011, this LULC change was accepted if the area was located within a state-owned forest (966 ha), but was changed to forest in 1990, 2005 and 2011 if the area was privately owned.
2. If input layers showed a LULC change from forest in 1990 and 2005 to partly water covered wetland in 2011, this LULC change was accepted if the area was located within a state-owned forest (2,071 ha), but was changed to forest in 1990, 2005 and 2011 if the area was privately owned.
3. If input layers showed a LULC change from grassland or wetland in 1990 and 2005 to forest in 2011, the LULC change was re-classified to forest for all years (15,669 ha).
4. If an area was included in the field block system in 1998 without information on the crop and in 2005 was classified as forest, the area was also classified as forest in 1990 (17,946 ha).
5. If an area was included in the field block system in 1998 without information on the crop, in 2005 was classified as forest and in 2011 classified as grassland, the area was re-classified to grassland for the whole period (271 ha).
6. If an area was included in the field block system in 1998 with agricultural crops, in 2005 classified was as forest and in 2011 included in the field block system but without information on crop, the land was reclassified to agriculture in 1990, and to forest in 2005 and in 2011 (7,596 ha).
7. If an area was included in the field block system in 1998 as a crop, in 2005 was classified as partly water covered wetland and in 2011 as forest, area was re-classified to cropland in 1990, and to forest in 2005 and 2011 (620 ha).
8. If an area was included in the field block system with a crop in 1998 but without a crop in 2005 and was classified as forest in 2011, the area is re-classified to cropland in 1990 and forest in 2005 and 2011 (50,670 ha).

## 5 Estimation of land use/land cover changes from 2011 to 2012

This section outlines how LULC changes between 2011 and 2012 were estimated. In contrast to the estimation of LULC changes until 2011, for the period between 2011 and 2012 only the field parcel map (Ministry of Food, Agriculture and Fisheries, 2012a), representing information from the agricultural register (Ministry of Food, Agriculture and Fisheries, 2012b) for cropland, grassland and wetland; and the topographical database Kort10 (Danish Geodata Agency, 2012b), which represent settlement, contained updated information about LULC. For the remaining input datasets, the LULC information for 2011 was also applied for 2012.

### 5.1 Assessment of LULC changes

After conversion to raster format, the settlement layer and the field parcel layer for 2012 were embedded in the 2011 LULC map. In principle the same hierarchy as for the 2011 map was applied (see Table 6). However, following exceptions were made:

1. For cells, where forest changes to settlement, the forest layer from Kort10 (Danish Geodata Agency, 2012b) was applied to qualify the cell as forest. I.e. if the forest layer from Kort10 contains forest, the cell is kept in forest in 2012, otherwise the cell is attributed the change from forest to settlement.
2. Cells, which change from non-forest in 2011 to forest in 2012, are only registered as afforestation if the cell contains forest in at least two successive years. I.e. that afforestation is registered if the cell contains forest in 2013. Therefore, afforestation is registered with a delay of one year. Consequently no afforestation is registered from 2011 to 2012. Afforestation from 2011 to 2012 is registered in the estimation of land use/land cover change from 2012 to 2013.
3. For cells, where LULC changed from grassland, cropland or wetland in 2011 to undefined LULC in the field parcel map for 2012, the cell is attributed the LULC from the 2011 map.
4. Cells with wetland (permanently covered) or with other land in 2011 are kept in the same class in 2012, also if 2012 data indicate a change.

If the information for 2012 indicated a change in LULC, the type and extent of change was assessed. In cases where information for 2012 indicated no change as well as cases where the input layers for 2012 (settlement layer or field parcel map) did not contain any LULC information, LULC was reported unchanged.

### 5.2 Elimination of small changes

A considerable proportion of changes, especially those including agricultural land uses, only contain few cells. These changes are most probably the result of imprecise mapping of input datasets (particularly for the field parcel maps) rather than actual changes. Therefore, regions, which change and have a size of  $\leq 8$  cells or 0.5 ha, were not accepted. This is in accordance with the elected Danish minimum forest definition (IR, 2006) and the IPCC guidelines (IPCC, 2003). These regions were identified and LULC for 2011 was applied to the 2012 map.

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## Appendix

Appendix 1 Applied object types from agricultural registers and aggregation to LULC object types.

Original object code	Original object name (Danish)	Original object name (English)	LULC object code	LULC object name
0	Anden afgrøde	Other agricultural land use	0	undefined
1	Vårbyg	Spring barley	13	cropland
2	Vårhvede	Spring wheat	13	cropland
3	Havre	Oat	13	cropland
4	Andre kornarter, vårsået	Other spring cereal	13	cropland
5	Majs til modenhed	Maize to maturity	13	cropland
6	Vårhvede, brødhvede	Spring wheat, near cereal	13	cropland
7	Korn/bælgsæd maks. 50 % bælg-sæd	Cereal/pulse, max. 50 % pulse	13	cropland
10	Vinterbyg	Winter barley	13	cropland
11	Vinterhvede	Winter wheat	13	cropland
13	Vinterhvede, brødhv.	Wither wheat, near cereal	13	cropland
14	Vinterrug	Winter rye	13	cropland
15	Hybridrug	Hybrid rye	13	cropland
16	Triticale	Triticale	13	cropland
17	Andre kornarter, efterårssået	Other cereals, winter sown	13	cropland
21	Vårrops	Spring rape	13	cropland
22	Vinterraps	Winter rape	13	cropland
23	Rybs	A rape variety	13	cropland
24	Solsikke	Sunflower	13	cropland
25	Sojabønner	Soya bean	13	cropland
30	Ærter	Pea	13	cropland
31	Hestebønner	Broad bean	13	cropland
32	Sødlupin	Lupine	13	cropland
35	Flerårig bælg-sæd	Perennial pulses	13	cropland
36	Anden bælg-sæd til modenhed	Other pulses to maturity	13	cropland
40	Oliehør	Flax grown as an oilseed crop	13	cropland
41	Spindhør	Fibre flax	13	cropland
42	Hamp	Hemp	13	cropland
44	Andet	Other	0	undefined
50	Anden bredbladet afgroede	Other broadleaved crop	13	cropland
52	Andet	Other	0	undefined
58	Andet	Other	0	undefined
101	Rajgræsfrø, alm.	Rye grass seed	13	cropland
102	Rajgræsfrø, alm. 1. år, efterårsudlagt	Rye grass seed, fall planted	13	cropland
103	Rajgræsfrø, ital.	Italian rye grass seed	13	cropland
104	Rajgræsfrø ital. 1. år efterslæt	Italian rye grass seed, fall planted	13	cropland
105	Timotéfrø	Timothy seed	13	cropland
106	Hundegræsfrø	Orchard grass seed	13	cropland
107	Engsvingelfrø	Fescue grass seed	13	cropland
108	Rødsvingelfrø	Red fescue seed	13	cropland

## Continued

109	Rajsvingel	Festulolium	13	cropland
110	Stivbladet svingelfrø	Stiff-leaved fescue seed	13	cropland
111	Strandsvingelfrø	Festuca littorea seed	13	cropland
112	Engrapgræsfrø (marktype)	Smooth meadow grass seed (field type)	13	cropland
113	Engrapgræsfrø (plæntype)	Smooth meadow grass seed (lawn type)	13	cropland
114	Alm. rapgræsfrø	Meadow grass seed	13	cropland
115	Hvenefrø, alm. og krybende	Browntop/bent grass seed	13	cropland
116	Rajgræs, hybrid	Rye grass, hybrid	13	cropland
117	Rajgræs efterårsudl. hybrid	Rye grass seed, fall planted, hybrid	13	cropland
118	Rajsvingelfrø, efterårsudlagt	Festulolium seed, fall planted	13	cropland
120	Kløverfrø	Clover seed	13	cropland
121	Græsmarksbælgplanter	Grass field pulses	13	cropland
122	Kommenfrø	Caraway seed	13	cropland
123	Valmuefrø	Poppy seed	13	cropland
124	Spinatfrø	Spinach seed	13	cropland
125	Bederoefrø	Beet seed	13	cropland
126	Andet markfrø til udsæd	Other seed for sowing	13	cropland
130	Andet	Other	0	undefined
150	Læggekartofler	Seed potato	13	cropland
151	Stivelseskartofler	Starch potato	13	cropland
152	Spisekartofler	Potato for consumption	13	cropland
153	Kartofler, andre	Potato, other	13	cropland
160	Roer til fabrik	Beet for industry	13	cropland
161	Cikorierødder	Chicory root	13	cropland
162	Andre industriafrgr./rodfr.	Other crop/root crop for industry	13	cropland
170	Græs/kløvergr. til fabrik (omdrift)	Grass/clover for industry	13	cropland
171	Lucerne slæt + eget foder	Lucerne for harvest and own fodder	13	cropland
172	Lucerne m/ min. 25 % græs slet (+eget foder)	Lucerne for harvest and own fodder, min. 25 % grass	13	cropland
173	Kløver til slæt.	Clover for harvest	13	cropland
174	Kløvergræs til fabrik	Clover for industry	13	cropland
180	Gul sennep	White mustard	13	cropland
181	Anden oliefrøart	Other oil seed	13	cropland
200	Fragået mark	Ceased field	0	undefined
201	Sammenlagt mark	Merged field	0	undefined
202	fragået mark, prod.skifte	Ceased field, production change	0	undefined
210	Vårbyg, helsæd	Spring barley, wholecrop	13	cropland
211	Vårhvede, helsæd	Spring wheat, wholecrop	13	cropland
212	Havre, helsæd	Oat, wholecrop	13	cropland
213	Blandkorn, vårsået, helsæd	Dredge corn, wholecrop	13	cropland
214	Korn/bælgsæd, helsæd, maks. 50 % bælgsæd	Cereal, pulse, wholecrop max. 50% pulse	13	cropland
215	Ærtehelsæd	Pea, wholecrop	13	cropland
216	Silomajs	Silo maize	13	cropland
218	Andet	Other	0	undefined
220	Vinterbyg, helsæd	Winter barley, wholecrop	13	cropland
221	Vinterhvede, helsæd	Winter wheat, wholecrop	13	cropland
222	Vinterrug, helsæd	Winter rye, wholecrop	13	cropland



## Continued

223	Vintertertricale, helsæd	Winter tricale, wholecrop	13	cropland
224	Blandkorn, efterårssået helsæd	Dredge corn, fall planted, wholecrop	13	cropland
225	Andet	Other	0	undefined
230	Vårkorn, grønkorn	Spring cereal, green grain	13	cropland
234	Korn/bælgsæd, grønkorn, maks. 50 % bælgsæd	Cereal/pulse, green grain. Max. 50 % pulse	13	cropland
235	Vinterkorn, grønkorn	Winter cereal, green grain	13	cropland
250	Permanent græs meget lavt udbytte	Permanent grass, very low yield	7	grassland
251	Permanent græs lavt udbytte	Permanent grass, low yield	7	grassland
252	Permanent græs normalt udbytte	Permanent grass, normal yield	13	cropland
253	Miljøgræs MVJ-ordn. 1 (80 N)	Environmental grass (max 80 tonnes N)	7	grassland
254	Miljøgræs MVJ-ordn. 2 (0 N)	Environmental grass (0 N)	7	grassland
255	Permanent græs under 50 % kløver	Permanent grass, <50 % clover	13	cropland
256	Perm.græs over 50 % kløver	Permanent grass, >50 % clover	13	cropland
257	Permanent græs uden kløver	Permanent grass, no clover	13	cropland
258	Perm. græs, ø-støtte	Permanent grass, subsidy for organic farming	13	cropland
259	Perm. græs, fabrik, min. 6 t. udbytte	Permanent grass for industry, min. 6 tonnes yield	13	cropland
260	Kløvergræs under 50 % kløver (omdrift)	Clover grass, <50 % clover	13	cropland
261	Kløvergræs >50 % kløver (omdrift)	Clover grass, >50 % clover	13	cropland
262	Lucerne, lucernegræs >50 % lucerne omdr.	Lucerne, lucerne grass >50 % lucerne	13	cropland
263	Græs uden kløver (omdrift)	Grass without clover	13	cropland
264	Græs og kløvergræs uden norm	Grass and clover grass without N-norm	7	grassland
265	Græs og kløver græs slæt før vårsåede afgrøder	Grass en clover grass before spring planted crop	13	cropland
266	Græs < 50 % kløver ekstremt lavt udbytte	Grass <50 % clover, extremely low yield	7	grassland
267	Græs <50 % kløver meget lavt udbytte	Grass <50 % clover, very low yield	7	grassland
268	Græs < 50 % kløver lavt udbytte	Grass <50 % clover, low yield	7	grassland
269	Rullegræs, omdrift.	Turf in rotations	13	cropland
270	Græs til udegrise.	Grass for pigs	13	cropland
271	Rekreative formål, arealer til	Areas for recreational purposes	7	grassland
272	Perm. græs fabrik, kløvergræs	Permanent grass for industry	13	cropland
273	Perm. lucerne til fabrik	Permanent lucerne for industry	13	cropland
274	Perm. Lucerne, min. 25 % græs til fabrik	Permanent lucerne, min. 25 % for industry	13	cropland
275	Rullegræs, perm. græs	Turf permanent grass	13	cropland
276	Perm. græs/kløvergræs uden norm	Permanent grass/clovergrass without N-norm	7	grassland
277	Perm. kløver til fabrik	Permanent clover for industry	13	cropland
278	Perm.græs og lucernegræs >50 % lucerne	Permanent grass and lucernegrass >50 % lucerne	13	cropland
279	Permanent græs til fabrik	Permanent grass for industry	13	cropland
280	Fodersukkerroer	Sugar cane, fodder	13	cropland
281	Kålroer	Swede	13	cropland
282	Fodermarvkål	Marrow-stem kale	13	cropland

Continued

283	Fodergulerødder	Carrot, fodder	13	cropland
300	Andet	Other	0	undefined
310	Udyrket mark	Uncultivated field	7	grassland
311	Skovrejsning på tidl. landbrugsjord 1	Afforestation on former agricultural land	3	forest
312	20-årig udtagning	20 year set-aside	7	grassland
313	20-årig udtagning med skov	20 year set-aside with forest	3	forest
315	Miljøgræs brugt som udtagning	Environmental grass for set-aside	7	grassland
317	Vådømråder brugt som udtagning	Wetland for set-aside	9	wetland (partly water covered)
318	MVJ-ej udtagn. ej landbrugsjord	Not agri-environmental scheme, not agricultural land	7	grassland
319	MVJ-udtagn. ej landbrugsjord	Agri-environmental scheme, not agricultural land	7	grassland
320	Braklagte randzoner	Fallow in marginal zones	7	grassland
321	Miljøtiltag, ej landbrugsarealer	Environmental initiative, not agricultural land	7	grassland
340	Randzoneordningen	Marginal zone	7	grassland
341	Randzoneordningen 2	Marginal zone 2	7	grassland
350	Miljøgræs med N-kvot	Environmental grass with N-quota	7	grassland
400	Asier	Gherkins	13	cropland
401	Asparges	Asparagus	13	cropland
402	Bladselleri	Celery	13	cropland
403	Blomkål	Cauliflower	13	cropland
404	Broccoli	Broccoli	13	cropland
405	Courgette, squash	Courgette, squash	13	cropland
406	Grønkål	Kale, borecole	13	cropland
407	Gulerod	Carrot	13	cropland
408	Hvidkål	Cabbage	13	cropland
409	Kinakål	Chinese cabbage	13	cropland
410	Knoldselleri	Celeriac, turnip-rooted celery	13	cropland
411	Løg	Onion	13	cropland
412	Pastinak	Parsnip	13	cropland
413	Rodpersille	Hamburg parsley	13	cropland
415	Porre	Leek	13	cropland
416	Rosenkål	Sprouts	13	cropland
417	Rødbede	Beetroot	13	cropland
418	Rødkål	Red cabbage	13	cropland
420	Salat	Lettuce	13	cropland
421	Savoykål, spidskål	Savoy cabbage, pointed cabbage	13	cropland
422	Spinat	Spinach	13	cropland
423	Sukkermajs	Sweet corn	13	cropland
424	Ærter til konsum	Peas for consumption	13	cropland
429	Jordskokker, konsum	Jerusalem artichoke for consumption	13	cropland
430	Bladpersille	Leaf parsley	13	cropland
431	Purløg	Chive	13	cropland
432	Krydderurter, støtteberet.	Herb, aromatic plant, with subsidy	13	cropland
433	Krydderurter, andre	Herb, aromatic plant, other	13	cropland
448	Medicinplanter, et- og to-årige	Medical plants, annual and biennial	13	cropland

Continued

449	Medicinplanter, stauder og vedplanter	Medical plants, perennial	13	cropland
450	Grøntsager, andre	Vegetable, other	13	cropland
452	Andet	Other	0	undefined
500	Buske og træer	Bushes and trees	13	cropland
501	Stauder	Perennial plants	13	cropland
502	Blomsterløg	Bulb	13	cropland
503	Et- og to-årige planter	Annual and biennial plants	13	cropland
504	Solbær, stiklingeopformering	Blackcurrant, propagation of cuttings	13	cropland
507	Hindbær, stiklingeopformering	Raspberry, propagation of cuttings	13	cropland
509	Kvæde	Quince	13	cropland
510	Melon	Melon	13	cropland
511	Græskar.	Gourd	13	cropland
512	Rabarber	Rhubarb	13	cropland
513	Jordbær	Strawberry	13	cropland
514	Solbær	Blackcurrant	13	cropland
515	Ribs	Redcurrant	13	cropland
516	Stikkelsbær	Gooseberry	13	cropland
517	Brombær	Blackberry	13	cropland
518	Hindbær	Raspberry	13	cropland
519	Blåbær	Blueberry	13	cropland
520	Kirsebær uden undervækst	Cherry without undergrowth	13	cropland
521	Kirsebær undervækst	Cherry with undergrowth	13	cropland
522	Blomme, uden undervækst	Plum without undergrowth	13	cropland
523	Blomme, undervækst	Plum with undergrowth	13	cropland
524	Sødkirsebær uden undervækst af græs	Sweet cherry, without grass undergrowth	13	cropland
525	Sødkirsebær med undervækst af græs	Sweet cherry, with grass undergrowth	13	cropland
526	Hyld	Elder	13	cropland
527	Hassel	Hazel	13	cropland
528	Æble	Apple	13	cropland
529	Pærer	Pear	13	cropland
530	Vindruer	Grape	13	cropland
531	Anden træfrugt	Other tree fruit	13	cropland
532	Anden buskfrugt.	Other bush fruit	13	cropland
533	Rønnebær	Rowanberry	13	cropland
534	Hyben	Hip	13	cropland
536	Spisedruer	Grape for consumption	13	cropland
539	Blandet støtteberettiget frugt	Mixed fruits with subsidy	13	cropland
540	Tomat	Tomato	13	cropland
541	Agurk	Cucumber	13	cropland
542	Salat	Lettuce	13	cropland
543	Andre grøntsager	Other vegetable	13	cropland
544	Snitblomster / snitgrønt	Cut flower/sprigs	13	cropland
545	Potteplanter	Pot plant	13	cropland
547	Planteskolekulturer (stauder/vedpl.)	Nursery, perennial/woody plants	13	cropland
548	Småplanter (et-årige)	Minor plants, annual	13	cropland

## Continued

549	Lukket system 1 (et-årige)	Closed system, annual	13	cropland
550	Lukket system 2 (stauder og vedpl.)	Closed system, perennial/woody plants	13	cropland
560	Containerplads 1 (frugtbuske)	Container, fruit bush	13	cropland
561	Containerplads 2 (et-årige)	Container, annual	13	cropland
562	Containerplads 3 (stauder og vedpl.)	Container, perennial/woody plants	13	cropland
563	Svampe, champignon	Mushroom	13	cropland
570	Humle	Hop	13	cropland
579	Tagetes, sygdomssanerende plante	Tagetes	13	cropland
580	Skovdrift, alm.	Forestry	3	forest
581	Nyplantning i skov med træhøjde under 3	Afforestation in forest with tree height <3 m	3	forest
582	Pyntegrønt, økologisk	Decorative greenery, organic	31	Christmas trees
583	Juletræer/pyntegrønt	Christmas tree, decorative greenery	31	Christmas trees
584	Juletræer/pyntegrønt i fredskov	Christmas tree, decorative greenery in protected forest	31	Christmas trees
585	Skovrejsning i projektområde, som ikke er omfattet af tilsagn	Afforestation within project area without approval	3	forest
586	Skovrejsning på tidligere landbr. 2, forpagtet	Afforestation on former agricultural land 2, rented	3	forest
587	Skovrejsning på tidl. landbrugsjord 3	Afforestation on former agricultural land 3	3	forest
588	Statslig skovrejsning	State-afforestation	3	forest
589	Bæredygtig skovdrift	Sustainable forestry	3	forest
591	Lavskov.	Coppice forest	13	cropland
592	Pil	Willow	13	cropland
593	Poppel	Poplar	3	forest
594	Ei	Alder	3	forest
596	Elefantgræs	Elephant grass	13	cropland
597	Rørgræs	Reed grass	13	cropland
598	Sorrel	Sorrel	13	cropland
650	Krysantemum Garland.	Chrysanthemum Garland	13	cropland
651	Dildfrø.	Dill seed	13	cropland
652	Kinesisk kålfrø.	Chinese kale seed	13	cropland
653	Karsefrø.	Cress seed	13	cropland
655	Radissefrø.	Radish seed	13	cropland
656	Bladbedefrø, rødbedefrø	Leaf beet seed, beetroot seed	13	cropland
658	Gulerodfrø	Carrot seed	13	cropland
659	Kålfrø (hvid- og rødkålfrø)	Cabbage seed, red cabbage seed	13	cropland
660	Persillefrø	Parsley seed	13	cropland
661	Kørvelfrø	Chervil seed	13	cropland
662	Majroefrø	Early garden turnip seed	13	cropland
663	Pastinakfrø	Parsnip seeds	13	cropland
664	Skorzonerodfrø.	Viper's grass seed	13	cropland
665	Havrerodfrø	Salsify seed	13	cropland
666	Purløgfrø	Chive seed	13	cropland
667	Timianfrø	Thyme seed	13	cropland
668	Blomsterfrø	Flower seed	13	cropland
669	Andet havefrø	Other garden seed	13	cropland

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777	Ex-non-food brak	Non-food fallow	13	cropland
800	Andre arealer i skovblokke	Other land uses in forest	3	forest
801	Skov i ikke skovblok	Forest outside forest blocks	3	forest
900	Øvrige afgrøder	Other crops	13	cropland
901	Naturarealer efter driftsloven	Nature areas	7	grassland
902	Naturlignende arealer	Nature like areas	7	grassland
903	Lysåbne arealer, fredsskovspligtige	Open nature in protected forest	7	grassland
904	Åbne arealer i skov	Open areas in forest	7	grassland
905	Anden anvendelse på tilsagnsarealer	Other land use on approved parcels	7	grassland
906	Afmeldte arealer	De-registered parcels	0	undefined
907	Økologiske naturarealer	Organic nature areas	7	grassland
908	Naturarealer, ansøgning om miljø-tilsagn	Nature areas, application for agri-environmental scheme	7	grassland
910	Ikke anmeldt mark	Not registered field	0	undefined
960	Græs, udlæg/eftersl. efter grønkorn o.lign.	Grass mowed after green grain	13	cropland
961	Græs, udlæg/eftersl. eft.helsæd/tidl.frø	Grass mowed after whole grain	13	cropland
962	Græs, udlæg/eftersl. eft.korn/sildig frø	Grass mowed after cereal	13	cropland
965	Kløvergræs, udlæg/efterslæt efter korn	Clovergrass after cereal	13	cropland
968	Pligtige efterafgrøder	Bidning by crop	13	cropland
998	Ukendt afgrøde	Unknown crop	0	undefined
999	Ugyldig afgrødekode	Invalid crop code	0	undefined

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# ESTIMATING LAND USE/LAND COVER CHANGES IN DENMARK FROM 1990 – 2012

Technical documentation for the assessment of land use/  
land cover changes for estimation of carbon dioxide fixation in soil

According to the article 3(4) of the Kyoto Protocol, Denmark is obliged to document sequestration and emission of carbon dioxide from land use and land cover and changes in these. This report documents and describes applied data and developed methods aiming at estimating amounts and changes in land use and land cover for Denmark for since 1990. Estimation of land use and land cover categories and changes in these is predominantly based on existing categorical (i.e. pre-classified) geographical information. Estimations are elaborated for the period from 1990 to 2005, from 2005 to 2011 and from 2011 to 2012. Due to limited availability of historical spatially explicit information, estimations of change in land use and land cover from 1990 up to 2011 do, to some degree, involve decisions based on expert knowledge. Due to a significant increase in the availability of detailed spatially specific categorical information, estimations of annual changes in land use and land cover from 2011 and onwards are based on identification of changes in land use and land cover based spatial on overlays with updated input layers.

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